FINALIZED DRAFT
(March 2019)

AUTOMOTIVE INDUSTRY STANDARD

Test Method, Testing Equipment and Related Procedures for Type Approval and Conformity of Production (CoP) testing of Agricultural Tractors, Construction Equipment Vehicles (CEVs) & Combine Harvesters for Emission Norms as per CMV Rules 115 and 126

Part-7 - A1 : Bharat Stage (CEV/TREM) - IV
Part-7 - A2 : Bharat Stage (CEV/TREM) - V

Date of hosting on website :------
Last date for comments :------

INTRODUCTION

Ministry of Road Transport and Highways (MoRTH) has notified next stage emission norms for Agricultural Tractors, Construction Equipment Vehicles (CEVs) and Combine Harvesters (vehicles having power exceeding 37 kW) vide G.S.R. 201(E) dated 5th March 2018 under CMVR. These norms are Bharat Stage (CEV/TREM-IV) w.e.f. 1st October 2020 and Bharat Stage (CEV/TREM –V) w.e.f. 1st April 2024.

This standard AIS-137 (Part 7 - A1 and A2) prescribes Test Method, Testing Equipment and related Procedures for Type Approval and Conformity of Production (CoP) testing of Agricultural Tractors, CEV and Combine Harvesters for emission norms as per CMV Rules 115 and 126. This standard is divided into two parts:

i) First Part, AIS-137 (Part 7-A1), prescribes the test procedure to be followed for regulatory emission testing of engines for Agricultural Tractors, Construction Equipment Vehicles and Combine Harvesters for Bharat Stage (CEV/TREM - IV) emission norms.

ii) Second Part, AIS-137 (Part 7-A2) prescribes the test procedure to be followed for regulatory emission testing of engines for Agricultural Tractors, Construction Equipment Vehicles and Combine Harvesters for Bharat Stage (CEV/TREM - V) emission norms.

For diesel engines up to 37kW existing emission norms Bharat (TREM IIIA) Stage - GSR 84 & Bharat Stage III (CEV) – G.S.R 276 to be followed until 31st March 2024 for Agricultural Tractors, Combine Harvesters and CEVs respectively.

For gasoline engines existing emission norms as per G.S.R. 543 (E) dated 30.07.2014 to be followed until 31st March, 2024.

While preparing this standard, considerable assistance has been taken from following regulations/documents:

For Part A1:

i) UN Regulation 96 (Supplement 1 to the 04 series of amendments – Date of entry into force: 15.06.2015): Uniform provisions concerning the approval of Compression Ignition (C.I.) engines to be installed in Agricultural and Forestry Tractors and in Non-road Mobile Machinery with regard to the emissions of pollutants by the engine

For Part A2

i) UN Regulation 96 (05 series of amendments Date of Entry into Force: 29.12.18): Uniform provisions concerning the approval of engines to be installed in Agricultural and Forestry Tractors and in Non-road Mobile Machinery with regard to the emissions of pollutants by the engine

ii) Commission Delegated Regulation (EU) 2017/655 of 19 December 2016 supplementing Regulation (EU) 2016/1628 of the European Parliament and of the Council with regard to monitoring of gaseous pollutant emissions from in-service internal combustion engines installed in Non-road Mobile Machinery

For Part A1 and A2

UN Regulation 120 : Uniform provisions concerning the approval of internal combustion engines to be installed in Agricultural and Forestry Tractors and in Non-road Mobile Machinery, with regard to the measurement of the net power, net torque and specific fuel consumption

The Committee Composition for formulation of this standard is given in Annex 15.
(To be included)

After approval of the standard by SCOE, The Automotive Research Association of India, (ARAI), Pune, being the Secretariat of the AIS Committee, has published this standard. For better dissemination of this information ARAI may publish this standard on their web site.

*****

CONTENTS

AIS-137 (Part 7- A1) - Applicable only for Bharat Stage (CEV/TREM) - IV

CLAUSE & ANNEX NOs.	DESCRIPTION	PAGE NOs. (To be included)
1.	Scope	9/813
2.	Definitions and abbreviations	
3.	Application for type approval	
4.	Type approval process	
5.	Specification and tests	
6.	Installation on the vehicle	
7.	Conformity of production	
8.	Production definitively discontinued	
Annex 1A	Information document relating to the type approval and referring to measures against the emission of gaseous and particulate pollutants from internal combustion engines	
	Appendix 1 - Essential characteristics of the (parent) engine	
	Appendix 2 - Essential characteristics of the engine family	
	Appendix 3 - Essential characteristics of engine types within the family	
Annex 1B	Characteristics of the engine family and choice of the parent engine	
Annex 2	Test report for compression ignition engines	
Annex 3	Labelling requirement	
Annex 4	Test procedure for compression-ignition engines to be installed in Agricultural Tractors, Construction Equipment Vehicles and Combine Harvesters with regard to the emissions of pollutants by the engine	
	Appendix A.1 - (Reserved)	
	Appendix A.2 - Statistics	
	Appendix A.3 - 1980 international gravity formula	
	Appendix A.4 - Carbon flow check	
	Appendix A.5 - (Reserved)	
	Appendix A.6 - (Reserved)	
	Appendix A.7 - Molar based emission calculations	
	Appendix A.7.1 - Diluted exhaust flow (CVS) calibration	
	Appendix A.7.2 - Drift correction	
	Appendix A.8 - Mass based emission calculations	
	Appendix A.8.1 - Diluted exhaust flow (CVS) calibration	
	Appendix A.8.2 - Drift correction	

Annex 5	Test cycles	
Annex 6	Technical characteristics of diesel fuel	
	Appendix 1 - Reference diesel fuel characteristics	
	Appendix 2 - Commercial diesel fuel characteristics	
Annex 7	Installation requirements for equipment and auxiliaries	
Annex 8	Durability requirement	
Annex 9	Requirements to ensure the correct operation of NOx control measures	
	Appendix 1 - Demonstration requirements	
	Appendix 2 - Description of the operator warning and inducement activation and deactivation mechanisms	
	Appendix 3 - Demonstration of the minimum acceptable reagent concentration CDmin	
Annex 10	COP administrative procedure	
Annex 11	Power measurement procedure	
	Apeendix 1 - Method for measuring internal combustion engine gross power	
	Appendix 2 - Results of tests for measuring gross engine power	
	Appendix 3 - Essential characteristics of the engine family	
	Appendix 4 - Checks on conformity of production	
	Appendix 5 - Technical data of reference fuels	
Annex 12	Determination of $CO_{2\ e}$missions	
Annex 13	Emission of visible pollutants at steady speeds over the full-load curve	

*****

CONTENTS

AIS-137 (Part 7 - A2) - Applicable only for Bharat Stage (CEV/TREM) – V

CLAUSE & ANNEX Nos	DESCRIPTION	PAGE NOS. (To be included)
1.	Scope	328/813
	Appendix – Definition of engine sub-categories referred to in clause 1.	
2.	Definitions and abbreviations	
3.	Application for type approval	
4.	Type approval process	
5.	Requirements and tests	
	Appendix 1 – Exhaust emission limits	
	Appendix 2 – Emission durability periods (EDP)	
	Appendix 3 – Requirements in relation to any specified fuels, fuel mixtures or fuel emulsions.	
6.	Installation on the vehicle	
	Appendix 1 – Details of the relevant information and instructions for the OEMs	
	Appendix 2 - Details of the relevant information and instructions for the end-users	
7.	Engine family and engine type	
8.	Conformity of production	
9.	Penalties for non-conformity of production	
10.	Modifications and extension of approval of the approved type	
11.	Production definitively discontinued	
Annex 1		
	Appendix A.1 - Templates for information folder and information document	
	Appendix A.2 - Confidential information on emission control strategy	
	Appendix A.3 - Template for information document	
Annex 2	Communication – Type approval and COP template to be attached here by Test Agencies	
	Appendix A.1 - Test report	
Annex 3	Labelling requirements	
Annex 4	Test procedure	
	Appendix A.1. - Particle number emissions measurement equipment	
	Appendix A.2 - Installation requirements for equipment and auxiliaries	

	Appendix A.3 - Verification of torque signal broadcast by electronic control unit	
	Appendix A.4 - Procedures for the measurement of ammonia	
	Appendix A.5 - Description of system responses	
	Appendix A.6 - Characteristics of the steady-state and transient test cycles	
Annex 5	Method for data evaluation and calculation	
	Appendix A.1 - Mass based emissions calculations	
	Appendix A.2 - Molar based emissions calculations	
	Appendix A.3 - Statistics	
	Appendix A.4 - 1980 international gravity formula	
	Appendix A.5 - Carbon flow check	
	Appendix A.6 - Particle number calculation	
	Appendix A.7 - Ammonia emission calculation	
Annex 6	Technical characteristics of reference fuels prescribed for approval tests and to verify conformity of production	
	Appendix 1 - Reference diesel fuel characteristics	
	Appendix 2 - Commercial diesel fuel characteristics	
	Appendix A.1 - Supplementary requirements for conducting emission testing using gaseous reference fuels comprising pipeline gas with admixture of other gases	
	Appendix A.2 - Calculation of λ-Shift factor (Sλ)	
	Appendix A.3 - Correction for CO_2 in the exhaust arising from CO_2 in the gaseous fuel	
Annex 7	Technical requirements for dual-fuel engines	
	Appendix A.1 - Dual-fuel engine dual-fuel indicator, warning system, operability restriction - Demonstration requirements	
	Appendix A.2 - Emission test procedure requirements for dual-fuel engines	
	Appendix A.3 - Types of dual-fuel engines operated on natural gas/ biomethane or LPG and a liquid fuel – illustration of the definitions and main requirements	
Annex 8	Methodology for adapting the emission laboratory test results to include the deterioration factors	
Annex 9	Requirements with regard to emission control strategies, NO_X control measures and particulate control measures	
	Appendix A.1 - Additional technical requirements on NOX control measures for engines of categorty NRE , including the method to demonstrate these strategies	

	Appendix A.2 - Technical requirements on particulate pollutant control measures, including the method to demonstrate these measures	
	Appendix A.3 - Technical details for prevention of tampering	
Annex 10	Parameters for the definition of engine types and engine families, and their operation modes	
Annex 11	COP Administrative procedure	
Annex 12	Power measurement procedure	
	Appendix 1 - Method for measuring internal combustion engine gross power	
	Appendix 2 - Results of tests for measuring gross engine power	
	Appendix 3 - Essential characteristics of the engine family	
	Appendix 4 - Checks on conformity of production	
	Appendix 5 - Technical data of reference fuels	
Annex 13	In-Service monitoring procedure	
Annex 14	Emission of visible pollutants at steady speeds over the full-load curve	

*****

AIS-137 (Part 7 - A1) : Bharat Stage (CEV/TREM) -IV

1. SCOPE

This Part applies to the emission of gaseous and particulate pollutants from diesel fuelled compression ignition engines

1.1. Used in agricultural tractors, construction equipment vehicles and combine harvesters having an installed gross power higher than 37 kW but not more than 560 kW, operated under variable speed.

1.2. Used in agricultural tractors, construction equipment vehicles and combine harvesters having an installed gross power higher than 37 kW but not more than 560 kW, operated under constant speed.

2. DEFINITIONS AND ABBREVIATIONS

2.1. For the purpose of this Part,

2.1.1. **"Adjustment factors"** mean additive (upward adjustment factor and downward adjustment factor) or multiplicative factors to be considered during the periodic (infrequent) regeneration;

2.1.2. **"Ageing cycle"** means the machine or engine operation (speed, load, power) to be executed during the service accumulation period;

2.1.3. **"Applicable emission limit"** means an emission limit to which an engine is subject;

2.1.4. **"Approval of an engine"** means the approval of an engine type or family with regard to the level of emission of gaseous and particulate pollutants by the engine;

2.1.5. **"Aqueous condensation"** means the precipitation of water-containing constituents from a gas phase to a liquid phase. Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulphuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition - including the amount of hydrogen and sulphur in the fuel;

2.1.6. **"Atmospheric pressure"** means the wet, absolute, atmospheric static pressure. Note that if the atmospheric pressure is measured in a duct, negligible pressure losses shall be ensured between the atmosphere and the measurement location, and changes in the duct's static pressure resulting from the flow shall be accounted for;

2.1.7. **"Calibration"** means the process of setting a measurement system's response so that its output agrees with a range of reference signals. Contrast with "*verification*";

2.1.8. **"Calibration gas"** means a purified gas mixture used to calibrate gas analysers. Calibration gases shall meet the specifications of clause 9.5.1 of Annex 4. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analysers and sample handling components might refer to either calibration gases or span gases;

2.1.9. **"Compression ignition (C.I.) engine"** means an engine which works on the compression-ignition principle (e.g. diesel engine);

2.1.10. **"Confirmed and active DTC"** means a DTC that is stored during the time the NCD system concludes that a malfunction exists;

2.1.11. **"Constant-speed engine" m**eans an engine whose type approval or certification is limited to constant-speed operation. Engines whose constant-speed governor function is removed or disabled are no longer constant-speed engines;

2.1.12. **"Constant-speed operation"** means engine operation with a governor that automatically controls the operator's demand to maintain engine speed, even under changing load. Governors do not always maintain exactly constant speed. Typically, speed can decrease (0.1 to 10) per cent below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power;

2.1.13. **"Continuous regeneration"** means the regeneration process of an exhaust after-treatment system that occurs either in a sustained manner or at least once over the applicable transient test cycle or ramped-modal cycle; in contrast to periodic (infrequent) regeneration;

2.1.14. **"Conversion efficiency of non-methane cutter (NMC) E"**means the efficiency of the conversion of a NMC that is used for removing the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent ($E_{CH4} = 0$) and for the other hydrocarbons represented by ethane is 100 per cent ($E_{C2H6} = 100$ per cent). For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate for methane and ethane. Contrast with "penetration fraction";

2.1.15. **"Critical emission-related components"** means the components which are designed primarily for emission control, that is, any exhaust after-treatment system, the electronic engine control unit and its associated sensors and actuators, and the EGR system including all related filters, coolers, control valves and tubing;

2.1.16. **"Critical emission-related maintenance"** means the maintenance to be performed on critical emission-related components;

2.1.17. **"Delay time"** means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point. For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector (see Figure 1);

2.1.18. ***"DeNO$_x$ system"*** means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO_x) (e.g. passive and active lean NO_x catalysts, NO_x adsorbers and selective catalytic reduction (SCR) systems);

2.1.19. **"Dew point"** means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity. Dew point is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured;

2.1.20. **"Diagnostic trouble code (DTC)"** means a numeric or alphanumeric identifier which identifies or labels a NO_x Control Malfunction;

2.1.21. **"Discrete-mode"** means relating to a discrete-mode type of steady-state test, as described in clause 7.4.1.1. of Annex 4 and Annex 5 (Test Cycles);

2.1.22. "***Drift"*** means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as the instrument was zeroed and spanned just before the test;

2.1.23. **"Electronic control unit"** means an engine's electronic device that uses data from engine sensors to control engine parameters;

2.1.24. **"Emission control system"** means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine;

2.1.25. **"Emission control strategy"** means a combination of an emission control system with one base emission control strategy and with one set of auxiliary emission control strategies, incorporated into the overall design of an engine or engine installed in agricultural tractor, construction equipment vehicle and combine harvester.

2.1.26. **"Emission durability period"** means the number of hours indicated in Annex 8 used to determine the deterioration factors;

2.1.27. **"Emission-related maintenance"** means the maintenance which substantially affects emissions or which is likely to affect emissions performance deterioration of the vehicle or the engine during normal in-use operation;

2.1.28. **"Engine-after-treatment system family"** means a manufacturer's grouping of engines that complies with the definition of engine family, but which are further grouped into a family of engine families utilising a similar exhaust after-treatment system;

2.1.29. **"Engine family"** means a manufacturer's grouping of engines which, through their design, are expected to have similar exhaust emission characteristics and comply with the requirements in clause 7. of this Part;

2.1.30. **"Engine governed speed"** means the engine operating speed when it is controlled by the installed governor;

2.1.31. **"Engine system"** means the engine, the emission control system and the communication interface (hardware and messages) between the engine system electronic control unit(s) (ECU) and any other powertrain or vehicle control unit;

2.1.32. **"Engine type"** means a category of engines which do not differ in such essential engine characteristics as defined in clauses 1. to 4. of Annex 1A, Appendix 3 to this Part;

2.1.33. **"Exhaust after-treatment system"** means a catalyst, particulate filter, deNO_x system, combined deNO_x particulate filter or any other emission-reducing device that is installed downstream of the engine. This definition excludes exhaust gas recirculation (EGR) and turbochargers, which are considered an integral part of the engine;

2.1.34. **"Exhaust-gas recirculation"** means a technology that reduces emissions by routing exhaust gases that have been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion. The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this Part;

2.1.35. **"Full flow dilution method"** means the process of mixing the total exhaust flow with dilution air prior to separating a fraction of the diluted exhaust stream for analysis;

2.1.36. **"Gaseous pollutants"** means carbon monoxide, hydrocarbons (assuming a ratio of $C_1H_{1.85}$) and oxides of nitrogen, the last named being expressed in nitrogen dioxide (NO_2) equivalent;

2.1.37. **"Good engineering judgment"** means judgments made consistent with generally accepted scientific and engineering principles and available relevant information;

2.1.38. **"HEPA filter"** means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97 per cent using ASTM F 1471–93 or equivalent standard;

2.1.39. **"Hydrocarbon (HC)"** means THC, NMHC as applicable. Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and engine;

2.1.40. **"High speed (n_{hi})"** means the highest engine speed where 70% of the maximum power (Annex 4) occurs;

2.1.41. **"Idle speed"** means the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine;

2.1.42. **"Intermediate speed"** means that engine speed which meets one of the following requirements:

(a) For engines which are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60 per cent and 75 per cent of the rated speed;

(b) If the declared maximum torque speed is less than 60 per cent of the rated speed, then the intermediate speed shall be 60 per cent of the rated speed;

(c) If the declared maximum torque speed is greater than 75 per cent of the rated speed then the intermediate speed shall be 75 per cent of the rated speed.

2.1.43. **"Linearity"** means the degree to which measured values agree with respective reference values. Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing;

2.1.44. **"Low speed (n_{lo})"** means the lowest engine speed where 50% of the maximum power (Annex 4) occurs;

2.1.45. **"Maximum power (P_{max})"** means the maximum power in kW as designed by the manufacturer;

2.1.46. **"Maximum torque speed"** means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer;

2.1.47. **"Means of a quantity"** based upon flow-weighted mean values means the mean level of a quantity after it is weighted proportionally to the corresponding flow rate;

2.1.48. **"NCD engine family"** means a manufacturer's grouping of engine systems having common methods of monitoring/diagnosing NCMs.

2.1.49. **"Gross power"** means the power in " kW" obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the method described in Annex 11 of this Part on the measurement of the gross power and gross torque of internal combustion engines for agricultural tractors, construction equipment vehicles and combine harvesters.

2.1.50. **"Non-emission-related maintenance"** means maintenance which does not substantially affect emissions and which does not have a lasting effect on the

emissions performance deterioration of the machine or the engine during normal in-use operation once the maintenance is performed;

2.1.51. **"Non-methane hydrocarbons (NMHC)"** means the sum of all hydrocarbon species except methane;

2.1.52. **"NO_x Control Diagnostic system (NCD)"** means a system on-board the engine which has the capability of:

(a) Detecting a NO_x Control Malfunction;

(b) Identifying the likely cause of NO_x control malfunctions by means of information stored in computer memory and/or communicating that information off-board;

2.1.53. **"NO_x Control Malfunction (NCM)"** means an attempt to tamper with the NO_x control system of an engine or a malfunction affecting that system that might be due to tampering, that is considered by this Part as requiring the activation of a warning or an inducement system once detected;

2.1.54. **"Open crankcase emissions"** means any flow from an engine's crankcase that is emitted directly into the environment;

2.1.55. **"Operator demand"** means an engine operator's input to control engine output. The "operator" may be a person (i.e. manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor set point or signal;

2.1.56. **"Oxides of nitrogen"** means compounds containing only nitrogen and oxygen as measured by the procedures specified in this Part. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO_2, such that an effective molar mass is used for all oxides of nitrogen equivalent to that of NO_2;

2.1.57. **"Parent engine"** means an engine selected from an engine family in such a way that its emissions characteristics are representative for that engine family and that it complies with the requirements set out in Annex 1B to this Part;

2.1.58. **"Partial pressure"** means the pressure, *p*, attributable to a single gas in a gas mixture. For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, *x*;

2.1.59. **"Particulate after-treatment device"** means an exhaust after-treatment system designed to reduce emissions of particulate pollutants (PM) through a mechanical, aerodynamic, diffusional or inertial separation;

2.1.60. **"Partial flow dilution method"** means the process of separating a part from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter;

2.1.61. **"Particulate matter (PM)"** means any material collected on a specified filter medium after diluting C.I. engine exhaust gas with clean filtered air so that the temperature does not exceed 325 K (52 °C);

2.1.62. **"Penetration fraction PF"** means the deviation from ideal functioning of a non-methane cutter (see Conversion efficiency of non-methane cutter (NMC) E). An ideal non-methane cutter would have a methane penetration factor, PF_{CH4}, of 1.000 (that is, a methane conversion efficiency E_{CH4} of 0), and the penetration fraction for all other hydrocarbons would be 0.000, as represented by PF_{C2H6} (that is, an ethane conversion efficiency E_{C2H6} of 1). The relationship is:

$PF_{CH4} = 1 – E_{CH4}$ and $PF_{C2H6} = 1 – E_{C2H6}$;

2.1.63. **"Per cent load"** means the fraction of the maximum available torque at an engine speed;

2.1.64. **"Periodic (or infrequent) regeneration"** means the regeneration process of an exhaust after-treatment system that occurs periodically in typically less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission limits may be exceeded;

2.1.65. Reserved.

2.1.66. **"Probe"** means the first section of the transfer line which transfers the sample to next component in the sampling system;

2.1.67. **"PTFE"** means polytetrafluoroethylene, commonly known as Teflon ™;

2.1.68. **"Ramped modal steady state test cycle"** means a test cycle with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined speed and torque ramps between these modes;

2.1.69. **"Rated speed"** means the maximum full load speed allowed by the governor, as designed by the manufacturer, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as designed by the manufacturer;

2.1.70. **"Reagent"** means any consumable or non-recoverable medium required and used for the effective operation of the exhaust after-treatment system;

2.1.71. **"Regeneration"** means an event during which emissions levels change while the after treatment performance is being restored by design. Two types of regeneration can occur: continuous regeneration (see clause 6.6.1 of Annex 4.) and infrequent (periodic) regeneration (see clause 6.6.2 of Annex 4.);

2.1.72. **"Response time"** means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and the devices for gas switching shall be specified to perform the gas switching in less than 0.1 s. The system response time consists of the delay time to the system and of the rise time of the system;

2.1.73. **"Rise time"** means the difference in time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$);

2.1.74. **"Scan-tool"** means an external test equipment used for off-board communication with the NCD system;

2.1.75. **"Service accumulation schedule"** means the ageing cycle and the service accumulation period for determining the deterioration factors for the engine-after-treatment system family;

2.1.76. **"Shared atmospheric pressure meter"** means an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell;

2.1.77. **"Shared humidity measurement"** means a humidity measurement that is used as the humidity for an entire test facility that has more than one dynamometer test cell;

2.1.78. **"Span"** means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 per cent and 100 per cent of the maximum value in the instrument range or expected range of use;

2.1.79. **"Span gas"** means a purified gas mixture used to span gas analysers. Span gases shall meet the specifications of clause 9.5.1. of Annex 4. Note that calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analysers and sample handling components might refer to either calibration gases or span gases;

2.1.80. **"Specific emissions**" means the mass emissions expressed in g/kWh;

2.1.81. **"Stand-alone"** means something that has no dependencies; it can "stand alone";

2.1.82. **"Steady-state"** means relating to emission tests in which engine speed and load are held at a finite set of nominally constant values. Discrete-mode tests or ramped-modal tests are steady-state tests;

2.1.83. **"Stoichiometric"** means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen;

2.1.84. **"Storage medium"** means a particulate filter, sample bag, or any other storage device used for batch sampling;

2.1.85. **"Test (or duty) cycle"** means a sequence of test points each with a defined speed and torque to be followed by the engine under steady state or transient operating conditions. Duty cycles are specified in the Annex 5. A single duty cycle may consist of one or more test intervals;

2.1.86. **"Test interval"** means a duration of time over which brake-specific emissions are determined. In cases where multiple test intervals occur over a duty cycle, the Part may specify additional calculations that weigh and combine results to arrive at composite values for comparison against the applicable emission limits;

2.1.87. **"Tolerance"** means the interval in which 95 per cent of a set of recorded values of a certain quantity shall lie, with the remaining 5 per cent of the recorded values deviating from the tolerance interval. The specified recording frequencies and time intervals shall be used to determine if a quantity is within the applicable tolerance;

2.1.88. **"Total hydrocarbon (THC)"** means the combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon, expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1.85:1;

2.1.89. **"Transformation time"** means the difference in time between the change of the component to be measured at the reference point and a system response of 50 per cent of the final reading (t_{50}) with the sampling probe being defined as the reference point. The transformation time is used for the signal alignment of different measurement instruments. See Figure 1;

2.1.90. **"Transient test cycle"** means a test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time(NRTC);

2.1.91. **"Type approval"** means the approval of an engine type with regard to its emissions measured in accordance with the procedures specified in this Part;

2.1.92. **"Updating-recording"** means the frequency at which the analyser provides new, current, values;

2.1.93. **"Useful life"** means the relevant period of distance and/or time over which compliance with the relevant gaseous and particulate emission limits has to be assured;

2.1.94. **"Variable-speed engine"** means an engine that is not a constant-speed engine;

2.1.95. **"Verification"** means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with "*calibration*";

2.1.96. **"To zero"** means to adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents;

2.1.97. **"Zero gas"** means a gas that yields a zero response in an analyser. This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen.

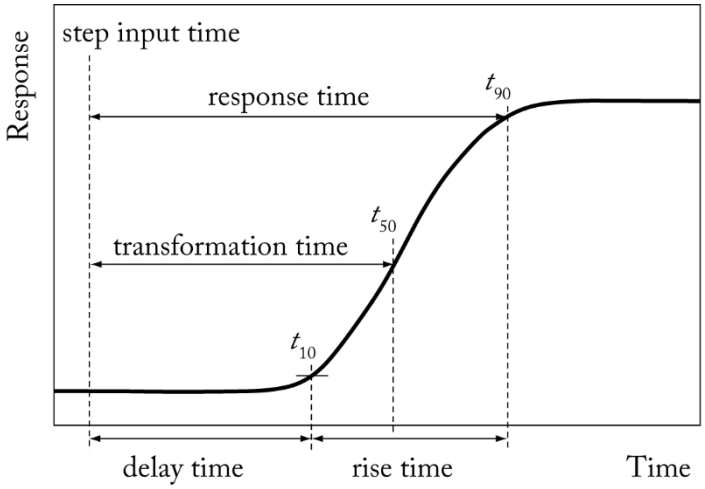


Figure 1
Definitions of system response: delay time (clause 2.1.17.), response time (clause 2.1.72.), rise time (clause 2.1.73.) and transformation time (clause 2.1.89.)

2.2. Symbols and abbreviations

2.2.1. Symbols

The symbols are explained in Annex 4, clause 3.2.

2.2.2. Symbols and abbreviations for the chemical components

Ar	Argon
C_1	Carbon 1 equivalent hydrocarbon
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
CO	Carbon monoxide
CO_2	Carbon dioxide
DOP	Di-octylphthalate
H	Atomic hydrogen
H_2	Molecular hydrogen
HC	Hydrocarbon

H_2O	Water
He	Helium
N_2	Molecular nitrogen
NMHC	Non-methane hydrocarbon
NO_x	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
O_2	Oxygen
PM	Particulate matter
PTFE	Polytetrafluoroethylene
S	Sulphur
THC	Total hydrocarbon

2.2.3. Abbreviations

ASTM	American Society for Testing and Materials
BMD	Bag mini-diluter
BSFC	Brake-specific fuel consumption
CFV	Critical Flow Venturi
CI	Compression-ignition
CLD	Chemiluminescent Detector
CVS	Constant Volume Sampler
$DeNO_x$	NO_x after-treatment system
DF	Deterioration factor
ECM	Electronic control module
EFC	Electronic flow control
EGR	Exhaust gas recirculation
FID	Flame Ionization Detector
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
IBP	Initial boiling point
ISO	International Organization for Standardization
LPG	Liquefied Petroleum Gas
NDIR	Nondispersive infrared (Analyser)
NDUV	Nondispersive ultraviolet (Analyser)
NIST	US National Institute for Standards and Technology
NMC	Non-Methane Cutter
PDP	Positive Displacement Pump

%FS	Per cent of full scale
PFD	Partial Flow Dilution
PFS	Partial Flow System
PTFE	Polytetrafluoroethylene (commonly known as Teflon™)
RMC	Ramped-modal cycle
RMS	Root-mean square
RTD	Resistive temperature detector
SAE	Society of Automotive Engineers
SSV	Subsonic Venturi
UCL	Upper confidence limit
UFM	Ultrasonic flow-meter

3. APPLICATION FOR TYPE APPROVAL

3.1. Application for approval of an engine as a separate technical unit

3.1.1. The application for approval of an engine or an engine family with regard to the level of the emission of gaseous and particulate pollutants shall be submitted by the engine manufacturer or by a duly accredited representative.

3.1.2. It shall be accompanied by the undermentioned documents in 1 set and the following particulars:

A description of the engine type comprising the particulars referred to in AIS-007 and if applicable the particulars of the engine family as referred to in AIS-007.

3.1.3. An engine conforming to the engine type characteristics described in AIS-007shall be submitted to the Test Agency responsible for conducting the approval tests defined in clause 5. If the Test Agency determines that the submitted engine does not fully represent the engine family described in AIS-007, an alternative and, if necessary, an additional engine shall be submitted for test according to clause 5. below.

4. TYPE APPROVAL PROCESS

4.1. Application for type approval of an engine as a separate technical unit

4.1.1. For the purpose of type approval and conformity of production certification, manufacturer's engine range shall be divided into model families, consisting of parent engine model and its variant and application for Type Approval shall be made in the proforma prescribed in AIS-007 as amended by time to time.

4.1.2. The determination of an engine family and the decision regarding parent engine shall be based on AIS-007. For the purpose of identification, the manufacturer shall designate the families as F1, F2, F3 ….. Fn..

4.1.3. The Test Agency shall decide the family, the parent model and its variants depending on the information provided by the manufacturer.

4.1.4 Testing of the parent model, shall, normally, be sufficient for type approval of the family. The Test Agency has the option to carry out the testing of more than

one model in the family to satisfy itself, subject to parent engine-concept as per Annex 1B.

4.1.5 At later stage if the manufacturer submits the application for type approval of a model, the Test Agency shall ascertain whether the model can be classified as belonging to a family of model(s) already certified. If the model does not belong to a family already certified, the Test Agency shall proceed with the testing of the model for type approval.

If the model belongs to a family already certified, the Test Agency shall decide whether the specific testing of the model is required. In case the specific testing of the model is not required, the type approval certificate for the family may be extended to include the model.

5. SPECIFICATION AND TESTS

5.1. General

The components liable to affect the emission of gaseous and particulate pollutants shall be so designed, constructed and assembled as to enable the engine, in normal use, despite the vibrations to which it may be subjected, to comply with the provisions of this Part

5.1.1. The technical measures taken by the manufacturer shall be such as to ensure that the mentioned emissions are effectively limited, pursuant to this Part, throughout the normal life of the engine and under normal conditions of use. These provisions are deemed to be met:

(a) If the provisions of clauses 5.2.1. and 7 of this Part are respectively complied with, and

(b) If, in addition, for engines of power bands greater than 37 kW, the provisions of clause 5.3. below are complied with.

5.1.2. The manufacturer shall prove the durability of the engine and after-treatment device, in accordance with Annex 8.

5.1.3. Systematic replacement of emission related components, after a certain running time of the engine, is permissible. Any adjustment, repair, disassembly, cleaning or replacement of engine components or systems which is performed on a periodic basis to prevent malfunction of the engine, shall only be done to the extent that is technologically necessary to ensure proper functioning of the emission control system. Accordingly, scheduled maintenance requirements shall be included in the "owner's manual" and "service station manual " and be approved before an approval is granted.

5.1.4. The corresponding extract from the manual with respect to maintenance/replacements of the after-treatment device(s) shall be included in the information document as set out in the appendices of Annex 1A to this Part.

5.2. Specifications concerning the emissions of pollutants

The gaseous and particulate components emitted by the engine submitted for testing shall be measured by the methods in Annex 4.

5.2.1. The emissions of the carbon monoxide, the emissions of hydrocarbons, the emissions of the oxides of nitrogen and the emissions of particulate matter obtained shall not exceed the amount shown in the table below:

	Applicable with effect from	CO	HC	NOx	PM	Test Cycle
Category, kW		g/ kWh				
37 ≤P < 56	1st October, 2020	5.0	4.7 (HC+NOx)		0.025	NRSC & NRTC
56 ≤P < 130	1st October, 2020	5.0	0.19	0.4	0.025	
130≤P < 560	1st October, 2020	3.5	0.19	0.4	0.025	

5.2.1.1 Rounding off

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus two additional significant figures, in accordance with IS:2-1960(R2016). No rounding of intermediate values leading to the final brake-specific emission result is permitted

5.2.2. Where, as defined, according to Annex 1B, one engine family covers more than one power band, the emission values of the parent engine (type approval) and of all engine types within the same family (COP) shall meet the more stringent requirements of the higher power band.

5.2.3. In addition, the following requirements shall apply:

(a) Durability requirements as set out in Annex 8 to this Part;

(b) Engine control area provisions as set out in clause 5.3.5. of this Part for tests of engines of power bands greater than or equal to 37 kW only

(c) CO_2 reporting requirements as set out in Annex 10 of this Part for tests according to Annex 4 of this Part.

(d) The requirements set out in clause 5.3. below for electronically controlled engines

5.3. Type approval requirements

5.3.1. This paragraph shall apply to the type approval of electronically controlled engines, which use electronic control to determine both the quantity and timing of injecting fuel (hereafter 'engine'). This paragraph shall apply irrespective of the technology applied to such engines so as to comply with the emission limit values set out in clause 5.2.1. of this Part.

5.3.2. General requirements

5.3.2.1. Requirements for base emission control strategy

5.3.2.1.1. The base emission control strategy, activated throughout the speed and torque operating range of the engine, shall be designed as to enable the engine to comply with the provisions of this Part.

5.3.2.1.2. Any base emission control strategy that can distinguish engine operation between a standardized type approval test and other operating conditions and subsequently reduce the level of emission control when not operating under conditions substantially included in the type approval procedure is prohibited.

5.3.2.2. Requirements for auxiliary emission control strategy

5.3.2.2.1. An auxiliary emission control strategy may be used by an engine or a agricultural tractor, construction equipment vehicle, or combine harvester, provided that the auxiliary emission control strategy, when activated, modifies the base emission control strategy in response to a specific set of ambient and/or operating conditions but does not permanently reduce the effectiveness of the emission control system.

(a) Where the auxiliary emission control strategy is activated during the type approval test, clauses 5.3.2.2.2. and 5.3.2.2.3. below shall not apply.

(b) Where the auxiliary emission control strategy is not activated during the type approval test, it shall be demonstrated that the auxiliary emission control strategy is active only for as long as required for the purposes identified in clause 5.3.2.2.3.below .

5.3.2.2.2 The control conditions applicable for 37≤ P < 560 kW:

(a) Control conditions for engines of power bands 37 ≤ P < 56 kW:

i) An altitude not exceeding 1000m (or equivalent atmospheric pressure of 90 kPa)

(ii) The ambient temperature within the following range:- 275 K to 315 K (2°C to 42°C);

(iii) The engine coolant temperature above 343 K (70 °C).

Where the auxiliary emission control strategy is activated when the engine is operating within the control conditions set out in points (i), (ii) and (iii), the strategy shall only be activated exceptionally.

(b) Control conditions for engines of power bands 56 ≤ P < 560 kW:

(i) The atmospheric pressure greater than or equal to 82.5 kPa;

(ii) The ambient temperature within the following range:

- Equal to or above 273 K (0°C);
- Less than or equal to the temperature determined by the following equation at the specified atmospheric pressure: Tc = -0.4514 • (101.3 – Pb) + 311, where: Tc is the calculated ambient air temperature, K and Pb is the atmospheric pressure, kPa.

(iii) The engine coolant temperature above 343 K (70 °C).

Where the auxiliary emission control strategy is activated when the engine is operating within the control conditions set out in points (i), (ii) and (iii), the strategy shall only be activated when demonstrated to be necessary for the purposes identified in clause 5.3.2.2.3. below and approved by the Test Agency.

(c) Cold temperature operation

By derogation from the requirements of point (b), an auxiliary emission control strategy may be used on a engine equipped with exhaust gas recirculation (EGR) of power bands 37 ≤ P < 560 kW when the ambient temperature is below 275 K (2 °C) and if one of the two following criteria is met:

(i) Intake manifold temperature is less than or equal to the temperature defined by the following equation: IMTc = PIM / 15.75 + 304.4, where: IMTc is the calculated intake manifold temperature, K and PIM is the absolute intake manifold pressure in kPa;

(ii) Engine coolant temperature is less than or equal to the temperature defined by the following equation: ECTc = PIM / 14.004 + 325.8;

Where:

ECTc is the calculated engine coolant temperature, K and PIM is the absolute intake manifold pressure, kPa.

5.3.2.2.3. An auxiliary emission control strategy may be activated in particular for the following purposes:

(a) By on-board signals, for protecting the engine (including air-handling device protection) and/or agricultural tractor, construction equipment vehicle or combine harvester into which the engine is installed from damage;

(b) For operational safety reasons;

(c) For prevention of excessive emissions, during cold start or warming-up, during shut-down;

(d) If used to trade-off the control of one regulated pollutant under specific ambient or operating conditions, for maintaining control of all other regulated pollutants, within the emission limit values that are appropriate for the engine concerned. The purpose is to compensate for naturally occurring phenomena in a manner that provides acceptable control of all emission constituents.

5.3.2.2.4. The manufacturer shall demonstrate to the Test Agency at the time of the type approval test that the operation of any auxiliary emission strategy complies with the provisions of clause 5.3.2.2. The demonstration shall consist of an evaluation of the documentation referred to in clause 5.3.2.3. below.

5.3.2.2.5. Any operation of an auxiliary emission control strategy not compliant with clause 5.3.2.2. above is prohibited.

5.3.2.3. Documentation requirements

5.3.2.3.1. The manufacturer shall provide an information folder accompanying the application for type approval at the time of submission to the Test Agency, which ensures access to any element of design and emission control strategy and the means by which the auxiliary strategy directly or indirectly controls the output variables. The information folder shall be made available in two parts:

(a) The documentation package, annexed to the application for type approval, shall include a full overview of the emission control strategy. Evidence shall be provided that all outputs permitted by a matrix, obtained from the range of control of the individual unit inputs, have been identified. This evidence shall be attached to the information folder as referred to in Annex 1 A.

(b) The additional material, presented to the Test Agency but not annexed to the application for type approval, shall include all the modified parameters by any auxiliary emission control strategy and the boundary conditions under which this strategy operates and in particular:

(i) A description of the control logic and of timing strategies and switch points, during all modes of operation for the fuel and other essential systems, resulting in effective emissions control (such as exhaust gas recirculation system (EGR) or reagent dosing);

(ii) A justification for the use of any auxiliary emission control strategy applied to the engine, accompanied by material and test data, demonstrating the effect on exhaust emissions. This

justification may be based on test data, sound engineering analysis, or a combination of both;

(iii) A detailed description of algorithms or sensors (where applicable) used for identifying, analysing, or diagnosing incorrect operation of the NO_x control system;

5.3.2.3.2. The additional material referred to in sub-clause (b) of clause 5.3.2.3.1. above shall be treated as strictly confidential. It shall be made available to the Test Agency on request. The Test Agency shall treat this material as confidential.

5.3.3 Reserved

5.3.4. Requirements on NOx control measures for engines

5.3.4.1. The manufacturer shall provide information that fully describes the functional operational characteristics of the NOx control measures using the documents set out in paragraph 2. of Appendix 1 to Annex 1A and in paragraph 2. of Appendix 3 to Annex 1A.

5.3.4.2. The engine emission control strategy shall be operational under all environmental conditions regularly pertaining in India. This requirement is not restricted to the conditions under which a base emission control strategy shall be used as specified in clause 5.3.2.2.2. above.

5.3.4.3. When a reagent is used, the manufacturer shall demonstrate that the emission of ammonia over the hot NRTC or NRSC at the type approval procedure does not exceed a mean value of 25 ppm for engine category less than or equal to 56kW and 10 ppm for engine power category above 56 kW.

5.3.4.4. If reagent containers are installed on or connected to a agricultural tractor, construction equipment vehicle or combine harvester, means for taking a sample of the reagent inside the containers shall be included. The sampling point shall be easily accessible without requiring the use of any specialised tool or device.

5.3.4.5. The type approval shall be made conditional, in accordance with clause 6.1., upon the following:

(a) Providing to each operator of agricultural tractor, construction equipment vehicle and combine harvester written maintenance instructions, as specified in Annex 9 to this Part;

(b) Providing to the OEM installation documents for the engine, inclusive of the emission control system that is part of the approved engine type;

(c) Providing to the OEM instructions for an operator warning system, an inducement system and (where applicable) reagent freeze protection;

(d) The application of provisions on operator instruction, installation documents, operator warning system, inducement system and reagent freeze protection that are set out in Annex 9 to this Part.

5.3.5. Control area for power bands

The emissions sampled within the control area defined in this section shall not exceed by more than 2 times the limit values of the emission specified in clause 5.2.1. of this Part

5.3.5.1 Demonstration requirements

The Test Agency shall select up to three random load and speed points within the control area for testing. The Test Agency shall also determine a random running order of the test points. The test shall be run in accordance with the principal requirements of the NRSC, but each test point shall be evaluated separately. Each test point shall meet the limit values defined in clause 5.3.5.

5.3.5.2 Test requirements

The test shall be carried out as follows:

(a) The test shall be carried out immediately after the discrete mode test cycles as described in points (a) to (e) of clause 7.8.1.2. of Annex 4 to this Part but before the post test procedures of point (f) or alternatively after the Ramped Modal Cycle (RMC) test in points (a) to (d) of clause 7.8.2.3 of Annex 4 to this Part but before the post test procedures of point (e) as relevant;

(b) The tests shall be carried out as required in points (b) to (e) of clause 7.8.1.2. of Annex 4 to this Part using the multiple filter method (one filter for each test point) for each of the three chosen test points;

(c) A specific emission value shall be calculated (in g/kWh) for each test point;

(d) Emissions values may be calculated on a molar basis using Appendix A.7 or on a mass basis using Appendix A.8 of Annex 4 to this Part, but should be consistent with the method used for the discrete mode or RMC test;

(e) For gaseous summation calculations the Nmode shall be set to 1 and a weighting factor of 1 shall be used;

(f) For particulate calculations use the multiple filter method and for summation calculations the Nmode shall be set to 1 and a weighting factor of 1 shall be used.

5.3.5.3. Control area requirements

5.3.5.3.1. Engine control area

The control area (see Figure 2) is defined as follows:

Speed range: speed A to high speed;

Where:

Speed A = low speed + 15 per cent (high speed - low speed);

High speed and low speed as defined in Annex 4 to this Part shall be used.

If the measured engine speed A is within ±3 per cent of the engine speed declared by the manufacturer, the declared engine speeds shall be used. If the tolerance is exceeded for any of the test speeds, the measured engine speeds shall be used.

5.3.5.3.2. The following engine operating conditions shall be excluded from testing:

(a) Points below 30 per cent of maximum torque;

(b) Points below 30 per cent of maximum power.

The manufacturer may request that the Test Agency excludes operating points from the control area defined in clause 5.3.5.3.1. during the certification/type approval. The Test Agency may grant this exclusion if the manufacturer can demonstrate that the engine is never capable of operating at such points when used in any machine combination.

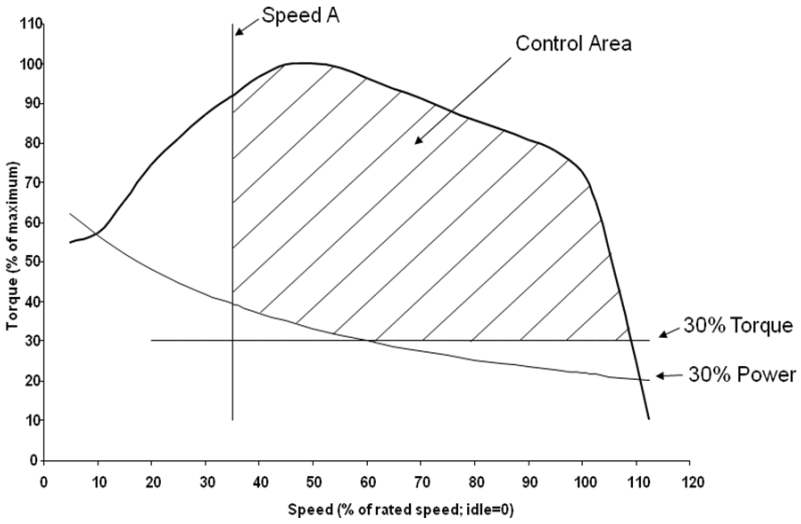


Figure 2
Control Area

5.3.6 Verifying emissions of crankcase gases for engines

5.3.6.1. No crankcase emissions shall be discharged directly into the ambient atmosphere, with the exception given in clause 5.3.6.3. below.

5.3.6.2. Engines may discharge crankcase emissions into the exhaust upstream of any after treatment device during all operation.

5.3.6.3. Engines equipped with turbochargers, pumps, blowers, or superchargers for air induction may discharge crankcase emissions to the ambient atmosphere. In this case the crankcase emissions shall be added to the exhaust emissions (either physically or mathematically) during all emission testing in accordance with clause 6.10. of Annex 4 to this Part.

5.4. Selection of engine power category

5.4.1. For the purposes of establishing the conformity of variable speed engines defined by clauses 1.1. of this Part with the emission limits given in clause 5.2.1. of this Part, they shall be allocated to power bands on the basis of the highest value of the gross power measured in accordance with clause 2.1.49. of this Part.

5.4.2. For other engine types rated gross power shall be used.

6. INSTALLATION ON THE VEHICLE

6.1. The engine installation on the vehicle shall comply with the following characteristics in respect to the approval of the engine.

6.1.1. Intake depression shall not exceed that specified for the approved engine in Annex 1A, Appendix 1 or 3 to this Part as applicable.

6.1.2. Exhaust back pressure shall not exceed that specified for the approved engine in Annex 1A, Appendix 1 or 3 to this Part as applicable.

6.1.3. The operator shall be informed on the reagent control as defined in Annex 9 to this Part..

6.1.4. The OEM shall be provided with the installation documents and instructions as defined in clause 5.3.4.5. above, if applicable.

7. CONFORMITY OF PRODUCTION

7.1. The conformity of production procedures shall comply with those set out in the AIS-137 (Part 6) with the following requirements:

7.2. Every produced agricultural tractor, construction equipment vehicle's or combine harvester's engine of the model approved under this Part shall conform with regard to components affecting the emission of gaseous pollutants by the engine to the vehicle model type approved. The Administrative procedure for carrying out conformity of production test is given in AIS-137 (Part 6)

7.3 Conformity of Production (COP) frequency and selection procedure shall be as per procedure laid down in AIS: 137- Part 6 and as amended time to time. For agricultural tractor, construction equipment vehicle and combine harvester with annual production/Import up to 200 numbers (per engine family), it shall be once in two years per family/model. For agricultural tractor, construction equipment vehicle and combine harvester with annual production/Import exceeding 200 numbers (per engine family), it shall be once in every year per family/model. The sampling size shall be one day's average production subject to a minimum of 10 and maximum of 100. For engine family produced less than 200 in the yearly period sample size may be less than 10.

7.4 The random selection shall be at OEM place where installing engine and exhaust after treatment happens on vehicle.

7.5 An engine, randomly taken from the series is subjected to the mass emission test described in Annex 4 according to clause 5.2 above. The emissions of the carbon monoxide, the emissions of the hydrocarbons, the emissions of the oxides of nitrogen and the emissions of particulate obtained shall not exceed the amounts shown in the table in clause 5.2.1., subject to the requirements of clause 5.2.2. above.

7.6. If the engine taken from the series does not satisfy the requirements of clause 7.5. above the manufacturer may ask for measurements to be performed on a sample of engines of the same specification taken from the series and including the engine originally taken. The manufacturer shall determine the size n of the sample in agreement with the Test Agency. Engines other than the engine originally taken shall be subjected to a test. The arithmetical mean $\left(\bar{x}\right)$ of the results obtained with the sample shall then be determined for each pollutant. The production of the series shall then be deemed to confirm if the following condition is met:

$$\bar{x} + kS \leq l$$

Where:

$S^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$ where x is any one of the individual results obtained with the sample n;

l is the limit value laid down in clause 5.2.1. for each pollutant considered;

k is a statistical factor depending on n and given in the following table:

n	2	3	4	5	6	7	8	9	10
k	0.973	0.613	0.489	0.421	0.376	0.342	0.317	0.296	0.279
n	11	12	13	14	15	16	17	18	19
k	0.265	0.253	0.242	0.233	0.224	0.216	0.210	0.203	0.198

If $n \geq 20,$ $k = \frac{0.860}{\sqrt{n}}$

8. PRODUCTION DEFINITIVELY DISCONTINUED

If the certificate holder wishes to withdraw Type Approval Certificate, he shall inform at least three month before stoppage of production to the Test Agency which granted the type approval. Upon receiving the relevant communication, Test Agency shall inform the manufacturer the acceptance of the communication and provide an acceptance letter.

9. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

The approval granted in respect of an engine type or family pursuant to this Part may be withdrawn if the requirements laid down in clause 7 above are not complied with or if the engine or engines taken fail to pass the tests prescribed in clause 7.6

ANNEX 1A

INFORMATION DOCUMENT RELATING TO THE TYPE APPROVAL AND REFERRING TO MEASURES AGAINST THE EMISSION OF GASEOUS AND PARTICULATE POLLUTANTS FROM INTERNAL COMBUSTION ENGINES

Parent engine/engine type:[1].....

1.	General
1.1.	Make (name of undertaking): .....
1.2.	Type and commercial description of the parent – and (if applicable) of the family engine(s):.....
1.3.	Manufacturer's type coding as marked on the engine(s): .....
1.4.	Specification of Agricultural tractor, Construction equipment vehicle and Combine harvester to be propelled by the engine:[2] .....
1.5.	Name and address of manufacturer:.....
	Name and address of manufacturer's authorized representative (if any):.....
1.6.	Location, coding and method of affixing of the engine identification.....
1.7.	Location and method of affixing of the approval mark:.....
1.8.	Address(es) of assembly plant(s): .....

Attachments:

1.1.	Essential characteristics of the (parent) engine(s) (see Appendix 1)
1.2.	Essential characteristics of the engine family (see Appendix 2)
1.3.	Essential characteristics of engine types within the family (see Appendix 3)
2.	Characteristics of engine-related parts (if applicable)
3.	Photographs of the parent engine
4.	List further attachments if any

Date, file

[1] Strike out what does not apply.
[2] Specify the tolerance.

ANEEX 1A - APPENDIX 1

ESSENTIAL CHARACTERISTICS OF THE (PARENT) ENGINE

1. Description of engine

1.1.	Manufacturer: .....
1.2.	Manufacturer's engine code:.....
1.3.	Cycle: four stroke/two stroke[1]
1.4.	Bore:.....mm
1.5.	Stroke:.....mm
1.6.	Number and layout of cylinders:.....
1.7.	Engine capacity: .....cm^3
1.8.	Rated speed:.....
1.9.	Maximum torque speed:.....
1.10.	Volumetric compression ratio:[2].....
1.11.	Combustion system description: .....
1.12.	Drawing(s) of combustion chamber and piston crown: .....
1.13.	Minimum cross sectional area of inlet and outlet ports:.....
1.14.	Cooling system
1.14.1.	Liquid
1.14.1.1.	Nature of liquid:.....
1.14.1.2.	Circulating pump(s): yes/no[1]
1.14.1.3.	Characteristics or make(s) and type(s) (if applicable):.....
1.14.1.4.	Drive ratio(s) (if applicable):.....
1.14.2.	Air
1.14.2.1.	Blower: yes/no[1]
1.14.2.2.	Characteristics or make(s) and type(s) (if applicable):.....
1.14.2.3.	Drive ratio(s) (if applicable):.....
1.15.	Temperature permitted by the manufacturer
1.15.1.	Liquid cooling: Maximum temperature at outlet:..... K
1.15.2.	Air cooling: Reference point:.....
	Maximum temperature at reference point:..... K
1.15.3.	Maximum charge air outlet temperature of the inlet intercooler (if applicable):K

[1] Strike out what does not apply.
[2] Specify the tolerance.

1.15.4.	Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the outer flange(s) of the exhaust manifold(s): ..... K
1.15.5.	Fuel temperature: .....min: K
	.....max: K
1.15.6	Lubricant temperature: .....min: K
	.....max: K
1.16.	Pressure charger: yes/no[1]
1.16.1.	Make: .....
1.16.2.	Type: .....
1.16.3.	Description of the system (e.g. max charge pressure, waste-gate, if applicable):
1.16.4.	Intercooler: yes/no[1]
1.17.	Intake system: Maximum allowable intake depression at rated engine speed and at 100 per cent load:..... kPa
1.18.	Exhaust system: Maximum allowable exhaust backpressure at rated engine speed and at 100 per cent load: ..... kPa
2.	**Measures taken against air pollution**
2.1.	Device for recycling crankcase gases: yes/no[1]
2.2.	Additional anti-pollution devices (if any, and if not covered by another heading)
2.2.1.	Catalytic converter: yes/no[1]
2.2.1.1.	Make(s): .....
2.2.1.2.	Type(s): .....
2.2.1.3.	Number of catalytic converters and elements .....
2.2.1.4.	Dimensions- and volume of the catalytic converter(s): .....
2.2.1.5.	Type of catalytic action: .....
2.2.1.6.	Total charge of precious metals: .....
2.2.1.7.	Relative concentration: .....
2.2.1.8.	Substrate (structure and material): .....
2.2.1.9.	Cell density: .....
2.2.1.10.	Type of casing for the catalytic converter(s): .....
2.2.1.11.	Location of the catalytic converter(s) (place(s) and maximum/minimum distance(s) from engine): .....
2.2.1.12.	Normal operating range (K): .....
2.2.1.13.	Consumable reagent (where appropriate): .....
2.2.1.13.1.	Type and concentration of reagent needed for catalytic action: .....
2.2.1.13.2.	Normal operational temperature range of reagent: .....

[1] Strike out what does not apply.
[2] Specify the tolerance.

2.2.1.13.3.	International standard (where appropriate):.....
2.2.1.14.	NO_x sensor: yes/no[1]
2.2.2.	Oxygen sensor: yes/no[1]
2.2.2.1.	Make(s):.....
2.2.2.2.	Type:.....
2.2.2.3.	Location:.....
2.2.3.	Air injection: yes/no[1]
2.2.3.1.	Type (pulse air, air pump, etc.):.....
2.2.4.	EGR: yes/no[1]
2.2.4.1.	Characteristics (cooled/uncooled, high pressure/low pressure, etc.):.....
2.2.5.	Particulate trap: yes/no[1]
2.2.5.1.	Dimensions and capacity of the particulate trap:.....
2.2.5.2.	Type and design of the particulate trap:.....
2.2.5.3.	Location (place(s) and maximum/minimum distance(s) from engine):.....
2.2.5.4.	Method or system of regeneration, description and/or drawing:.....
2.2.5.5.	Normal operating temperature (K) and pressure (kPa) range:.....
2.2.6.	Other systems: yes/no[1]
2.2.6.1.	Description and operation:.....
3.	**Fuel feed**
3.1.	Feed pump
	Pressure[2] or characteristic diagram:..... kPa
3.2.	Injection system
3.2.1.	Pump
3.2.1.1.	Make(s):.....
3.2.1.2.	Type(s):.....
3.2.1.3.	Delivery: ..... mm^3 per stroke[2] or cycle at pump speed of:.....min^{-1} at full injection, or characteristic diagram.
	Mention the method used: On engine/on pump bench[1]
3.2.1.4.	Injection advance
3.2.1.4.1.	Injection advance curve:[2] .....
3.2.1.4.2.	Timing:[2] .....

1 Strike out what does not apply.
[2] Specify the tolerance.

3.2.2.	Injection piping
3.2.2.1.	Length: ..... mm
3.2.2.2.	Internal diameter: ..... mm
3.2.3.	Injector(s)
3.2.3.1.	Make(s): .....
3.2.3.2.	Type(s): .....
3.2.3.3.	Opening pressure[2] or characteristic diagram: ..... kPa
3.2.4.	Governor
3.2.4.1.	Make(s): .....
3.2.4.2.	Type(s): .....
3.2.4.3.	Speed at which cut-off starts under full load:[2] ..... min^{-1}
3.2.4.4.	Maximum no-load speed:[2] ..... min^{-1}
3.2.4.5.	Idling speed:[2] ..... min^{-1}
3.3.	Cold Start System
3.3.1.	Make(s): .....
3.3.2.	Type(s): .....
3.3.3.	Description: .....
4.	**Reserved**
5.	**Valve timing**
5.1.	Maximum lift and angles of opening and closing in relation to dead centres or equivalent data: .....
5.2.	Reference and/or setting ranges[1]
5.3.	Variable valve timing system (if applicable and where intake and/or exhaust)[1]
5.3.1.	Type: continuous or on/off[1]
5.3.2.	Cam phase shift angle: .....
6.	Reserved
7.	Reserved

---

1 Strike out what does not apply.
[2] Specify the tolerance.

ANNEX 1A- APPENDIX 2

ESSENTIAL CHARACTERISTICS OF THE ENGINE FAMILY

1. Common parameters[1]

1.1. Combustion cycle: .....

1.2. Cooling medium: .....

1.3. Method of air aspiration: .....

1.4. Combustion chamber type/design: .....

1.5. Valve and porting 3/4 configuration, size and number: .....

1.6. Fuel system: .....

1.7. Engine management systems .....

Proof of identity pursuant to drawing number(s): .....

1.7.1. Charge cooling system: .....

1.7.2. Exhaust gas recirculation:[2] .....

1.7.3. Water injection/emulsion:[2] .....

1.7.4. Air injection:[2] .....

1.8. Exhaust after-treatment system:[3] .....

Proof of identical (or lowest for the parent engine) ratio: system capacity/fuel delivery per stroke, pursuant to diagram number(s): .....

2. Engine family listing

2.1. Engine family name: .....

2.2. Specification of engines within this family:

	Parent engine (*)	Engines within family (**)			
Engine type					
No. of cylinders					
Rated speed (min^{-1})					
Fuel delivery per stroke (mm^3) at rated gross power					
Rated gross power (kW)					
Maximum power speed (min^{-1})					
Maximum gross power (kW)					

[1] Strike out what does not apply.
[2] Specify the tolerance.
[3] If not applicable mark n.a.

Maximum torque speed (min^{-1})					
Fuel delivery per stroke (mm^3) at maximum torque					
Maximum torque (Nm)					
Low idle speed (min^{-1})					
Cylinder displacement (in % of parent engine)	100				

(*) For full details see Appendix 1.

(**) For full details see Appendix 3.

2.3. In addition, for each engine type within the family, the information required in Annex 1A – Appendix 3 shall be submitted to the Test Agency.

ANNEX 1A - APPENDIX 3

ESSENTIAL CHARACTERISTICS OF ENGINE TYPES WITHIN THE FAMILY

1.	**Description of engine**
1.1.	Manufacturer: .....
1.2.	Manufacturer's engine code:.....
1.3.	Cycle: four stroke/two stroke[1]
1.4.	Bore:.....mm
1.5.	Stroke:.....mm
1.6.	Number and layout of cylinders:.....
1.7.	Engine capacity: .....cm^3
1.8.	Rated speed:.....
1.9.	Maximum torque speed:.....
1.10.	Volumetric compression ratio:[2].....
1.11.	Combustion system description: .....
1.12.	Drawing(s) of combustion chamber and piston crown.....
1.13.	Minimum cross-sectional area of inlet and outlet ports: .....
1.14.	Cooling system
1.14.1.	Liquid
1.14.1.1.	Nature of liquid:.....
1.14.1.2.	Circulating pump(s): yes/no[1]
1.14.1.3.	Characteristics or make(s) and type(s) (if applicable):.....
1.14.1.4.	Drive ratio(s) (if applicable):.....
1.14.2.	Air
1.14.2.1.	Blower: yes/no[1]
1.14.2.2.	Characteristics or make(s) and type(s) (if applicable):.....
1.14.2.3.	Drive ratio(s) (if applicable):.....
1.15.	Temperature permitted by the manufacturer
1.15.1.	Liquid cooling: Maximum temperature at outlet:..... K
1.15.2.	Air cooling: Reference point:.....
	Maximum temperature at reference point:..... K
1.15.3.	Maximum charge air outlet temperature of the inlet intercooler (if applicable):..... K

[1] Strike out what does not apply.
[2] Specify the tolerance.

1.15.4.	Maximum exhaust temperature at the point in the exhaust pipe(s) adjacent to the outer flange(s) of the exhaust manifold(s): ..... K
1.15.5.	Fuel temperature: .....min: K
	.....max: K
1.15.6.	Lubricant temperature: .....min: K
	.....max: K
1.16.	Pressure charger: yes/no[1]
1.16.1.	Make: .....
1.16.2.	Type: .....
1.16.3.	Description of the system (e.g. max. charge pressure, waste-gate, if applicable):
1.16.4.	Intercooler: yes/no[1]
1.17.	Intake system: Maximum allowable intake depression at rated engine speed and at 100 per cent load:..... kPa
1.18.	Exhaust system: Maximum allowable exhaust backpressure at rated engine speed and at 100 per cent load: ..... kPa
2.	**Measures taken against air pollution**
2.1.	Device for recycling crankcase gases: yes/no[1]
2.2.	Additional anti-pollution devices (if any, and if not covered by another heading)
2.2.1.	Catalytic converter: yes/no[1]
2.2.1.1.	Make(s): .....
2.2.1.2.	Type(s): .....
2.2.1.3.	Number of catalytic converters and elements: .....
2.2.1.4.	Dimensions and volume of the catalytic converter(s): .....
2.2.1.5.	Type of catalytic action: .....
2.2.1.6.	Total charge of precious metals: .....
2.2.1.7.	Relative concentration: .....
2.2.1.8.	Substrate (structure and material): .....
2.2.1.9.	Cell density: .....
2.2.1.10.	Type of casing for the catalytic converter(s): .....
2.2.1.11.	Location of the catalytic converter(s) (place(s) and maximum/minimum distance(s) from engine): .....
2.2.1.12.	Normal operating range (K) .....
2.2.1.13.	Consumable reagent (where appropriate): .....

1 Strike out what does not apply.

2.2.1.13.1.	Type and concentration of reagent needed for catalytic action: .....
2.2.1.13.2.	Normal operational temperature range of reagent: .....
2.2.1.13.3.	International standard (where appropriate): .....
2.2.1.14.	NO_x sensor: yes/no[1]
2.2.2.	Oxygen sensor: yes/no[1]
2.2.2.1.	Make(s): .....
2.2.2.2.	Type: .....
2.2.2.3.	Location: .....
2.2.3.	Air injection: yes/no[1]
2.2.3.1.	Type (pulse air, air pump, etc.): .....
2.2.4.	EGR: yes/no[1]
2.2.4.1.	Characteristics (cooled/uncooled, high pressure/low pressure, etc.): .....
2.2.5.	Particulate trap: yes/no[1]
2.2.5.1.	Dimensions and capacity of the particulate trap: .....
2.2.5.2.	Type and design of the particulate trap: .....
2.2.5.3.	Location (place(s) and maximum/minimum distance(s) from engine): .....
2.2.5.4.	Method or system of regeneration, description and/or drawing: .....
2.2.5.5.	Normal operating temperature (K) and pressure (kPa) range: .....
2.2.6.	Other systems: yes/no[1]
2.2.6.1.	Description and operation: .....
3.	**Fuel feed**
3.1.	Feed pump
	Pressure[2] or characteristic diagram: ..... kPa
3.2.	Injection system
3.2.1.	Pump
3.2.1.1.	Make(s): .....
3.2.1.2.	Type(s): .....
3.2.1.3.	Delivery: ..... mm^3 per stroke[2] or cycle at pump speed of ..... min^{-1} at full injection, or characteristic diagram.
	Mention the method used: On engine/on pump bench[1]
3.2.1.4.	Injection advance
3.2.1.4.1.	Injection advance curve:[2] .....
3.2.1.4.2.	Timing:[2] .....

1 Strike out what does not apply.
[2] Specify the tolerance.

3.2.2.	Injection piping
3.2.2.1.	Length: ..... mm
3.2.2.2.	Internal diameter: ..... mm
3.2.3.	Injector(s)
3.2.3.1.	Make(s): .....
3.2.3.2.	Type(s): .....
3.2.3.3.	Opening pressure[2] or characteristic diagram: ..... kPa
3.2.4.	Governor
3.2.4.1.	Make(s): .....
3.2.4.2.	Type(s): .....
3.2.4.3.	Speed at which cut-off starts under full load:[2] ..... min^{-1}
3.2.4.4.	Maximum no-load speed:[2] ..... min^{-1}
3.2.4.5.	Idling speed:[2] ..... min^{-1}
3.3.	Cold Start System
3.3.1.	Make(s): .....
3.3.2.	Type(s): .....
3.3.3.	Description: .....
4.	**Reserved**
5.	**Valve timing**
5.1.	Maximum lift and angles of opening and closing in relation to dead centres or equivalent data: .....
5.2.	Reference and/or setting ranges[1]
5.3.	Variable valve timing system (if applicable and where intake and/or exhaust)[1]
5.3.1.	Type: continuous or on/off[1]
5.3.2.	Cam phase shift angle: .....
6.	Reserved
7.	Reserved
8.	Emission test result NRSC & NRTC of parent engine & engines within family shall be submitted along with application.

---

1 Strike out what does not apply.
[2] Specify the tolerance.

ANNEX 1B

CHARACTERISTICS OF THE ENGINE FAMILY AND CHOICE OF THE PARENT ENGINE

1. PARAMETERS DEFINING THE ENGINE FAMILY

1.1. General

An engine family is characterized by design parameters. These shall be common to all engines within the family. The engine manufacturer may decide which engines belong to an engine family, as long as the membership criteria listed in clause 1.3. below are respected. The engine family shall be approved by the Test Agency. The manufacturer shall provide to the Test Agency the appropriate information relating to the emission levels of the members of the engine family.

1.2. Special cases

1.2.1. Interactions between parameters

In some cases there may be interaction between parameters, which may cause emissions to change. This shall be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

1.2.2. Devices or features having a strong influence on emissions

In case of devices or features, which are not listed in clause 1.3. below and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer using good engineering judgment, and shall be notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

1.2.3. Additional criteria

In addition to the parameters listed in clause 1.3. below, the manufacturer may introduce additional criteria allowing the definition of families of a more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

1.3. Parameters defining the engine family

1.3.1. Combustion cycle:

(a) 2-stroke cycle;

(b) 4-stroke cycle;

(c) Rotary engine;

(d) Others.

1.3.2. Configuration of the cylinders

1.3.2.1. Position of the cylinders in the block:

(a) V;

(b) In-line;

(c) Radial;

(d) Others (F, W, etc.).

1.3.2.2. Relative position of the cylinders

Engines with the same block may belong to the same family as long as their bore centre-to-centre dimensions are the same.

1.3.3. Main cooling medium:

(a) Air;

(b) Water;

(c) Oil.

1.3.4. Individual cylinder displacement

Within 85 per cent and 100 per cent for engines with a unit cylinder displacement ≥ 0.75 dm^3 of the largest displacement within the engine family.

Within 70 per cent and 100 per cent for engines with a unit cylinder displacement < 0.75 dm^3 of the largest displacement within the engine family.

1.3.5. Method of air aspiration:

(a) Naturally aspirated;

(b) Pressure charged;

(c) Pressure charged with charge cooler.

1.3.6. Combustion chamber type/design:

(a) Open chamber;

(b) Divided chamber;

(c) Other types.

1.3.7. Valves and porting:

(a) Configuration;

(b) Number of valves per cylinder.

1.3.8. Fuel supply type:

(a) Pump, (high pressure) line and injector;

(b) In-line pump or distributor pump;

(c) Unit injector;

(d) Common rail.

1.3.9. Miscellaneous devices:

(a) Exhaust gas recirculation (EGR);

(b) Water injection;

(c) Air injection;

(d) Others.

1.3.10. Electronic control strategy

The presence or absence of an Electronic Control Unit (ECU) on the engine is regarded as a basic parameter of the family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engines can be expected to satisfy the same emission requirements.

The electronic governing of speed does not need to be in a different family from those with mechanical governing. The need to separate electronic engines from mechanical engines should only apply to the fuel injection characteristics, such as timing, pressure, rate shape, etc.

1.3.11. Exhaust after-treatment systems

The function and combination of the following devices are regarded as membership criteria for an engine family:

(a) Oxidation catalyst;

(b) $DeNO_x$ system with selective reduction of NO_x (addition of reducing agent);

(c) Other $DeNO_x$ systems;

(d) Particulate trap with passive regeneration;

(e) Particulate trap with active regeneration;

(f) Other particulate traps;

(g) Other devices.

When an engine has been certified without an after-treatment system, whether as parent engine or as member of the family, then this engine, when equipped with an oxidation catalyst (not with particulate trap), may be included in the same engine family, if it does not require different fuel characteristics.

If it requires specific fuel characteristics (e.g. particulate traps requiring special additives in the fuel to ensure the regeneration process), the decision to include it in the same family shall be based on technical elements provided by the manufacturer. These elements shall indicate that the expected emission level of the equipped engine complies with the same limit value as the non-equipped engine.

When an engine has been certified with after-treatment system, whether as parent engine or as member of a family, whose parent engine is equipped with the same after-treatment system, then this engine, when equipped without after-treatment system, shall not be added to the same engine family.

2. CHOICE OF THE PARENT ENGINE

2.1. The parent engine of the family shall be selected using the primary criteria of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criteria of highest fuel delivery per stroke at rated speed. Under certain circumstances, the Test Agency may conclude that the worst case emission rate of the family can best be characterized by testing a second engine. Thus, the Test Agency may select an additional engine for test based upon features which indicate that it may have the highest emission levels of the engines within that family.

2.2. If engines within the family incorporate other variable features which could be considered to affect exhaust emissions, these features shall also be identified and taken into account in the selection of the parent engine.

ANNEX 2

TEST REPORT FOR COMPRESSION IGNITION ENGINES

Test results[1]

Information concerning the test engine

Engine type: .....

Engine identification number: .....

1. Information concerning the conduct of the test:

1.1. Reference fuel used for test

1.1.1. Cetane number: .....

1.1.2. Sulphur content: .....

1.1.3. Density: .....

1.2. Lubricant

1.2.1. Make(s): .....

1.2.2. Type(s): .....

(state percentage of oil in mixture if lubricant and fuel are mixed)

1.3. Engine driven equipment (if applicable)

1.3.1. Enumeration and identifying details: .....

[1] For the case of several parent engines, the following are to be indicated for each of them.

1.3.2. Power absorbed at indicated engine speeds (as specified by the manufacturer):

	Power absorbed by engine driven equipment at various engine speeds[1,2], taking into account Annex 7		
Equipment	Intermediate speed (if applicable)	Maximum power speed (if different from rated)	Rated speed[3]
Total:			

[1] Delete as appropriate.

[2] Shall not be greater than 10 per cent of the power measured during the test.

[3] Insert values at engine speed corresponding to 100 per cent normalised speed if NRSC test uses this speed.

1.4. Engine performance

1.4.1. Engine speeds:

Idle: .....min^{-1}

Intermediate: .....min^{-1}

Maximum Power: .....min^{-1}

Rated:[2].....min^{-1}

1.4.2. Engine power[3]

[2] Insert engine speed corresponding to 100 per cent normalised speed if NRSC test uses this speed.

[3] Uncorrected power measured in accordance with clause 2.1.49.

	Power setting (kW) at various engine speeds		
Condition	Intermediate speed (if applicable)	Maximum power speed (if different from rated)	Rated speed[1]
Maximum power measured at specified test speed (kW) (*a*)			
Total power absorbed by engine driven equipment as per clause 1.3.2. of this Appendix taking into account Annex7 (kW) (*b*)			
Gross engine power as specified in clause 2.1.49 (kW) (*c*)			
$c = a + b$			

[1] Replace with values at engine speed corresponding to 100 per cent normalised speed if NRSC test uses this speed.

2. Information concerning the conduct of the NRSC test:

2.1. Dynamometer setting (kW)

	Dynamometer setting (kW) at various engine speeds	
Per cent Load	Intermediate (if applicable)	Rated speed[1]
10 (if applicable)		
25 (if applicable)		
50		
75		
100		

[1] Replace with values at engine speed corresponding to 100 per cent normalised speed if NRSC test uses this speed.

2.2. Emission results of the engine/parent engine[4]

Deterioration Factor (DF): calculated/fixed[5]

Specify the DF values and the emission results in the following table:[5]

NRSC Test					
DF mult/add[1]	CO	HC	NO_x	PM	
Emissions	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	CO_2 (g/kWh)
Test result					
Final test result with DF					

[4] Delete as appropriate.

Additional control area test points (if applicable)						
Emissions at test point	Engine speed	Load (%)	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Test result 1						
Test result 2						
Test result 3						

2.3. Sampling system used for the NRSC test:

[4] Delete as appropriate.

[5] Replace with values at engine speed corresponding to 100 per cent normalised speed if NRSC test uses this speed.

2.3.1. Gaseous emissions:[6] .....

2.3.2. PM:[6] .....

2.3.2.1. Method:[4] single/multiple filter

3. Information concerning the conduct of the NRTC test(if applicable):[7]

3.1. Emission results of the engine/parent engine[4]

Deterioration Factor (DF): calculated/fixed[4]

Specify the DF values and the emission results in the following table:[6]

Regeneration related data shall be reported for engines. ~~of power bands Q and R.~~

NRTC Test

	CO	HC	NO_x		PM	
DF mult/add[1]						
Emissions	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	$HC+NO_x$ (g/kWh)	PM (g/kWh)	
Cold start						
Emissions	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	$HC+NO_x$ (g/kWh)	PM (g/kWh)	CO_2 (g/kWh)
Hot start without regeneration						
Hot start with regeneration[1]						
$k_{r,u}$(mult/add)[1] $k_{r,d}$ (mult/add)[1]						
Weighted test result						
Final test result with DF						

[1] Delete as appropriate.

Cycle work for hot start without regeneration kWh

3.2. Sampling system used for the NRTC test:

Gaseous emissions:[6] .....

PM:[6] .....

[6] Indicate figure numbers of system used as defined in clause 9 of Annex 4 to this Part.

[7] Indicate figure numbers of system used as defined in clause 9 of Annex 4 to this Part.

Method:[4] single/multiple filter

ANNEX 3

LABELLING REQUIREMENT

1. The engine must be affixed with a conformance label meeting the following requirements:
    a. The label shall be durable and legible
    b. The label shall be affixed on a part necessary for normal operation of the engine and not normally requiring replacement during the life of the engine.
    c. Name and location of the engine manufacturer from where engine is manufacture
    d. Type Approval Test Report number.
    e. Engine Unique Identification Number (Serial Number, etc.)
    f. Engine family and Power band or Power
    g. Month and year of manufacturing
    h. All the above information mentioned in the conformance label must be in English language

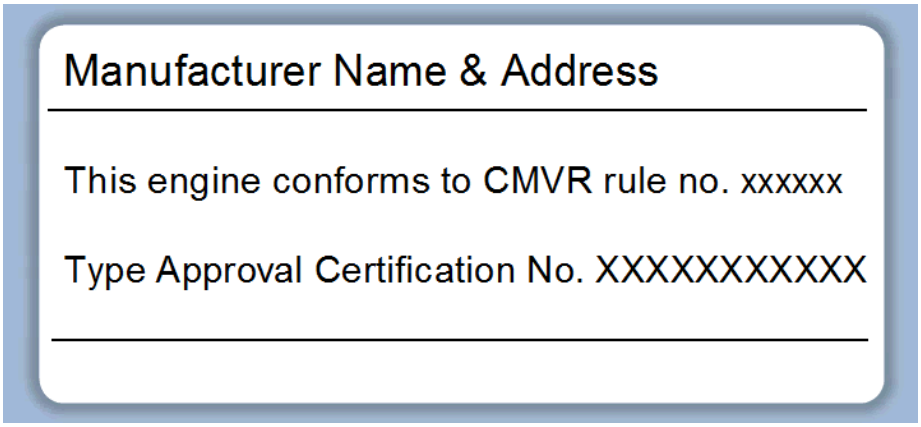
Notes :

For (b), Plant location shall be mentioned either in through CODE via Engine Serial Number or mentioned explicitly in Emission data label. The same shall be mentioned in AIS-007.

Engine Serial Number shall be mentioned in emission label or punched in Engine block as per Manufacturer choices and agree with Test Agency

Power band or Power based on Manufacturer's choice shall be declared in emission label

Manufacturers may choose to mention Month and Year separately in emission label or will have Month and Year as part of Engine Serial Number/Bar Codes.



ANNEX 4

TEST PROCEDURE FOR COMPRESSION-IGNITION ENGINES TO BE INSTALLED IN AGRICULTURAL TRACTORS, CONSTRUCTION EQUIPMENT VEHICLES AND COMBINE HARVESTERS WITH REGARD TO THE EMISSIONS OF POLLUTANTS BY THE ENGINE

1. **RESERVED**

2. **RESERVED**

3. **DEFINITIONS, SYMBOLS AND ABBREVIATIONS**

3.1. Definitions

See clause 2.1. of this Part

3.2. General symbols[1]

Symbol	Unit	Term
a_0	-	*y* intercept of the regression line
a_1	-	Slope of the regression line
α_{sp}	rad/s^2	Derivative of the engine speed at the set point
A/F_{st}	-	Stoichiometric air to fuel ratio
c	ppm, per cent vol	Concentration (also in µmol/mol = ppm)
D	-	Dilution factor

[1] Specific symbols are found in annexes.

Symbol	Unit	Term
d	m	Diameter
E	per cent	Conversion efficiency
e	g/kWh	Brake specific basis
e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	g/kWh	Specific emission of particulates
e_w	g/kWh	Weighted specific emission
F		F-test statistics
F	-	Frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs
f_a	-	Laboratory atmospheric factor
k_r	-	Multiplicative regeneration factor
k_{Dr}	-	downward adjustment factor
k_{Ur}	-	upward adjustment factor
λ	-	Excess air ratio
L	-	Per cent torque
M_a	g/mol	Molar mass of the intake air
M_e	g/mol	Molar mass of the exhaust
M_{gas}	g/mol	Molar mass of gaseous components
m	kg	Mass
m_{gas}	g	Mass of gaseous emissions over the test cycle
m_{PM}	g	Mass of particulate emissions over the test cycle
n	min^{-1}	Engine rotational speed
n_{hi}	min^{-1}	High engine speed
n_{lo}	min^{-1}	Low engine speed
P	kW	Power
P_{max}	kW	Maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer)
P_{AUX}	kW	Declared total power absorbed by auxiliaries fitted for the test
p	kPa	Pressure
p_a	kPa	Dry atmospheric pressure
PF	per cent	Penetration fraction
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mdw}	kg/s	Dilution air mass flow rate on wet basis
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis
q_{mf}	kg/s	Fuel mass flow rate
q_{mp}	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_V	m^3/s	Volume flow rate
RF	-	Response factor

Symbol	Unit	Term
r_d	-	Dilution ratio
r^2	-	Coefficient of determination
ρ	kg/m³	Density
σ	-	Standard deviation
S	kW	Dynamometer setting
SEE	-	Standard error of estimate of y on x
T	°C	Temperature
T_a	K	Absolute temperature
T	N·m	Engine torque
T_{sp}	N·m	Demanded torque with "sp" set point
u	-	Ratio between densities of gas component and exhaust gas
t	s	Time
Δt	s	Time interval
t_{10}	s	Time between step input and 10 per cent of final reading
t_{50}	s	Time between step input and 50 per cent of final reading
t_{90}	s	Time between step input and 90 per cent of final reading
V	m^3	Volume
W	kWh	Work
y		Generic variable
$\overline{y}$		Arithmetic mean

3.3. Subscripts

abs	Absolute quantity
act	Actual quantity
air	Air quantity
amb	Ambient quantity
atm	Atmospheric quantity
cor	Corrected quantity
CFV	Critical flow venturi
denorm	Denormalized quantity
dry	Dry quantity
exp	Expected quantity
filter	PM sample filter
i	Instantaneous measurement (e.g. 1 Hz)
i	An individual of a series
idle	Condition at idle
in	Quantity in
leak	Leak quantity
max	Maximum (peak) value

meas	Measured quantity
min	Minimum value
mix	Molar mass of air
out	Quantity out
PDP	Positive displacement pump
ref	Reference quantity
SSV	Subsonic venturi
total	Total quantity
uncor	Uncorrected quantity
vac	Vacuum quantity
weight	Calibration weight
wet	Wet quantity

3.4. Symbols and abbreviations for the chemical components (used also as a subscript)

See clause 2.2.2. of this Part

3.5. Abbreviations

See clause 2.2.3. of this Part

4. GENERAL REQUIREMENTS

The engine system shall be designed, constructed and assembled so as to enable it to comply with the provisions of this Part. The technical measures taken by the manufacturer shall be such as to ensure that the mentioned emissions are effectively limited, pursuant to this Part, throughout the useful life of the engine and under normal conditions of use. For this, engines shall meet the performance requirements of clause 5. when tested in accordance with the test conditions of clause 6. and the test procedure of clause 7.

5. PERFORMANCE REQUIREMENTS

5.1. General requirements

5.1.1. Reserved

5.1.2. Emissions of gaseous and particulate pollutants

The pollutants are represented by:

(a) Oxides of nitrogen, NO_x;

(b) Hydrocarbons, which may be expressed in the following ways:

(i) Total hydrocarbons, HC or THC;

(ii) Non-methane hydrocarbons, NMHC.

(c) Particulate matter, PM;

(d) Carbon monoxide, CO.

The measured values of gaseous and particulate pollutants exhausted by the engine refer to the brake-specific emissions in grams per kilowatt-hour (g/kWh). Other system of units may be used with appropriate conversion.

The emissions shall be determined on the duty cycles (steady-state and/or transient), as described in clause 7. The measurement systems shall meet the calibration and performance checks of clause 8. with measurement equipment of clause 9.

Other systems or analysers may be approved by the Test Agency if it is found that they yield equivalent results in accordance with clause 5.1.3.

5.1.3. Equivalency

The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the systems of this annex.

"Results" refer to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics as described in Annex 4, Appendix A.2. obtained under the laboratory test cell and the engine conditions described above. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. The systems to be used for correlation testing shall be subject to the approval by the Test Agency.

5.2. Reserved

6. TEST CONDITIONS

6.1. Laboratory test conditions

The absolute temperature (T_a) of the engine air at the inlet to the engine expressed in Kelvin, and the dry atmospheric pressure (p_s), expressed in kPa shall be measured and the parameter f_a shall be determined according to the following provisions. In multi-cylinder engines having distinct groups of intake manifolds, such as in a 'V' engine configuration, the average temperature of the distinct groups shall be taken. The parameter f_a shall be reported with the test results. For better repeatability and reproducibility of the test results, it is recommended that the parameter f_a be such that: $0.93 \leq f_a \leq 1.07$.

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \cdot \left(\frac{T_a}{298}\right)^{0.7} \quad (6\text{-}1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \cdot \left(\frac{T_a}{298}\right)^{1.5} \quad (6\text{-}2)$$

The temperature of intake air shall be maintained to (25 ± 5) °C, as measured upstream of any engine component.

It is allowed to use:

(a) A shared atmospheric pressure meter as long as the equipment for handling intake air maintains ambient pressure, where the engine is tested, within ±1 kPa of the shared atmospheric pressure;

(b) A shared humidity measurement for intake air as long as the equipment for handling intake air maintains dew point, where the engine is tested, within ±0.5 °C of the shared humidity measurement.

6.2. Engines with charge air cooling

(a) A charge-air cooling system with a total intake-air capacity that represents production engines' in-use installation shall be used. Any laboratory charge-air cooling system to minimize accumulation of condensate shall be designed. Any accumulated condensate shall be drained and all drains shall be completely closed before emission testing. The drains shall be kept closed during the emission test. Coolant conditions shall be maintained as follows:

(i) A coolant temperature of at least 20 °C shall be maintained at the inlet to the charge-air cooler throughout testing;

(ii) At the engine conditions specified by the manufacturer, the coolant flow rate shall be set to achieve an air temperature within ±5 °C of the value designed by the manufacturer after the charge-air cooler's outlet. The air-outlet temperature shall be measured at the location specified by the manufacturer. This coolant flow rate set point shall be used throughout testing. If the engine manufacturer does not specify engine conditions or the corresponding charge-air cooler air outlet temperature, the coolant flow rate shall be set at maximum engine power to achieve a charge-air cooler air outlet temperature that represents in-use operation;

(iii) If the engine manufacturer specifies pressure-drop limits across the charge-air cooling system, it shall be ensured that the pressure drop across the charge-air cooling system at engine conditions specified by the manufacturer is within the manufacturer's specified limit(s). The pressure drop shall be measured at the manufacturer's specified locations;

(b) The objective is to produce emission results that are representative of in-use operation. If good engineering judgment indicates that the specifications in this section would result in unrepresentative testing (such as overcooling of the intake air), more sophisticated set points and controls of charge-air pressure drop, coolant temperature, and flow rate may be used to achieve more representative results.

6.3. Engine power

6.3.1. Basis for emission measurement

The basis of specific emissions measurement is uncorrected power.

6.3.2. Auxiliaries to be fitted

During the test, the auxiliaries necessary for the engine operation shall be installed on the test bench according to the requirements of Annex 7.

6.3.3. Auxiliaries to be removed

Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test.

Where auxiliaries cannot be removed, the power they absorb in the unloaded condition may be determined and added to the measured engine power (see note g in the table of Annex 7). If this value is greater than 3 per cent of the maximum power at the test speed it may be verified by the Test Agency. The power absorbed by auxiliaries shall be used to adjust the set values and to calculate the work produced by the engine over the test cycle.

6.4. Engine intake air

6.4.1. Introduction

The intake-air system installed on the engine or one that represents a typical in-use configuration shall be used. This includes the charge-air cooling and exhaust gas recirculation systems.

6.4.2. Intake air restriction

An engine air intake system or a test laboratory system shall be used presenting an air intake restriction within ±300 Pa of the maximum value specified by the manufacturer for a clean air cleaner at the rated speed and full load. The static differential pressure of the restriction shall be measured at the location and at the speed and torque set points specified by the manufacturer. If the manufacturer does not specify a location, this pressure shall be measured upstream of any turbocharger or exhaust gas recirculation system connection to the intake air system. If the manufacturer does not specify speed and torque points, this pressure shall be measured while the engine outputs maximum power.

6.5. Engine exhaust system

The exhaust system installed with the engine or one that represents a typical in-use configuration shall be used. For aftertreatment devices the exhaust restriction shall be defined by the manufacturer according to the aftertreatment condition (e.g. degreening/aging and regeneration/loading level). The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in clause 9.3. An engine exhaust system or a test laboratory system shall be used presenting a static exhaust backpressure within 80 to 100 per cent of the maximum exhaust restriction at the engine speed and torque specified by the manufacturer. If the maximum restriction is 5 kPa or less, the set point shall be no less than 1.0 kPa from the maximum. If the manufacturer does not specify speed and torque points, this pressure shall be measured while the engine produces maximum power.

6.6. Engine with exhaust after-treatment system

If the engine is equipped with an exhaust after-treatment system, the exhaust pipe shall have the same diameter as found in-use for at least four pipe diameters upstream of the expansion section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment system shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above, and may be set with a valve. The after-treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

The emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with an exhaust after-treatment system that requires the consumption of a reagent, the reagent used for all tests shall be declared by the manufacturer.

For engines equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis, as described in clause 6.6.2., emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs. After-treatment systems with continuous regeneration according to clause 6.6.1. do not require a special test procedure.

6.6.1. Continuous regeneration

For an exhaust aftertreatment system based on a continuous regeneration process the emissions shall be measured on an aftertreatment system that has been stabilized so as to result in repeatable emissions behaviour. The regeneration process shall occur at least once during the NRTC hot start test or ramped-modal cycle (RMC) test and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust back-pressure, etc.). In order to demonstrate that the regeneration process is continuous, at least three NRTC hot start tests or ramped-modal cycle (RMC) tests shall be conducted. In case of NRTC hot start test, the engine shall be warmed up in accordance with clause 7.8.2.1., the engine be soaked according to clause 7.4.2. and the first NRTC hot start test be run. The subsequent NRTC hot start tests shall be started after soaking according to clause 7.4.2. During the tests, exhaust temperatures and pressures shall be recorded (temperature before and after the after-treatment system, exhaust back pressure, etc.). The aftertreatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test during a sufficient time and the emission results do not scatter by more than ± 25 per cent or 0.005 g/kWh, whichever is greater. If the exhaust aftertreatment has a security mode that shifts to a periodic (infrequent) regeneration mode, it shall be checked according to clause 6.6.2. For that specific case, the applicable emission limits could be exceeded and would not be weighted.

6.6.2. Infrequent (periodic) regeneration

This provision only applies for engines equipped with emission controls that are regenerated on a periodic basis. For engines which are run on the discrete mode cycle this procedure cannot be applied.

The emissions shall be measured on at least three NRTC hot start tests or ramped-modal cycle (RMC) tests, one with and two without a regeneration event on a stabilized aftertreatment system. The regeneration process shall occur at least once during the NRTC or RMC test. If regeneration takes longer than one NRTC or RMC test, consecutive NRTC or RMC tests shall be run and emissions continued to be measured without shutting the engine off until regeneration is completed and the average of the tests shall be calculated. If regeneration is completed during any test, the test shall be continued over its entire length. The engine may be equipped with a switch capable of preventing or permitting the regeneration process provided this operation has no effect on the original engine calibration.

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure, etc.). The manufacturer shall also provide the frequency of the regeneration event in terms of number of tests during which the regeneration occurs. The exact procedure to determine this frequency shall be agreed by the Test Agency based upon good engineering judgement.

For a regeneration test, the manufacturer shall provide an aftertreatment system that has been loaded. Regeneration shall not occur during this engine conditioning phase. As an option, the manufacturer may run consecutive NRTC hot start or RMC tests until the aftertreatment system is loaded. Emissions measurement is not required on all tests.

Average emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant NRTC hot start or RMC tests. As a minimum, at least one hot NRTC or RMC as close as possible prior to a regeneration test and one hot NRTC or RMC immediately after a regeneration test shall be conducted.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO_x emissions, temperature before and after the after-treatment system, exhaust back pressure, etc.). During the regeneration process, the applicable emission limits may be exceeded. The test procedure is schematically shown in Figure 6.1.

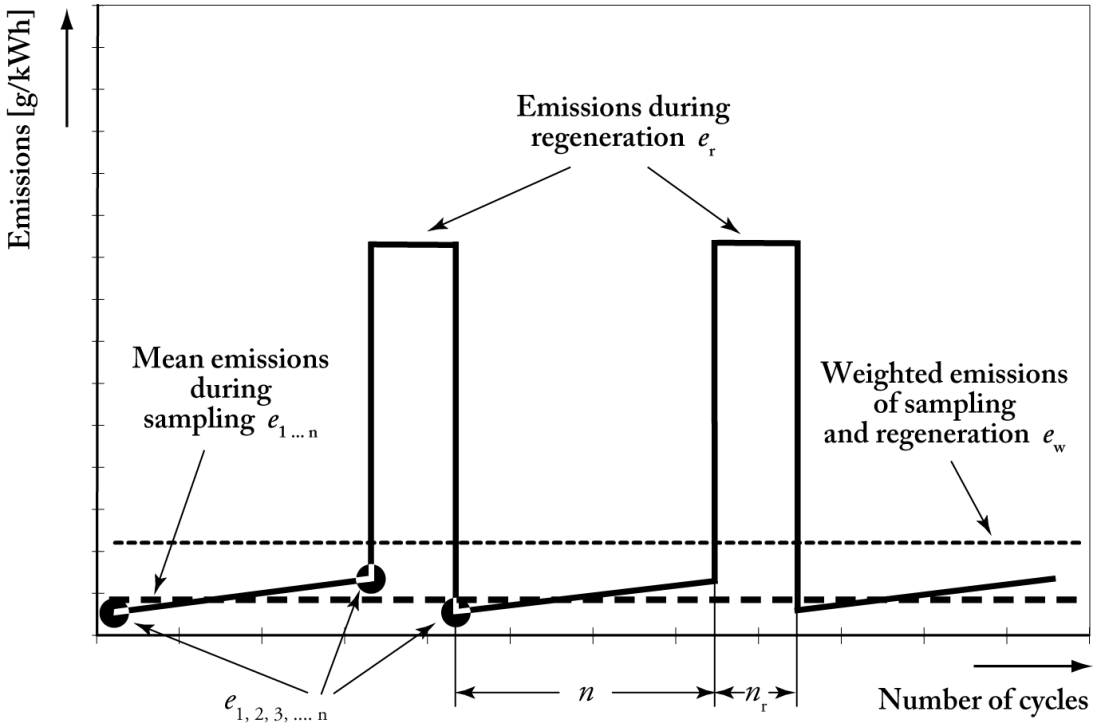


Figure 6.1
Scheme of Infrequent (Periodic) Regeneration with *N* Number of Measurements and N_r Number of Measurements during Regeneration

The average specific emission rate related to hot start $\overline{e}_w$ [g/kWh] shall be weighted as follows (see Figure 6.1):

$$\bar{e}_w = \frac{n \cdot \bar{e} + n_r \cdot \bar{e}_r}{n + n_r} \quad (6\text{-}3)$$

where:

n = number of tests in which regeneration does not occur,

n_r = number of tests in which regeneration occurs (minimum one test),

$\bar{e}$ = average specific emission from a test in which the regeneration does not occur [g/kWh]

$\bar{e}_r$ = average specific emission from a test in which the regeneration occurs [g/kWh]

At the choice of the manufacturer and based on upon good engineering analysis, the regeneration adjustment factor k_r, expressing the average emission rate, may be calculated either multiplicative or additive as follows:

Multiplicative

$$k_{Ur} = \frac{\bar{e}_w}{\bar{e}} \text{ (upward adjustment factor)} \quad (6\text{-}4a)$$

$$k_{Dr} = \frac{\bar{e}_w}{\bar{e}_r} \text{ (downward adjustment factor)} \quad (6\text{-}4b)$$

Additive

$$k_{Ur} = \bar{e}_w - \bar{e} \text{ (upward adjustment factor)} \quad (6\text{-}5)$$

$$k_{Dr} = \bar{e}_w - \bar{e}_r \text{ (downward adjustment factor)} \quad (6\text{-}6)$$

Upward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration does not occur. Downward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration occurs. The occurrence of the regeneration shall be identified in a manner that is readily apparent during all testing. Where no regeneration is identified, the upward adjustment factor shall be applied.

With reference to Annex 4, Appendices A.7-8 on brake specific emission calculations, the regeneration adjustment factor:

(a) Shall be applied to the results of the weighted NRTC test and RMC tests;

(b) May be applied to the ramped modal cycles and cold NRTC, if a regeneration occurs during the cycle;

(c) May be extended to other members of the same engine family;

(d) May be extended to other engine families using the same aftertreatment system with the prior approval of the Test Agency based on technical evidence to be supplied by the manufacturer that the emissions are similar.

The following options shall be considered:

(a) A manufacturer may elect to omit adjustment factors for one or more of its engine families (or configurations) because the effect of the

regeneration is small, or because it is not practical to identify when regenerations occur. In these cases, no adjustment factor shall be used, and the manufacturer is liable for compliance with the emission limits for all tests, without regard to whether a regeneration occurs;

(b) Upon request by the manufacturer, the type approval or certification Test Agency may account for regeneration events differently than is provided in sub- clause (a). However, this option only applies for events that occur extremely infrequently, and which cannot be practically addressed using the adjustment factors described in sub-clause (a).

6.7. Cooling system

An engine cooling system with sufficient capacity to maintain the engine, with its intake-air, oil, coolant, block and head temperatures, at normal operating temperatures prescribed by the manufacturer shall be used. Laboratory auxiliary coolers and fans may be used.

6.8. Lubricating oil

The lubricating oil shall be specified by the manufacturer and be representative of lubricating oil available in the market; the specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

6.9. Specification of the diesel fuel

The reference fuel is specified in Annex 6, Appendix 1 and Commercial fuel is specified in Annex 6, Appendix 2.

The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded. For Type approval and Conformity of Production (COP) test, fuel shall be Reference fuel or commercial fuel as recommended by manufacturer.

6.10. Crankcase emissions

No crankcase emissions shall be discharged directly into the ambient atmosphere, with the following exception: engines equipped with turbochargers, pumps, blowers, or superchargers for air induction may discharge crankcase emissions to the ambient atmosphere if the emissions are added to the exhaust emissions (either physically or mathematically) during all emission testing. Manufacturers taking advantage of this exception shall install the engines so that all crankcase emission can be routed into the emissions sampling system. For the purpose of this clause, crankcase emissions that are routed into the exhaust upstream of exhaust aftertreatment during all operation are not considered to be discharged directly into the ambient atmosphere.

Open crankcase emissions shall be routed into the exhaust system for emission measurement, as follows:

(a) The tubing materials shall be smooth-walled, electrically conductive, and not reactive with crankcase emissions. Tube lengths shall be minimized as far as possible;

(b) The number of bends in the laboratory crankcase tubing shall be minimized, and the radius of any unavoidable bend shall be maximized;

(c) The laboratory crankcase exhaust tubing shall meet the engine manufacturer's specifications for crankcase back pressure;

(d) The crankcase exhaust tubing shall connect into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. The crankcase exhaust tube shall extend into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. The crankcase exhaust tube's outlet may orient in any direction relative to the raw exhaust flow.

7. TEST PROCEDURES

7.1. Introduction

This clause describes the determination of brake specific emissions of gaseous and particulate pollutants on engines to be tested. The test engine shall be the parent engine configuration for the engine family as specified in clause 5.2. of this Part.

A laboratory emission test consists of measuring emissions and other parameters for the test cycles specified in this annex. The following aspects are treated (in this Annex 4):

(a) The laboratory configurations for measuring the brake specific emissions (clause 7.2.);

(b) The pre-test and post-test verification procedures (clause 7.3.);

(c) The test cycles (clause 7.4.);

(d) The general test sequence (clause 7.5.);

(e) The engine mapping (clause 7.6.);

(f) The test cycle generation (clause 7.7.);

(g) The specific test cycle running procedure (clause 7.8.).

7.2. Principle of emission measurement

To measure the brake-specific emissions the engine shall be operated over the test cycles defined in clause 7.4., as applicable. The measurement of brake-specific emissions requires the determination of the mass of pollutants in the exhaust (i.e. HC, NMHC, CO, NO_x and PM) and the corresponding engine work.

7.2.1. Mass of constituent

The total mass of each constituent shall be determined over the applicable test cycle by using the following methods:

7.2.1.1. Continuous sampling

In continuous sampling, the constituent's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) exhaust flow rate at the emission sampling location to determine the constituent's flow rate. The constituent's emission is continuously summed over the test interval. This sum is the total mass of the emitted constituent.

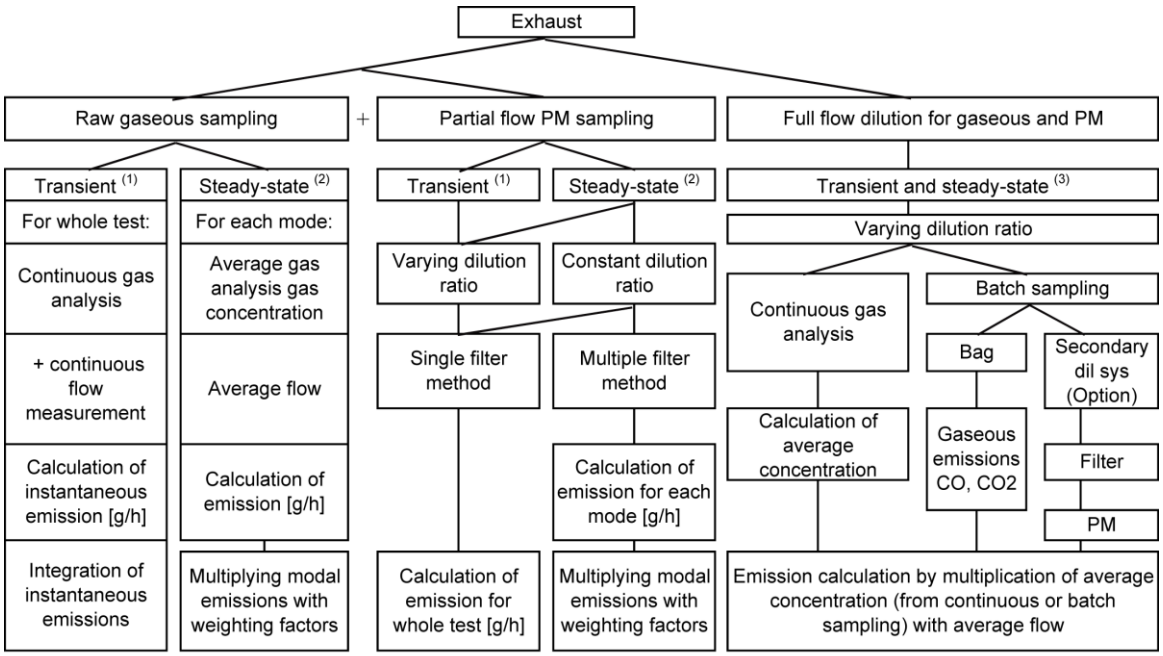
7.2.1.2. Batch sampling

In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In principal the method of emission calculation is done as follows: the batch sampled concentrations are multiplied by the total mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted constituent. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.

7.2.1.3. Combined sampling

Any combination of continuous and batch sampling is permitted (e.g. PM with batch sampling and gaseous emissions with continuous sampling).

The following Figure 7.1 illustrates the two aspects of the test procedures for measuring emissions: the equipments with the sampling lines in raw and diluted exhaust gas and the operations requested to calculate the pollutant emissions in steady-state and transient test cycles (Figure 7.1).



(1) Transient and Ramped Modal Test Cycle; (2) Discrete Mode Steady State Cycle; (3) Transient, ramped modal and discrete mode Steady-State Cycles

Note on Figure 7.1: The term "Partial flow PM sampling" includes the partial flow dilution to extract only raw exhaust with constant or varying dilution ratio.

Figure 7.1
Test Procedures for Emission Measurement

7.2.2. Work determination

The work shall be determined over the test cycle by synchronously multiplying speed and brake torque to calculate instantaneous values for engine brake power. Engine brake power shall be integrated over the test cycle to determine total work.

7.3. Verification and calibration

7.3.1. Pre-test procedures

7.3.1.1. Preconditioning

To achieve stable conditions, the sampling system and the engine shall be preconditioned before starting a test sequence as specified in clauses 7.3. and 7.4. The preconditioning for cooling down the engine in view of a cold start transient test is specially indicated in clause 7.4.2. below.

7.3.1.2. Verification of HC contamination

If there is any presumption of an essential HC contamination of the exhaust gas measuring system, the contamination with HC may be checked with zero gas and the hang-up may then be corrected. If the amount of contamination of the measuring system and the background HC system has to be checked, it shall be conducted within 8 hours of starting each test-cycle. The values shall be recorded for later correction. Before this check, the leak check has to be performed and the FID analyser has to be calibrated.

7.3.1.3. Preparation of measurement equipment for sampling

The following steps shall be taken before emission sampling begins:

(a) Leak checks shall be performed within 8 hours prior to emission sampling according to clause 8.1.8.7. below;

(b) For batch sampling, clean storage media shall be connected, such as evacuated bags or tare-weighed filters;

(c) All measurement instruments shall be started according to the instrument manufacturer's instructions and good engineering judgment;

(d) Dilution systems, sample pumps, cooling fans, and the data-collection system shall be started;

(e) The sample flow rates shall be adjusted to desired levels, using bypass flow, if desired;

(f) Heat exchangers in the sampling system shall be pre-heated or pre-cooled to within their operating temperature ranges for a test;

(g) Heated or cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilize at their operating temperatures;

(h) Exhaust dilution system flow shall be switched on at least 10 minutes before a test sequence;

(i) Calibration of gas analysers and zeroing of continuous analysers shall be carried out according to the procedure of the next clause 7.3.1.4. below;

(j) Any electronic integrating devices shall be zeroed or re-zeroed, before the start of any test interval.

7.3.1.4. Calibration of gas analysers

Appropriate gas analyser ranges shall be selected. Emission analysers with automatic or manual range switching are allowed. During a ramped modal or a

NRTC test and during a sampling period of a gaseous emission at the end of each mode for discrete mode testing, the range of the emission analysers may not be switched. Also the gains of an analyser's analogue operational amplifier(s) may not be switched during a test cycle.

All continuous analysers shall be zeroed and spanned using internationally-traceable gases that meet the specifications of clause 9.5.1. of this annex FID analysers shall be spanned on a carbon number basis of one (C_1).

7.3.1.5. PM filter preconditioning and tare weighing

The procedures for PM filter preconditioning and tare weighing shall be followed according to clause 8.2.3. of this Annex.

7.3.2. Post-test procedures

The following steps shall be taken after emission sampling is complete:

7.3.2.1. Verification of proportional sampling

For any proportional batch sample, such as a bag sample or PM sample, it shall be verified that proportional sampling was maintained according to clause 8.2.1. For the single filter method and the discrete steady-state test cycle, effective PM weighing factor shall be calculated. Any sample that does not fulfil the requirements of clause 8.2.1. of this Annex shall be voided.

7.3.2.2. Post-test PM conditioning and weighing

Used PM sample filters shall be placed into covered or sealed containers or the filter holders shall be closed, in order to protect the sample filters against ambient contamination. Thus protected, the loaded filters have to be returned to the PM-filter conditioning chamber or room. Then the PM sample filters shall be conditioned and weighted accordingly to clause 8.2.4. of this Annex (PM filter post-conditioning and total weighing procedures).

7.3.2.3. Analysis of gaseous batch sampling

As soon as practical, the following shall be performed:

(a) All batch gas analysers shall be zeroed and spanned no later than 30 minutes after the test cycle is complete or during the soak period if practical to check if gaseous analysers are still stable;

(b) Any conventional gaseous batch samples shall be analysed no later than 30 minutes after the hot-start test cycle is complete or during the soak period;

(c) The background samples shall be analysed no later than 60 minutes after the hot-start test cycle is complete.

7.3.2.4. Drift verification

After quantifying exhaust gases, drift shall be verified as follows:

(a) For batch and continuous gas analysers, the mean analyser value shall be recorded after stabilizing a zero gas to the analyser. Stabilization may include time to purge the analyser of any sample gas, plus any additional time to account for analyser response;

(b) The mean analyser value shall be recorded after stabilizing the span gas to the analyser. Stabilization may include time to purge the analyser of any sample gas, plus any additional time to account for analyser response;

(c) These data shall be used to validate and correct for drift as described in clause 8.2.2. of this annex.

7.4. Test cycles

The following duty cycles apply:

(a) For variable-speed engines, the 8-mode test cycle or the corresponding ramped modal cycle, and the transient cycle NRTC as specified in Annex 5;

(b) For constant-speed engines, the 5-mode test cycle or the corresponding ramped modal cycle as specified in Annex 5.

7.4.1. Steady-state test cycles

Steady-state test cycles are specified in Annex 5 as a list of discrete modes (operating points), where each operating point has one value of speed and one value of torque. A steady-state test cycle shall be measured with a warmed up and running engine according to manufacturer's specification. A steady-state test cycle may be run as a discrete-mode cycle or a ramped-modal cycle, as explained in the following clauses.

7.4.1.1. Steady-state discrete mode test cycles

The steady-state discrete 8-mode test cycle consists of eight speed and load modes (with the respective weighing factor for each mode) which cover the typical operating range of variable speed engines. The cycle is shown in Annex 5.

The steady-state discrete 5-mode constant-speed test cycle consists of five load modes (with the respective weighing factor for each mode) all at rated speed which cover the typical operating range of constant speed engines. The cycle is shown in Annex 5.

7.4.1.2. Steady-state ramped test cycles

The ramped modal test cycles (RMC) are hot running cycles where emissions shall be started to be measured after the engine is started, warmed up and running as specified in clause 7.8.2.1. below. The engine shall be continuously controlled by the test bed control unit during the RMC test cycle. The gaseous and particulate emissions shall be measured and sampled continuously during the RMC test cycle in the same way as in a transient cycle.

In case of the 5-mode test cycle the RMC consists of the same modes in the same order as the corresponding discrete steady-state test cycle. For the 8-mode test cycle the RMC has one mode more (split idle mode) and the mode sequence is not the same as the corresponding steady-state discrete mode cycle, in order to avoid extreme changes in the after-treatment temperature. The length of the modes shall be selected to be equivalent to the weighing factors of the corresponding discrete steady-state test cycle. The change in engine speed and load from one mode to the next one has to be linearly controlled in a time of 20 ± 1 s. The mode change time is part of the new mode (including the first mode).

7.4.2. Transient test cycle (NRTC)

The Non-Road Transient Cycle (NRTC) is specified in Annex 5 as a second-by-second sequence of normalized speed and torque values. In order to perform the test in an engine test cell, the normalized values shall be converted to their equivalent reference values for the individual engine to be tested, based on

specific speed and torque values identified in the engine-mapping curve. The conversion is referred to as denormalization, and the resulting test cycle is the reference NRTC test cycle of the engine to be tested (see clause 7.7.2. below).

A graphical display of the normalized NRTC dynamometer schedule is shown in Annex 5.

The transient test cycle shall be run twice (see clause 7.8.3.):

(a) As cold start after the engine and aftertreatment systems have cooled down to room temperature after natural engine cool down, or as cold start after forced cool down and the engine, coolant and oil temperatures, aftertreatment systems and all engine control devices are stabilized between 20 and 30 °C. The measurement of the cold start emissions shall be started with the start of the cold engine;

(b) Hot soak period — Immediately upon completion of the cold start phase, the engine shall be conditioned for the hot start by a 20 minutes ± 1 minute hot soak period;

(c) The hot-start shall be started immediately after the soak period with the cranking of the engine. The gaseous analysers shall be switched on at least 10 s before the end of the soak period to avoid switching signal peaks. The measurement of emissions shall be started in parallel with the start of the hot start phase including the cranking of the engine.

Brake specific emissions expressed in (g/kWh) shall be determined by using the procedures of this section for both the cold and hot start test cycles. Composite weighted emissions shall be computed by weighing the cold start results by 10 per cent and the hot start results by 90 per cent as detailed in Annex 4, Appendices A.7-A.8.

7.5. General test sequence

To measure engine emissions the following steps have to be performed:

(a) The engine test speeds and test loads have to be defined for the engine to be tested by measuring the max torque (for constant speed engines) or max torque curve (for variable speed engines) as function of the engine speed;

(b) Normalized test cycles have to be denormalized with the torque (for constant speed engines) or speeds and torques (for variable speed engines) found in the previous sub-clause (a) of this clause;

(c) The engine, equipment, and measurement instruments shall be prepared for the following emission test or test series (cold and hot cycle) in advance;

(d) Pre-test procedures shall be performed to verify proper operation of certain equipment and analysers. All analysers have to be calibrated. All pre-test data shall be recorded;

(e) The engine shall be started (NRTC) or kept running (steady-state cycles) at the beginning of the test cycle and the sampling systems shall be started at the same time;

(f) Emissions and other required parameters shall be measured or recorded during sampling time (for NRTC and steady-state ramped modal cycles throughout the whole test cycle;

(g) Post-test procedures shall be performed to verify proper operation of certain equipment and analysers;

(h) PM filter(s) shall be pre-conditioned, weighed (empty weight), loaded, re-conditioned, again weighed (loaded weight) and then samples shall be evaluated according to pre- (clause 7.3.1.5.) and post-test (clause 7.3.2.2.) procedures;

(i) Emission test results shall be evaluated.

The following diagram gives an overview about the procedures needed to conduct NRSC and NRTC test cycles with measuring exhaust engine emissions.

Test Sequence

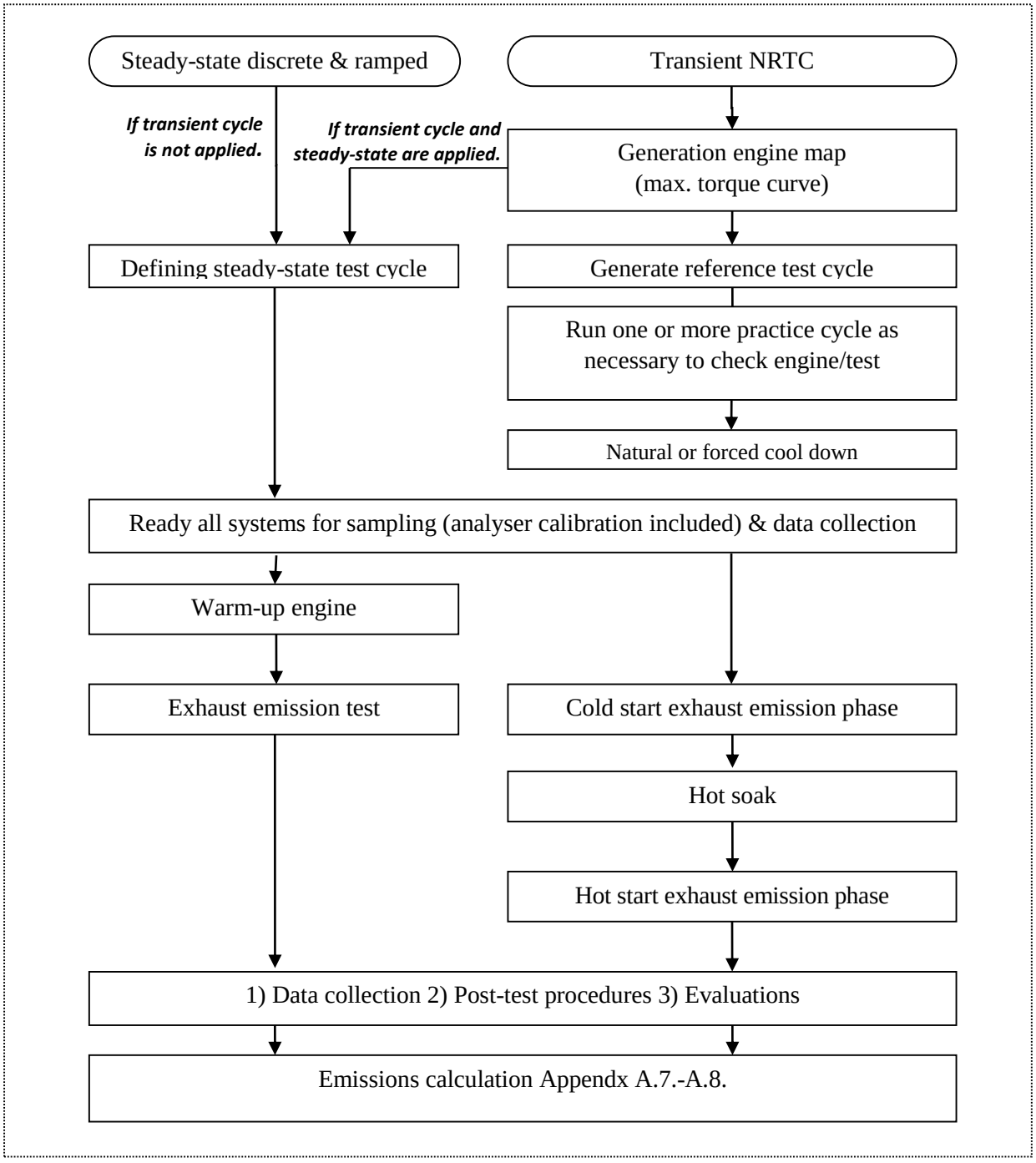


Figure 7.3

7.5.1. Engine starting, and restarting

7.5.1.1. Engine start

The engine shall be started:

(a) As recommended in the owner's manual using a production starter motor or air-start system and either an adequately charged battery, a suitable power supply or a suitable compressed air source; or

(b) By using the dynamometer to crank the engine until it starts. Typically motor the engine within ±25 per cent of its typical in-use cranking speed or start the engine by linearly increasing the dynamometer speed from zero to 100 min^{-1} below low idle speed but only until the engine starts.

Cranking shall be stopped within 1 s of starting the engine. If the engine does not start after 15 s of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owner's manual or the service-repair manual describes a longer cranking time as normal.

7.5.1.2. Engine stalling

(a) If the engine stalls anywhere during the cold start test of the NRTC, the test shall be voided;

(b) If the engine stalls anywhere during the hot start test of the NRTC, the test shall be voided. The engine shall be soaked according to clause 7.8.3., and the hot start test repeated. In this case, the cold start test does not need to be repeated;

(c) If the engine stalls anywhere during the steady-state cycle (discrete or ramped), the test shall be voided and be repeated beginning with the engine warm-up procedure. In the case of PM measurement utilizing the multifilter method (one sampling filter for each operating mode), the test shall be continued by stabilizing the engine at the previous mode for engine temperature conditioning and then initiating measurement with the mode where the engine stalled.

7.6. Engine mapping

Before starting the engine mapping, the engine shall be warmed up and towards the end of the warm up it shall be operated for at least 10 minutes at maximum power or according to the recommendation of the manufacturer and good engineering judgment in order to stabilize the engine coolant and lube oil temperatures. When the engine is stabilized, the engine mapping shall be performed.

Except constant speed engines, engine mapping shall be performed with fully open fuel lever or governor using discrete speeds in ascending order. The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = warm idle speed

Maximum mapping speed = n_{hi} x 1.02 or speed where max torque drops off to zero, whichever is smaller.

Where n_{hi} is the high speed, defined as the highest engine speed where 70 per cent of the maximum power is delivered.

If the highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative one.

7.6.1. Engine mapping for steady-state 8-mode cycle

In the case of engine mapping for the steady-state 8-mode cycle (only for engines which have not to run the NRTC cycle), good engineering judgment shall be used to select a sufficient number (20 to 30) of evenly spaced set-points. At each set point, speed shall be stabilized and torque allowed to stabilize at least for 15 seconds. The mean speed and torque shall be recorded at each set-point. Linear interpolation shall be used to determine the 8-mode test speeds and torques if needed. If the derived test speeds and loads do not deviate for more than ±2.5 per cent from the speeds and torques indicated by the manufacturer, the manufacturer defined speeds and loads shall be applied. When engines shall be run on the NRTC too, then the NRTC engine mapping curve shall be used to determine steady-state test speeds and torques.

7.6.2. Engine mapping for NRTC cycle

The engine mapping shall be performed according to the following procedure:

(a) The engine shall be unloaded and operated at idle speed:

(i) For engines with a low-speed governor, the operator demand shall be set to the minimum, the dynamometer or another loading device shall be used to target a torque of zero on the engine's primary output shaft and the engine shall be allowed to govern the speed. This warm idle speed shall be measured;

(ii) For engines without a low-speed governor, the dynamometer shall be set to target a torque of zero on the engine's primary output shaft, and the operator demand shall be set to control the speed to the manufacturer-declared lowest engine speed possible with minimum load (also known as manufacturer-declared warm idle speed);

(iii) The manufacturer declared idle torque may be used for all variable-speed engines (with or without a low-speed governor), if a nonzero idle torque is representative of in-use operation.

(b) Operator demand shall be set to maximum and engine speed shall be controlled to between warm idle and 95 per cent of its warm idle speed. For engines with reference duty cycles, which lowest speed is greater than warm idle speed, the mapping may be started at between the lowest reference speed and 95 per cent of the lowest reference speed;

(c) The engine speed shall be increased at an average rate of 8 ± 1 min^{-1}/s or the engine shall be mapped by using a continuous sweep of speed at a constant rate such that it takes 4 to 6 min to sweep from minimum to maximum mapping speed. The mapping speed range shall be started between warm idle and 95 per cent of warm idle and ended at the highest speed above maximum power at which less than 70 per cent of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative speed. Engine speed and torque points shall be recorded at a sample rate of at least 1 Hz;

(d) If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternate mapping techniques

may be used. These alternate techniques shall satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this clause for reasons of safety or representativeness shall be approved by the Test Agency along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines;

(e) An engine need not be mapped before each and every test cycle. An engine shall be remapped if:

(i) An unreasonable amount of time has transpired since the last map, as determined by good engineering judgement; or

(ii) Physical changes or recalibrations have been made to the engine which potentially affect engine performance; or

(iii) The atmospheric pressure near the engine's air inlet is not within ±5 kPa of the value recorded at the time of the last engine map.

7.6.3. Engine mapping for constant-speed engines:

(a) The engine may be operated with a production constant-speed governor or a constant-speed governor maybe simulated by controlling engine speed with an operator demand control system. Either isochronous or speed-droop governor operation shall be used, as appropriate;

(b) With the governor or simulated governor controlling speed using operator demand, the engine shall be operated at no-load governed speed (at high speed, not low idle) for at least 15 s;

(c) The dynamometer shall be used to increase torque at a constant rate. The map shall be conducted such that it takes 2 to 4 min to sweep from no-load governed speed to the maximum torque. During the engine mapping actual speed and torque shall be recorded with at least 1 Hz;

(d) In case of a gen-set engine to be used for 50 Hz and 60 Hz power generation (for example 1,500 and 1,800 min^{-1}) engine has to be tested in both constant speeds separately.

For constant speed engines good engineering judgment shall be used to apply other methods to record max torque and power at the defined operating speed(s).

7.7. Test cycle generation

7.7.1. Generation of steady-state test cycles (NRSC)

7.7.1.1. Rated and denormalization speed

For engines that are tested with the NRSC and also the NRTC, the denormalization speed shall be calculated according to the transient procedure (clauses 7.6.2. and 7.7.2.1. and Figure 7.3 of this annex). In case of the steady state cycle, the denormalization speed (n_{denorm}) shall be used in place of the rated speed.

If the calculated denormalization speed (n_{denorm}) is within ±2.5 per cent of the denormalization speed as declared by the manufacturer, the declared denormalization speed (n_{denorm}) may be used for the emission test. If the tolerance is exceeded, the calculated denormalization speed (n_{denorm}) shall be used for the emissions test.

For variable speed engines that are not tested with the NRTC, the rated speed of tables in Annex 5 to this Part for the 8-mode discrete and the derived ramped mode cycle shall be calculated according to the steady state procedure (clause 7.6.1. and Figure 7.3. of this annex). The rated speed is defined in clause 2.1.69. of this Part.

For constant speed engines, the rated speed and engine governed speed of tables in Annex 5 to this Part for the 5-mode discrete and the derived ramped mode cycle shall be that defined in clauses 2.1.30. and 2.1.69.

7.7.1.2. Generation of steady-state 8-mode test cycle (discrete and ramp modal)

The intermediate speed shall be determined from the calculations according to its definition (see clause 2.1.42. of this Part). Consistent with clause 7.7.1.1. above, for engines that are tested with the NRSC and also the NRTC the denormalization speed (n_{denorm}) shall be used in place of rated speed when determining the intermediate speed.

The engine setting for each test mode shall be calculated using the formula:

$$S = \left(\left(P_{max} + P_{AUX} \right) \cdot \frac{L}{100} \right) - P_{AUX} \qquad (7\text{-}1)$$

Where:

S = dynamometer setting in kW

P_{max} = maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer) in kW

P_{AUX} = declared total power absorbed by auxiliaries fitted for the test (see clause 6.3.) at the test speed in kW

L = per cent torque

During the test cycle, the engine shall be operated at the engine speeds and torques that are defined in Annex 5.

The maximum mapping torque values at the specified test speeds shall be derived from the mapping curve (see clause 7.6.1. or 7.6.2. above). "Measured" values are either directly measured during the engine mapping process or they are determined from the engine map. "Declared" values are specified by the manufacturer. When both measured and declared values are available, declared values may be used instead of torques if they don't deviate more than ±2.5 per cent. Otherwise, measured torques derived from the engine mapping shall be used.

7.7.1.3. Generation of steady-state 5-mode test cycle (discrete and ramp modal)

During the test cycle, the engine shall be operated at the engine speeds and torques that are defined in Annex 5.

The maximum mapping torque value at the specified rated speed (see clause 7.7.1.1. above) shall be used to generate the 5-mode test cycle. A warm minimum torque that is representative of in-use operation may be declared. For example, if the engine is typically connected to a machine that does not operate below a certain minimum torque, this torque may be declared and used for cycle generation. When both measured and declared values are available for the maximum test torque for cycle generation, the declared value may be used instead of the measured value if it is within 95 to 100 per cent of the measured value.

The torque figures are percentage values of the torque corresponding to the prime power[3] rating. The prime power is defined as the maximum power available during a variable power sequence, which may be run for an unlimited number of hours per year, between stated maintenance intervals and under the stated ambient conditions. The maintenance shall be carried out as prescribed by the manufacturer.

7.7.2. Generation of transient test cycle (NRTC denormalization)

Annex 5 defines applicable test cycles in a normalized format. A normalized test cycle consists of a sequence of paired values for speed and torque per cent.

Normalized values of speed and torque shall be transformed using the following conventions:

(a) The normalized speed shall be transformed into a sequence of reference speeds, n_{ref},according to clause 7.7.2.2. below;

(b) The normalized torque is expressed as a percentage of the mapped torque at the corresponding reference speed. These normalized values shall be transformed into a sequence of reference torques, T_{ref}, according to clause 7.7.2.3.;

(c) The reference speed and reference torque values expressed in coherent units are multiplied to calculate the reference power values.

7.7.2.1. Denormalization speed (n_{denorm})

The denormalization speed (n_{denorm}) is selected to equal the 100 per cent normalized speed values specified in the engine dynamometer schedule of Annex 5. The reference engine cycle resulting from denormalization to the reference speed, depends on the selection of the proper denormalization speed (n_{denorm}). For the calculation of the denormalization speed (n_{denorm}), obtained from the measured mapping curve, either of the following equivalent formulations can be used in agreement with the Test Agency:

(a) $$n_{denorm} = n_{lo} + 0.95 \cdot (n_{hi} - n_{lo}) \quad (7\text{-}2)$$

Where:

n_{denorm} = denormalization speed

n_{hi} = high speed (see clause 2.1.40.)

n_{lo} = low speed (see clause 2.1.44.)

(b) n_{denorm} corresponding to the longest vector defined as:

[3] For further understanding of the prime power definition, see Figure 2 of ISO 8528-1:2005.

$$n_{\text{denorm}} = n_i \text{ at the maximum of } \left(n_{\text{norm}i}^2 + P_{\text{norm}i}^2\right) \qquad (7\text{-}3)$$

Where:

i = an indexing variable that represents one recorded value of an engine map

n_{normi} = an engine speed normalized by dividing it by $n_{P\text{max}}$.

P_{normi} = an engine power normalized by dividing it by P_{max}.

Note that if multiple maximum values are found, the denormalization speed (n_{denorm}) should be taken as the lowest speed of all points with the same maximum sum of squares. A higher declared speed may be used if the length of the vector at the declared speed is within 2 per cent of the length of the vector at the measured value.

If the falling part of the full load curve has a very steep edge, this may cause problems to drive the 105 per cent speeds of the NRTC test cycle correctly. In this case it is allowed with previous agreement with Test Agency, to reduce the denormalization speed (n_{denorm}) slightly (maximum 3 per cent) in order to make correct driving of the NRTC possible.

If the measured denormalization speed (n_{denorm}) is within ±3 per cent of the denormalization speed as declared by the manufacturer, the declared denormalization speed (n_{denorm}) may be used for the emissions test. If the tolerance is exceeded, the measured denormalization speed (n_{denorm}) shall be used for the emissions test.

7.7.2.2. Denormalization of engine speed

The engine speed shall be denormalized using the following equation:

$$n_{\text{ref}} = \frac{\%speed \cdot (n_{\text{denorm}} - n_{\text{idle}})}{100} + n_{\text{idle}} \qquad (7\text{-}4)$$

where:

n_{ref} = reference speed

n_{denorm} = denormalization speed

n_{idle} = idle speed

%speed= tabled NRTC normalized speed

7.7.2.3. Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex 5, clause 1.3. are normalized to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalized, using the mapping curve determined according to clause 7.6.2., as follows:

$$T_{\text{ref}} = \frac{\%torque \cdot max.torque}{100} \qquad (7\text{-}5)$$

for the respective reference speed as determined in clause 7.7.2.2.

7.7.2.4. Example of denormalization procedure

As an example, the following test point shall be denormalized:

%speed = 43 per cent

%torque = 82 per cent

Given the following values:

n_{denorm} = 2200 min^{-1}

n_{idle} = 600 min^{-1}

results in

$$n_{ref} = \frac{43 \cdot (2200 - 600)}{100} + 600 = 1288 \text{min}^{-1}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1288 min^{-1}

$$T_{ref} = \frac{82 \times 700}{100} = 574 \text{Nm}$$

7.8. Specific test cycle running procedure

7.8.1. Emission test sequence for discrete steady-state test cycles

7.8.1.1. Engine warming-up for steady state discrete-mode test cycles

For preconditioning the engine shall be warmed up according to the recommendation of the manufacturer and good engineering judgment. Before emission sampling can start, the engine shall be running until engine temperatures (cooling water and lube oil) have been stabilized (normally at least 10 minutes) on mode 1 (100 per cent torque and rated speed for the 8-mode test cycle and at rated or nominal constant engine speed and 100 per cent torque for the 5-mode test cycle). Immediately from this engine conditioning point, the test cycle measurement starts.

Pre-test procedure according to clause 7.3.1. shall be performed, including analyser calibration.

7.8.1.2. Performing discrete-mode test cycles

(a) The test shall be performed in ascending order of mode numbers as set out for the test cycle (see Annex 5);

(b) Each mode has a mode length of at least 10 minutes. In each mode the engine shall be stabilized for at least 5 minutes and emissions shall be sampled for 1-3 minutes for gaseous emissions at the end of each mode. Extended time of sampling is permitted to improve the accuracy of PM sampling;

The mode length shall be recorded and reported.

(c) The particulate sampling may be done either with the single filter method or with the multiple filter method. Since the results of the methods may differ slightly, the method used shall be declared with the results;

For the single filter method the modal weighing factors specified in the test cycle procedure and the actual exhaust flow shall be taken into account during sampling by adjusting sample flow rate and/or sampling time, accordingly. It is required that the effective weighing factor of the PM sampling is within ±0.003 of the weighing factor of the given mode;

Sampling shall be conducted as late as possible within each mode. For the single filter method, the completion of particulate sampling shall be coincident within ±5 s with the completion of the gaseous emission

measurement. The sampling time per mode shall be at least 20 s for the single filter method and at least 60 s for the multifilter method. For systems without bypass capability, the sampling time per mode shall be at least 60 s for single and multiple filter methods;

(d) The engine speed and load, intake air temperature, fuel flow and air or exhaust gas flow shall be measured for each mode at the same time interval which is used for the measurement of the gaseous concentrations;

Any additional data required for calculation shall be recorded.

(e) If the engine stalls or the emission sampling is interrupted at any time after emission sampling begins for a discrete mode and the single filter method, the test shall be voided and be repeated beginning with the engine warm-up procedure. In the case of PM measurement utilizing the multifilter method (one sampling filter for each operating mode), the test shall be continued by stabilizing the engine at the previous mode for engine temperature conditioning and then initiating measurement with the mode where the engine stalled;

(f) Post-test procedures according to clause 7.3.2. shall be performed.

7.8.1.3. Validation criteria

During each mode of the given steady-state test cycle after the initial transition period, the measured speed shall not deviate from the reference speed for more than ±1 per cent of rated speed or ±3 min^{-1}, whichever is greater except for idle which shall be within the tolerances declared by the manufacturer. The measured torque shall not deviate from the reference torque for more than ±2 per cent of the maximum torque at the test speed.

7.8.2. Ramped modal test cycles

7.8.2.1. Engine warming-up

Before starting the steady-state ramped modal test cycles (RMC), the engine shall be warmed-up and running until engine temperatures (cooling water and lube oil) have been stabilized on 50 per cent speed and 50 per cent torque for the RMC test cycle (derived from the 8-mode test cycle) and at rated or nominal engine speed and 50 per cent torque for the RMC test cycle (derived from 5-mode test cycle). Immediately after this engine conditioning procedure, engine speed and torque shall be changed in a linear ramp of 20 ± 1 s to the first mode of the test. In between 5 to 10 s after the end of the ramp, the test cycle measurement shall start.

7.8.2.2. Performing a ramped modal test cycle

The ramped modal cycles derived from 8-mode and 5-mode test cycle are shown in Annex 5.

The engine shall be operated for the prescribed time in each mode. The transition from one mode to the next shall be done linearly in 20 s ± 1 s following the tolerances prescribed in clause 7.8.2.4.

For ramped modal cycles, reference speed and torque values shall be generated at a minimum frequency of 1 Hz and this sequence of points shall be used to run the cycle. During the transition between modes, the denormalized reference speed and torque values shall be linearly ramped between modes to generate reference points. The normalized reference torque values shall not be linearly ramped between modes and then denormalized. If the speed and torque ramp runs through a point above the engine's torque curve, it shall be continued to

command the reference torques and it shall be allowed for the operator demand to go to maximum.

Over the whole RMC test cycle (during each mode and including the ramps between the modes), the concentration of each gaseous pollutant shall be measured and the PM be sampled. The gaseous pollutants may be measured raw or diluted and be recorded continuously; if diluted, they can also be sampled into a sampling bag. The particulate sample shall be diluted with conditioned and clean air. One sample over the complete test procedure shall be taken, and collected on a single PM sampling filter.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the complete cycle.

7.8.2.3. Emission test sequence:

(a) Execution of the RMC, sampling exhaust gases, recording data, and integrating measured values shall be started simultaneously;

(b) Speed and torque shall be controlled to the first mode in the test cycle;

(c) If the engine stalls anywhere during the RMC execution, the test shall be voided. The engine shall be pre-conditioned and the test repeated;

(d) At the end of the RMC, sampling shall be continued, except for PM sampling, operating all systems to allow system response time to elapse. Then all sampling and recording shall be stopped, including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the test cycle shall be indicated in the recorded data;

(e) Post-test procedures according to clause 7.3 shall be performed.

7.8.2.4. Validation criteria

RMC tests shall be validated using the regression analysis as described in clauses 7.8.3.3. and 7.8.3.5. The allowed RMC tolerances are given in the following Table 7.1. Note that the RMC tolerances are different from the NRTC tolerances of Table 7.2.

Table 7.1
RMC Regression Line Tolerances

	Speed	Torque	Power
Standard error of estimate (*SEE*) of *y* on *x*	max 1 % of rated speed	max 2 % of maximum engine torque	max 2 % of maximum engine power
Slope of the regression line, a_1	0.99 to 1.01	0.98 to 1.02	0.98 to 1.02
Coefficient of determination, r^2	min 0.990	min 0.950	min 0.950
y intercept of the regression line, a_0	±1 % of rated speed	±20 Nm or 2 % of maximum torque, whichever is greater	±4 kW or 2 % of maximum power, whichever is greater

In case of running the RMC test not on a transient test bed, where the second by second speed and torque values are not available, the following validation criteria shall be used.

At each mode the requirements for the speed and torque tolerances are given in clause 7.8.1.3. For the 20 s linear speed and linear torque transitions between the RMC steady-state test modes (clause 7.4.1.2.) the following tolerances for speed and load shall be applied for the ramp, the speed shall be held linear within ±2 per cent of rated speed. The torque shall be held linear within ±5 per cent of the maximum torque at rated speed.

7.8.3. Transient test cycle (NRTC)

Reference speeds and torques commands shall be sequentially executed to perform the transient test cycle. Speed and torque commands shall be issued at a frequency of at least 5 Hz. Because the reference test cycle is specified at 1 Hz, the in between speed and torque commands shall be linearly interpolated from the reference torque values generated from cycle generation.

Small denormalized speed values near warm idle speed may cause low-speed idle governors to activate and the engine torque to exceed the reference torque even though the operator demand is at a minimum. In such cases, it is recommended to control the dynamometer so it gives priority to follow the reference torque instead of the reference speed and let the engine govern the speed.

Under cold-start conditions engines may use an enhanced-idle device to quickly warm up the engine and aftertreatment devices. Under these conditions, very low normalized speeds will generate reference speeds below this higher enhanced idle speed. In this case it is recommended controlling the dynamometer so it gives priority to follow the reference torque and let the engine govern the speed when the operator demand is at minimum.

During an emission test, reference speeds and torques and the feedback speeds and torques shall be recorded with a minimum frequency of 1 Hz, but preferably of 5 Hz or even 10 Hz. This larger recording frequency is important as it helps to minimize the biasing effect of the time lag between the reference and the measured feedback speed and torque values.

The reference and feedback speeds and torques maybe recorded at lower frequencies (as low as 1 Hz), if the average values over the time interval between recorded values are recorded. The average values shall be calculated based on feedback values updated at a frequency of at least 5 Hz. These recorded values shall be used to calculate cycle-validation statistics and total work.

7.8.3.1. Engine preconditioning

To meet stable conditions for the following Emission test, the sampling system and the engine shall be preconditioned either by driving a full pre-NRTC cycle or driving the engine and the measuring systems under similar conditions as in the test cycle itself. If the test before was also a NRTC hot test, no additional conditioning is needed.

A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-

treatment cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.

Pre-test procedures according to clause 7.3.1. have to be performed, including analyser calibration.

7.8.3.2. Performing an NRTC transient cycle test

Testing shall be started as follows:

The test sequence shall commence immediately after the engine has started from cooled down condition in case of the cold NRTC test or from hot soak condition in case of the hot NRTC test. The instructions (Annex 5) shall be followed.

Data logging, sampling of exhaust gases and integrating measured values shall be initiated simultaneously at the start of the engine. The test cycle shall be initiated when the engine starts and shall be executed according to the schedule of Annex 5.

At the end of the cycle, sampling shall be continued, operating all systems to allow system response time to elapse. Then all sampling and recording shall be stopped, including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the test cycle shall be indicated in the recorded data.

Post-test procedures according to clause 7.3.2. have to be performed.

7.8.3.3. Cycle validation criteria for transient test cycle

In order to check the validity of a test, the cycle-validation criteria in this clause shall be applied to the reference and feedback values of speed, torque, power and overall work.

7.8.3.4. Calculation of cycle work

Before calculating the cycle work, any speed and torque values recorded during engine starting shall be omitted. Points with negative torque values have to be accounted for as zero work. The actual cycle work W_{act} (kWh) shall be calculated based on engine feedback speed and torque values. The reference cycle work W_{ref} (kWh) shall be calculated based on engine reference speed and torque values. The actual cycle work W_{act} is used for comparison to the reference cycle work W_{ref} and for calculating the brake specific emissions (see clause 7.2.)

W_{act} shall be between 85 per cent and 105 per cent of W_{ref}.

7.8.3.5. Validation statistics (see Annex 4, Appendix A.2.)

Linear regression between the reference and the feedback values shall be calculated for speed, torque and power.

To minimize the biasing effect of the time lag between the reference and feedback cycle values, the entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque shall be shifted by the same amount in the same direction.

The method of least squares shall be used, with the best-fit equation having the form:

$y = a_1 x + a_0$ (7-6)

where:

y = feedback value of speed (min^{-1}), torque (Nm), or power (kW)

a_1 = slope of the regression line

x = reference value of speed (min^{-1}), torque (Nm), or power (kW)

a_0 = y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each regression line (Annex 4, Appendix A.2.).

It is recommended that this analysis be performed at 1 Hz. For a test to be considered valid, the criteria of Table 7.2 below shall be met.

Table 7.2
Regression Line Tolerances

	Speed	**Torque**	**Power**
Standard error of estimate (*SEE*) of *y* on *x*	≤ 5.0 per cent of maximum test speed	≤ 10.0 per cent of maximum mapped torque	≤ 10.0 per cent of maximum mapped power
Slope of the regression line, a_1	0.95 to 1.03	0.83 to 1.03	0.89 to 1.03
Coefficient of determination, r^2	minimum 0.970	minimum 0.850	minimum 0.910
y intercept of the regression line, a_0	≤ 10 per cent of idle	±20 Nm or ±2 per cent of maximum torque whichever is greater	±4 kW or ±2 per cent of maximum power whichever is greater

For regression purposes only, point deletions are permitted where noted in Table 7.3 below before doing the regression calculation. However, those points shall not be deleted for the calculation of cycle work and emissions. An idle point is defined as a point having a normalised reference torque of 0 per cent and a normalized reference speed of 0 per cent. Point deletion may be applied to the whole or to any part of the cycle; points to which the point deletion is applied have to be specified.

Table 7.3

Permitted Point Deletions from Regression Analysis

Event	Conditions (n = engine speed, T = torque)	Permitted point deletions
Minimum operator demand (idle point)	$n_{ref} = n_{idle}$ and $T_{ref} = 0$ and $T_{act} > (T_{ref} - 0.02\ T_{maxmappedtorque})$ and $T_{act} < (T_{ref} + 0.02\ T_{maxmappedtorque})$	speed and power
Minimum operator demand	$n_{act} \leq 1.02\ n_{ref}$ and $T_{act} > T_{ref}$ or $n_{act} > n_{ref}$ and $T_{act} \leq T_{ref}$ or $n_{act} > 1.02\ n_{ref}$ and $T_{ref} < T_{act} \leq (T_{ref} + 0.02\ T_{maxmappedtorque})$	power and either torque or speed
Maximum operator demand	$n_{act} < n_{ref}$ and $T_{act} \geq T_{ref}$ or $n_{act} \geq 0.98\ n_{ref}$ and $T_{act} < T_{ref}$ or $n_{act} < 0.98\ n_{ref}$ and $T_{ref} > T_{act} \geq (T_{ref} - 0.02\ T_{maxmappedtorque})$	power and either torque or speed

8. MEASUREMENT PROCEDURES

8.1. Calibration and performance checks

8.1.1. Introduction

This clause describes required calibrations and verifications of measurement systems. See clause 9.4. for specifications that apply to individual instruments.

Calibrations or verifications shall be generally performed over the complete measurement chain.

If a calibration or verification for a portion of a measurement system is not specified, that portion of the system shall be calibrated and its performance verified at a frequency consistent with any recommendations from the measurement system manufacturer and consistent with good engineering judgment.

Internationally recognized-traceable standards shall be used to meet the tolerances specified for calibrations and verifications.

8.1.2. Summary of calibration and verification

The Table 8.1 summarizes the calibrations and verifications described in this section and indicates when these have to be performed.

Table 8.1

Summary of Calibration and Verifications

Type of calibration or verification	Minimum frequency[a]
8.1.3.: Accuracy, repeatability and noise	Accuracy: Not required, but recommended for initial installation. Repeatability: Not required, but recommended for initial installation. Noise: Not required, but recommended for initial installation.
8.1.4.: Linearity	Speed: Upon initial installation, within 370 days before testing and after major maintenance. Torque: Upon initial installation, within 370 days before testing and after major maintenance. Clean gas and diluted exhaust flows: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Gas analysers: Upon initial installation, within 35 days before testing and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Stand-alone pressure and temperature: Upon initial installation, within 370 days before testing and after major maintenance.
8.1.5.: Continuous gas analyser system response and updating-recording verification – for gas analysers not continuously compensated for other gas species	Upon initial installation or after system modification that would effect response.
8.1.6.: Continuous gas analyser system response and updating-recording verification – for gas analysers continuously compensated for other gas species	Upon initial installation or after system modification that would effect response.
8.1.7.1.: Torque	Upon initial installation and after major maintenance.
8.1.7.2.: Pressure, temperature, dew point	Upon initial installation and after major maintenance.
8.1.8.1.: Fuel flow	Upon initial installation and after major maintenance.
8.1.8.2.: Intake flow	Upon initial installation and after major maintenance.
8.1.8.3.: Exhaust flow	Upon initial installation and after major maintenance.

Type of calibration or verification	Minimum frequency[a]
8.1.8.4.: Diluted exhaust flow (CVS and PFD)	Upon initial installation and after major maintenance.
8.1.8.5.: CVS/PFD and batch sampler verification[b]	Upon initial installation, within 35 days before testing, and after major maintenance. (Propane check)
8.1.8.8.: Vacuum leak	Before each laboratory test according to clause 7.1.
8.1.9.1.: CO_2 NDIR H_2O interference	Upon initial installation and after major maintenance.
8.1.9.2.: CO NDIR CO_2 and H_2O interference	Upon initial installation and after major maintenance.
8.1.10.1.: FID calibration THC FID optimization and THC FID verification	Calibrate, optimize, and determine CH_4 response: upon initial installation and after major maintenance. Verify CH_4 response: upon initial installation, within 185 days before testing, and after major maintenance.
8.1.10.2.: Raw exhaust FID O_2 interference	For all FID analysers: upon initial installation, and after major maintenance. For THC FID analysers: upon initial installation, after major maintenance, and after FID optimization according to 8.1.10.1.
8.1.10.3.: Non-methane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
8.1.11.1.: CLD CO_2 and H_2O quench	Upon initial installation and after major maintenance.
8.1.11.3.: NDUV HC and H_2O interference	Upon initial installation and after major maintenance.
8.1.11.4.: Cooling bath NO_2 penetration (chiller)	Upon initial installation and after major maintenance.
8.1.11.5.: NO_2-to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
8.1.12.1.: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.

[a] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

[b] The CVS verification is not required for systems that agree within ±2 per cent based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

8.1.3. Verifications for accuracy, repeatability, and noise

The performance values for individual instruments specified in Table 9.3 are the basis for the determination of the accuracy, repeatability, and noise of an instrument.

It is not required to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

8.1.4. Linearity check

8.1.4.1. Scope and frequency

A linearity verification shall be performed on each measurement system listed in Table 8.2 at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification shall consist of introducing a series of at least 10 reference values to a measurement system, unless otherwise specified. The measurement system quantifies each reference value. The measured values shall be collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table 8.2 below.

8.1.4.2. Performance requirements

If a measurement system does not meet the applicable linearity criteria in Table 8.2, the deficiency shall be corrected by re-calibrating, servicing, or replacing components as needed. The linearity verification shall be repeated after correcting the deficiency to ensure that the measurement system meets the linearity criteria.

8.1.4.3. Procedure

The following linearity verification protocol shall be used:

(a) A measurement system shall be operated at its specified temperatures, pressures, and flows;

(b) The instrument shall be zeroed as it would before an emission test by introducing a zero signal. For gas analysers, a zero gas shall be used that meets the specifications of clause 9.5.1. of this Annex and it shall be introduced directly at the analyser port;

(c) The instrument shall be spanned as it would before an emission test by introducing a span signal. For gas analysers, a span gas shall be used that meets the specifications of clause 9.5.1. of this Annex and it shall be introduced directly at the analyser port;

(d) After spanning the instrument, zero shall be checked with the same signal which has been used in sub- clause (b) of this clause. Based on the zero reading, good engineering judgment shall be used to determine whether or not to re-zero and or re-span the instrument before proceeding to the next step;

(e) For all measured quantities manufacturer recommendations and good engineering judgment shall be used to select the reference values, y_{refi}, that cover the full range of values that are expected during emission testing, thus avoiding the need of extrapolation beyond these values. A zero reference signal shall be selected as one of the reference values of the linearity verification. For stand-alone pressure and temperature linearity

verifications, at least three reference values shall be selected. For all other linearity verifications, at least ten reference values shall be selected;

(f) Instrument manufacturer recommendations and good engineering judgment shall be used to select the order in which the series of reference values will be introduced;

(g) Reference quantities shall be generated and introduced as described in clause 8.1.4.4. of this annex. For gas analysers, gas concentrations known to be within the specifications of clause 9.5.1. of this Annex shall be used and they shall be introduced directly at the analyser port;

(h) Time for the instrument to stabilize while it measures the reference value shall be allowed;

(i) At a recording frequency of at least the minimum frequency, as specified in Table 9.2, the reference value shall be measured for 30 s and the arithmetic mean of the recorded values, $\overline{y}_i$ recorded;

(j) Steps in sub-clauses (g) through (i) of this clause shall be repeated until all reference quantities are measured;

(k) The arithmetic means $\overline{y}_i$, and reference values, y_{refi}, shall be used to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 8.2. The calculations described in Annex 4, Appendix A.2, shall be used.

8.1.4.4. Reference signals

This clause describes recommended methods for generating reference values for the linearity-verification protocol in clause 8.1.4.3. of this section. Reference values shall be used that simulate actual values, or an actual value shall be introduced and measured with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems shall be internationally traceable.

For temperature measurement systems with sensors like thermocouples, RTDs, and thermistors, the linearity verification may be performed by removing the sensor from the system and using a simulator in its place. A simulator that is independently calibrated and cold junction compensated, as necessary shall be used. The internationally traceable simulator uncertainty scaled to temperature shall be less than 0.5 per cent of maximum operating temperature T_{max}. If this option is used, it is necessary to use sensors that the supplier states are accurate to better than 0.5 per cent of T_{max} compared to their standard calibration curve.

8.1.4.5. Measurement systems that require linearity verification

Table 8.2 indicates measurement systems that require linearity verifications. For this table the following provisions apply.

(a) A linearity verification shall be performed more frequently if the instrument manufacturer recommends it or based on good engineering judgment;

(b) "min" refers to the minimum reference value used during the linearity verification;

Note that this value may be zero or a negative value depending on the signal;

(c) "max" generally refers to the maximum reference value used during the linearity verification. For example for gas dividers, x_{max} is the undivided,

undiluted, span gas concentration. The following are special cases where "max" refers to a different value:

(i) For PM balance linearity verification, m_{max} refers to the typical mass of a PM filter;

(ii) For torque linearity verification, T_{max} refers to the manufacturer's specified engine torque peak value of the highest torque engine to be tested.

(d) The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for the slope a_1 means $0.98 \leq a_1 \leq 1.02$;

(e) These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described 8.1.8.5. for the propane check or for systems that agree within ±2 per cent based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust;

(f) a_1 criteria for these quantities shall be met only if the absolute value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value;

(g) Stand-alone temperatures include engine temperatures and ambient conditions used to set or verify engine conditions; temperatures used to set or verify critical conditions in the test system; and temperatures used in emissions calculations:

(i) These temperature linearity checks are required. Air intake; aftertreatment bed(s) (for engines tested with aftertreatment devices on cycles with cold start criteria); dilution air for PM sampling (CVS, double dilution, and partial flow systems); PM sample; and chiller sample (for gaseous sampling systems that use chillers to dry samples);

(ii) These temperature linearity checks are only required if specified by the engine manufacturer. Fuel inlet; test cell charge air cooler air outlet (for engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler); test cell charge air cooler coolant inlet (for engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler); and oil in the sump/pan; coolant before the thermostat (for liquid cooled engines);

(h) Stand-alone pressures include engine pressures and ambient conditions used to set or verify engine conditions; pressures used to set or verify critical conditions in the test system; and pressures used in emissions calculations:

(i) Required pressure linearity checks are: air intake restriction; exhaust back pressure; barometer; CVS inlet gage pressure (if measurement using CVS); chiller sample (for gaseous sampling systems that use chillers to dry samples);

(ii) Pressure linearity checks that are required only if specified by the engine manufacturer: test cell charge air cooler and interconnecting pipe pressure drop (for turbo-charged engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler) fuel inlet; and fuel outlet.

Table 8.2

Measurement Systems that Require Linearity Verifications

Measurement System	Quantity	Minimum verification frequency	Linearity Criteria			
			$\lvert x_{min} \cdot (a_1 - 1) + a_0 \rvert$	a	SEE	r^2
Engine speed	n	Within 370 days before testing	≤ 0.05 % n_{max}	0.98-1.02	≤ 2 % n_{max}	≥ 0.990
Engine torque	T	Within 370 days before testing	≤1 % T_{max}	0.98-1.02	≤ 2 % T_{max}	≥0.990
Fuel flow rate	q_m	Within 370 days before testing	≤1 % $q_{m,\,max}$	0.98-1.02	≤2 % $q_{m,\,max}$	≥0.990
Intake-air flow rate	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Dilution air flow rate	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Diluted exhaust flow rate	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Raw exhaust flow rate	q_V	Within 185 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Batch sampler flow rates	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Gas dividers	x/x_{span}	Within 370 days before testing	≤0.5 % x_{max}	0.98-1.02	≤2 % x_{max}	≥0.990
Gas analysers	x	Within 35 days before testing	≤0.5 % x_{max}	0.99-1.01	≤1 % x_{max}	≥0.998
PM balance	m	Within 370 days before testing	≤1 % m_{max}	0.99-1.01	≤1 % m_{max}	≥0.998
Stand-alone pressures	p	Within 370 days before testing	≤1 % p_{max}	0.99-1.01	≤1 % p_{max}	≥0.998
Analog-to-digital conversion of stand-alone temperature signals	T	Within 370 days before testing	≤1 % T_{max}	0.99-1.01	≤1 % T_{max}	≥0.998

8.1.5. Continuous gas analyser system-response and updating-recording verification

This section describes a general verification procedure for continuous gas analyser system response and update recording. See clause 8.1.6. below for verification procedures for compensation type analysers.

8.1.5.1. Scope and frequency

This verification shall be performed after installing or replacing a gas analyser that is used for continuous sampling. Also this verification shall be performed if

the system is reconfigured in a way that would change system response. This verification is needed for continuous gas analysers used for transient or ramped-modal testing but is not needed for batch gas analyser systems or for continuous gas analyser systems used only for discrete-mode testing.

8.1.5.2. Measurement principles

This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyser systems shall be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that continuous gas analyser systems meet a minimum response time.

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analysers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The devices for gas switching shall have a specification to perform the switching in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent full scale (FS).

The concentration trace of each single gas component shall be recorded.

8.1.5.3. System requirements

(a) The system response time shall be ≤ 10 s with a rise time of ≤ 2.5 s or with a rise and fall time of ≤ 5 s each for all measured components (CO, NO_x, CO_2 and HC) and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 10 s.

All data (concentration, fuel and air flows) have to be shifted by their measured response times before performing the emission calculations given in Appendices A.7-A.8.

(b) To demonstrate acceptable updating and recording with respect to the system's overall response, the system shall meet one of the following criteria:

(i) The product of the mean rise time and the frequency at which the system records an updated concentration shall be at least 5. In any case the mean rise time shall be no more than 10 s;

(ii) The frequency at which the system records the concentration shall be at least 2 Hz (see also Table 9.2).

8.1.5.4. Procedure

The following procedure shall be used to verify the response of each continuous gas analyser system: (a) The analyser system manufacturer's start-up and operating instructions for the instrument setup shall be followed. The measurement system shall be adjusted as needed to optimize performance. This verification shall be run with the analyser operating in the same manner as used for emission testing. If the analyser shares its sampling system with other analysers, and if gas flow to the other analysers will affect the system response time, then the other analysers shall be started up and operated while running this verification test. This verification test may be run on multiple analysers sharing the same sampling system at the same time. If analogue or real-time digital

filters are used during emission testing, those filters shall be operated in the same manner during this verification;

(b) For equipment used to validate system response time, minimal gas transfer line lengths between all connections are recommended to be used, a zero-air source shall be connected to one inlet of a fast-acting 3-way valve (2 inlets, 1 outlet) in order to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. Normally the gas flow rate is higher than the probe sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the probe flow rate, the gas concentrations shall be adjusted to account for the dilution from ambient air drawn into the probe. Binary or multi-gas span gases may be used. A gas blending or mixing device may be used to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N_2 with span gases diluted in air;

Using a gas divider, an NO–CO–CO_2–C_3H_8–CH_4 (balance N_2) span gas shall be equally blended with a span gas of NO_2, balance purified synthetic air. Standard binary span gases may be also be used, where applicable, in place of blended NO-CO-CO_2-C_3H_8-CH_4, balance N_2 span gas; in this case separate response tests shall be run for each analyser. The gas divider outlet shall be connected to the other inlet of the 3-way valve. The valve outlet shall be connected to an overflow at the gas analyser system's probe or to an overflow fitting between the probe and transfer line to all the analysers being verified. A setup that avoids pressure pulsations due to stopping the flow through the gas blending device shall be used. Any of these gas constituents if they are not relevant to the analysers for this verification shall be omitted. Alternatively the use of gas bottles with single gases and a separate measurement of response times is allowed;

(c) Data collection shall be done as follows:

(i) The valve shall be switched to start the flow of zero gas;

(ii) Stabilization shall be allowed for, accounting for transport delays and the slowest analyser's full response;

(iii) Data recording shall be started at the frequency used during emission testing. Each recorded value shall be a unique updated concentration measured by the analyser; interpolation or filtering may not be used to alter recorded values;

(iv) The valve shall be switched to allow the blended span gases to flow to the analysers. This time shall be recorded as t_0;

(v) Transport delays and the slowest analyser's full response shall be allowed for;

(vi) The flow shall be switched to allow zero gas to flow to the analyser. This time shall be recorded as t_{100};

(vii) Transport delays and the slowest analyser's full response shall be allowed for;

(viii) The steps in sub- clauses (c) (iv) through (vii) of this clause shall be repeated to record seven full cycles, ending with zero gas flowing to the analysers;

(ix) Recording shall be stopped.

8.1.5.5. Performance evaluation

The data from sub-clauses (c) of clause 8.1.5.4. above shall be used to calculate the mean rise time, T_{10-90} for each of the analysers.

(a) If it is chosen to demonstrate compliance with sub- clauses (b) (i) of clause 8.1.5.3. above, the following procedure has to be applied: The rise times (in s) shall be multiplied by their respective recording frequencies in Hertz (1/s). The value for each result shall be at least 5. If the value is less than 5, the recording frequency shall be increased or the flows adjusted or the design of the sampling system shall be changed to increase the rise time as needed. Also digital filters may be configured to increase rise time;

(b) If it is choosen to demonstrate compliance with sub- clauses (b) (ii) of clause 8.1.5.3. above, the demonstration of compliance with the requirements of sub- clauses (b) (ii) of clause 8.1.5.3. is sufficient.

8.1.6. Response time verification for compensation type analysers

8.1.6.1. Scope and frequency

This verification shall be performed to determine a continuous gas analyser's response, where one analyser's response is compensated by another's to quantify a gaseous emission. For this check water vapour shall be considered to be a gaseous constituent. This verification is required for continuous gas analysers used for transient or ramped-modal testing. This verification is not needed for batch gas analysers or for continuous gas analysers that are used only for discrete-mode testing. This verification does not apply to correction for water removed from the sample done in post-processing and it does not apply to NMHC determination from THC and CH_4 quoted in Appendices A.7 and A.8 concerning the emission calculations. This verification shall be performed after initial installation (i.e. test cell commissioning). After major maintenance, clause 8.1.5. may be used to verify uniform response provided that any replaced components have gone through a humidified uniform response verification at some point.

8.1.6.2. Measurement principles

This procedure verifies the time-alignment and uniform response of continuously combined gas measurements. For this procedure, it is necessary to ensure that all compensation algorithms and humidity corrections are turned on.

8.1.6.3. System requirements

The general response time and rise time requirement given in sub- clause (a) of 8.1.5.3. is also valid for compensation type analysers. Additionally, if the recording frequency is different than the update frequency of the continuously combined/compensated signal, the lower of these two frequencies shall be used for the verification required by sub- clause (b) (i) of clause 8.1.5.3.

8.1.6.4. Procedure

All procedures given in sub- clauses (a) - (c) of clause 8.1.5.4. have to be used. Additionally also the response and rise time of water vapour has to be measured, if a compensation algorithm based on measured water vapour is used. In this case at least one of the used calibration gases (but not NO_2) has to be humidified as follows:

If the system does not use a sample dryer to remove water from the sample gas, the span gas shall be humidified by flowing the gas mixture through a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling by bubbling it through distilled water. If the system uses a sample dryer during testing that has passed the sample dryer verification check, the humidified gas mixture may be introduced downstream of the sample dryer by bubbling it through distilled water in a sealed vessel at (25 ± 10 °C), or a temperature greater than the dew point. In all cases, downstream of the vessel, the humidified gas shall be maintained at a temperature of at least 5 ºC above its local dew point in the line. Note that it is possible to omit any of these gas constituents if they are not relevant to the analysers for this verification. If any of the gas constituents are not susceptible to water compensation, the response check for these analysers may be performed without humidification.

8.1.7. Measurement of engine parameters and ambient conditions

The engine manufacturer shall apply internal quality procedures traceable to recognised national or international standards. Otherwise the following procedures apply.

8.1.7.1. Torque calibration

8.1.7.1.1. Scope and frequency

All torque-measurement systems including dynamometer torque measurement transducers and systems shall be calibrated upon initial installation and after major maintenance using, among others, reference force or lever-arm length coupled with dead weight. Good engineering judgment shall be used to repeat the calibration. The torque transducer manufacturer's instructions shall be followed for linearizing the torque sensor's output. Other calibration methods are permitted.

8.1.7.1.2. Dead-weight calibration

This technique applies a known force by hanging known weights at a known distance along a lever arm. It shall be made sure that the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. At least six calibration-weight combinations shall be applied for each applicable torque-measuring range, spacing the weight quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. Each weight's force shall be determined by multiplying its internationally-traceable mass by the local acceleration of Earth's gravity.

8.1.7.1.3. Strain gage or proving ring calibration

This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used as part of the reference torque determination) or by operating the dynamometer at different torques. At least six force combinations shall be applied for each applicable torque-measuring range, spacing the force quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the force output from the reference meter (such as a strain gage or proving ring) by its effective lever-arm length, which is measured from the point where the force measurement is made to the dynamometer's rotational axis. It shall be made sure that this length is measured perpendicular to the reference meter's measurement axis and perpendicular to the dynamometer's rotational axis.

8.1.7.2. Pressure, temperature, and dew point calibration

Instruments shall be calibrated for measuring pressure, temperature, and dew point upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

For temperature measurement systems with thermocouple, RTD, or thermistor sensors, the calibration of the system shall be performed as described in clause 8.1.4.4. for linearity verification.

8.1.8. Flow-related measurements

8.1.8.1. Fuel flow calibration

Fuel flow-meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.2. Intake air flow calibration

Intake air flow-meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.3. Exhaust flow calibration

Exhaust flow-meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.4. Diluted exhaust flow (CVS) calibration

8.1.8.4.1. Overview

(a) This section describes how to calibrate flow-meters for diluted exhaust constant-volume sampling (CVS) systems;

(b) This calibration shall be performed while the flow-meter is installed in its permanent position. This calibration shall be performed after any part of the flow configuration upstream or downstream of the flow-meter has been changed that may affect the flow-meter calibration. This calibration shall be performed upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (*i.e.*, propane check) in clause 8.1.8.5.;

(c) A CVS flow-meter shall be calibrated using a reference flow-meter such as a subsonic venturi flow-meter, a long-radius flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow-meter. A reference flow-meter shall be used that reports quantities that are internationally-traceable within ±1 per cent uncertainty. This reference flow-meter's response to flow shall be used as the reference value for CVS flow-meter calibration;

(d) An upstream screen or other restriction that could affect the flow ahead of the reference flow-meter may not be used, unless the flow-meter has been calibrated with such a restriction;

(e) The calibration sequence described under this clause 8.1.8.4. refers to the molar based approach. For the corresponding sequence used in the mass based approach, see Annex A.8 of this Annex.

8.1.8.4.2. PDP calibration

A positive-displacement pump (PDP) shall be calibrated to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Unique equation coefficients shall be determined for each speed at which the PDP is operated. A PDP flow-meter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure 8.1;

(b) Leaks between the calibration flow-meter and the PDP shall be less than 0.3 per cent of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point;

(c) While the PDP operates, a constant temperature at the PDP inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(d) The PDP speed is set to the first speed point at which it is intended to calibrate;

(e) The variable restrictor is set to its wide-open position;

(f) The PDP is operated for at least 3 min to stabilize the system. Then by continuously operating the PDP, the mean values of at least 30 s of sampled data of each of the following quantities are recorded:

(i) The mean flow rate of the reference flow-meter, $\overline{q}_{Vref}$;

(ii) The mean temperature at the PDP inlet, $T_{in;}$

(iii) The mean static absolute pressure at the PDP inlet, $p_{in;}$

(iv) The mean static absolute pressure at the PDP outlet, $p_{out;}$

(v) The mean PDP speed, n_{PDP};

(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the PDP, p_{in};

(h) The steps in sub- clauses (f) and (g) of this clause shall be repeated to record data at a minimum of six restrictor positions reflecting the full range of possible in-use pressures at the PDP inlet;

(i) The PDP shall be calibrated by using the collected data and the equations in Appendices A.7-A.8;

(j) The steps in sub- clauses (f) through (i) of this section shall be repeated for each speed at which the PDP is operated;

(k) The equations in Annex 4 Appendix A.7 (molar based approach) or A.8 (mass based approach) shall be used to determine the PDP flow equation for emission testing;

(l) The calibration shall be verified by performing a CVS verification (*i.e.*, propane check) as described in clause 8.1.8.5. below;

(m) The PDP may not be used below the lowest inlet pressure tested during calibration.

8.1.8.4.3. CFV calibration

A critical-flow venturi (CFV) shall be calibrated to verify its discharge coefficient, C_d, at the lowest expected static differential pressure between the CFV inlet and outlet. A CFV flow-meter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure 8.1;

(b) The blower shall be started downstream of the CFV;

(c) While the CFV operates, a constant temperature at the CFV inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(d) Leaks between the calibration flow-meter and the CFV shall be less than 0.3 per cent of the total flow at the highest restriction;

(e) The variable restrictor shall be set to its wide-open position. In lieu of a variable restrictor the pressure downstream of the CFV may be varied by varying blower speed or by introducing a controlled leak. Note that some blowers have limitations on non-loaded conditions;

(f) The CFV shall be operated for at least 3 min to stabilize the system. The CFV shall continue operating and the mean values of at least 30 s of sampled data of each of the following quantities shall be recorded:

(i) The mean flow rate of the reference flow-meter, $\bar{q}_{Vref}$;

(ii) Optionally, the mean dew point of the calibration air, T_{dew}. See Appendices A.7-A.8 for permissible assumptions during emission measurements;

(iii) The mean temperature at the venturi inlet, T_{in};

(iv) The mean static absolute pressure at the venturi inlet, p_{in};

(v) The mean static differential pressure between the CFV inlet and the CFV outlet, Δp_{CFV};

(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the CFV, p_{in};

(h) The steps in sub- clauses (f) and (g) of this clause shall be repeated to record mean data at a minimum of ten restrictor positions, such that the fullest practical range of Δp_{CFV} expected during testing is tested. It is not required to remove calibration components or CVS components to calibrate at the lowest possible restrictions;

(i) C_d and the lowest allowable pressure ratio r shall be determined as described in Annexes A.7-A.8;

(j) C_d shall be used to determine CFV flow during an emission test. The CFV shall not be used below the lowest allowed r, as determined in Annexes A.7-A.8;

(k) The calibration shall be verified by performing a CVS verification (i.e., propane check) as described in clause 8.1.8.5.;

(l) If the CVS is configured to operate more than one CFV at a time in parallel, the CVS shall be calibrated by one of the following:

(i) Every combination of CFVs shall be calibrated according to this clause and Appendices A.7-A.8. See Appendices A.7-A.8 for instructions on calculating flow rates for this option;

(ii) Each CFV shall be calibrated according to this clause and Appendices A.7-A.8. See Appendices A.7-A.8 for instructions on calculating flow rates for this option.

8.1.8.4.4. SSV calibration

A subsonic venturi (SSV) shall be calibrated to determine its calibration coefficient, C_d , for the expected range of inlet pressures. An SSV flow-meter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure 8.1;

(b) The blower shall be started downstream of the SSV;

(c) Leaks between the calibration flow-meter and the SSV shall be less than 0.3 per cent of the total flow at the highest restriction;

(d) While the SSV operates, a constant temperature at the SSV inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(e) The variable restrictor or variable-speed blower shall be set to a flow rate greater than the greatest flow rate expected during testing. Flow rates may not be extrapolated beyond calibrated values, so it is recommended that it is made certain that a Reynolds number, *Re*, at the SSV throat at the greatest calibrated flow rate is greater than the maximum *Re* expected during testing;

(f) The SSV shall be operated for at least 3 min to stabilize the system. The SSV shall continue operating and the mean of at least 30 s of sampled data of each of the following quantities shall be recorded:

(i) The mean flow rate of the reference flow-meter, $\overline{\boldsymbol{q}}_{\boldsymbol{Vref}}$;

(ii) Optionally, the mean dew point of the calibration air, T_{dew}. See Annexes A.7-A.8 for permissible assumptions;

(iii) The mean temperature at the venturi inlet, T_{in};

(iv) The mean static absolute pressure at the venturi inlet, p_{in};

(v) Static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, Δp_{SSV};

(g) The restrictor valve shall be incrementally closed or the blower speed decreased to decrease the flow rate;

(h) The steps in sub-clauses (f) and (g) of this clause shall be repeated to record data at a minimum of ten flow rates;

(i) A functional form of C_d versus *Re* shall be determined by using the collected data and the equations in Annexes A.7-A.8;

(j) The calibration shall be verified by performing a CVS verification (i.e., propane check) as described in clause 8.1.8.5. below using the new C_d versus *Re* equation;

(k) The SSV shall be used only between the minimum and maximum calibrated flow rates;

(l) The equations in Annex 4, Appendix A.7 (molar based approach) or Annex 4, Appendix A.8 (mass based approach) shall be used to determine SSV flow during a test.

8.1.8.4.5. Ultrasonic calibration (reserved)

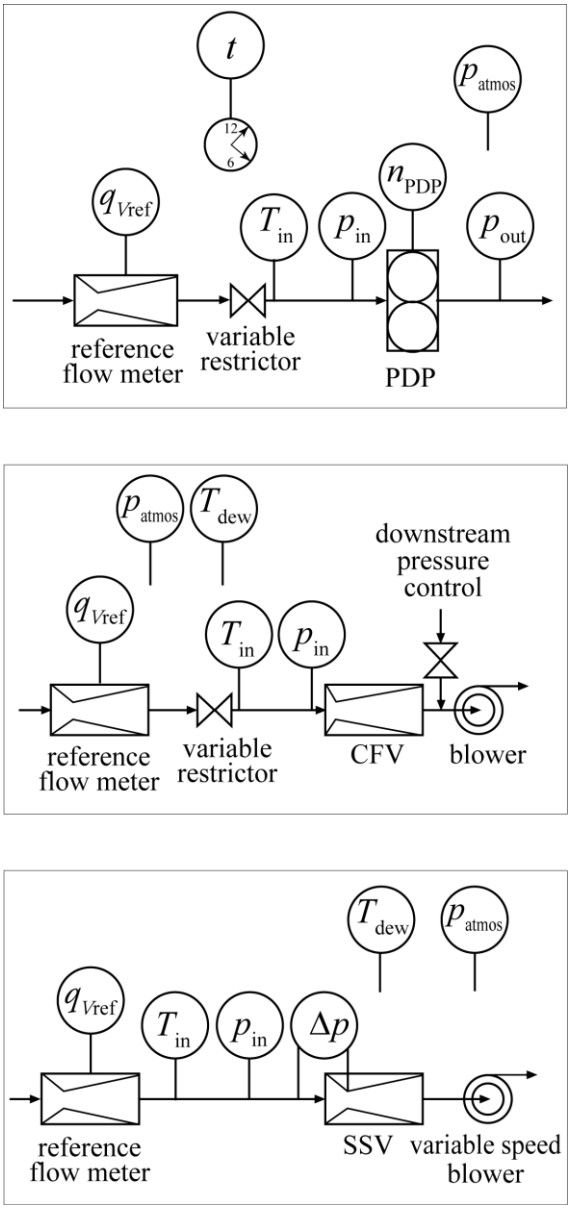


Figure 8.1
Schematic Diagrams for
Diluted Exhaust Flow CVS Calibration

8.1.8.5. CVS and batch sampler verification (propane check)

8.1.8.5.1. Introduction

(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in sub- clause (f) of this clause. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO_2 or CO. A failed propane

check might indicate one or more problems that may require corrective action, as follows:

(i) Incorrect analyser calibration. The FID analyser shall be re-calibrated, repaired, or replaced;

(ii) Leak checks shall be performed on CVS tunnel, connections, fasteners, and HC sampling system according to clause 8.1.8.7.;

(iii) The verification for poor mixing shall be performed in accordance with clause 9.2.2.;

(iv) The hydrocarbon contamination verification in the sample system shall be performed as described in clause 7.3.1.2.;

(v) Change in CVS calibration. An in-situ calibration of the CVS flow-meter shall be performed as described in clause 8.1.8.4.;

(vi) Other problems with the CVS or sampling verification hardware or software. The CVS system, CVS verification hardware, and software shall be inspected for discrepancies;

(b) A propane check uses either a reference mass or a reference flow rate of C_3H_8 as a tracer gas in a CVS. If a reference flow rate is used, any non-ideal gas behaviour of C_3H_8 in the reference flow-meter shall be accounted for. See Appendix A.7 (molar based approach) or A.8 (mass based approach), which describe how to calibrate and use certain flow-meters. No ideal gas assumption may be used in clause 8.1.8.5. and Appendices A.7 or A.8. The propane check compares the calculated mass of injected C_3H_8 using HC measurements and CVS flow rate measurements with the reference value.

8.1.8.5.2. Method of introducing a known amount of propane into the CVS system

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to Annexes A.7-A.8. Either of the following two techniques shall be used.

(a) Metering by means of a gravimetric technique shall be done as follows: A mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ±0.01 g. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated;

(b) Metering with a critical flow orifice shall be done as follows: A known quantity of pure gas (carbon monoxide or propane) shall be fed into the CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

8.1.8.5.3. Preparation of the propane check

The propane check shall be prepared as follows:

(a) If a reference mass of C_3H_8 is used instead of a reference flow rate, a cylinder charged with C_3H_8 shall be obtained. The reference cylinder's mass of C_3H_8 shall be determined within ±0.5 per cent of the amount of C_3H_8 that is expected to be used;

(b) Appropriate flow rates shall be selected for the CVS and C_3H_8;

(c) A C_3H_8 injection port shall be selected in the CVS. The port location shall be selected to be as close as practical to the location where engine exhaust is introduced into the CVS. The C_3H_8 cylinder shall be connected to the injection system;

(d) The CVS shall be operated and stabilized;

(e) Any heat exchangers in the sampling system shall be pre-heated or pre-cooled;

(f) Heated and cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilize at operating temperature;

(g) If applicable, a vacuum side leak verification of the HC sampling system shall be performed as described in 8.1.8.7.

8.1.8.5.4. Preparation of the HC sampling system for the propane check

Vacuum side leak check verification of the HC sampling system may be performed according to sub- clause (g) of this clause. If this procedure is used, the HC contamination procedure in clause 7.3.1.2. may be used. If the vacuum side leak check is not performed according to sub- clause (g), then the HC sampling system shall be zeroed, spanned, and verified for contamination, as follows:

(a) The lowest HC analyser range that can measure the C_3H_8 concentration expected for the CVS and C_3H_8 flow rates shall be selected;

(b) The HC analyser shall be zeroed using zero air introduced at the analyser port;

(c) The HC analyser shall be spanned using C_3H_8 span gas introduced at the analyser port;

(d) Zero air shall be overflowed at the HC probe or into a fitting between the HC probe and the transfer line;

(e) The stable HC concentration of the HC sampling system shall be measured as overflow zero air flows. For batch HC measurement, the batch container (such as a bag) shall be filled and the HC overflow concentration measured;

(f) If the overflow HC concentration exceeds 2 µmol/mol, the procedure may not be advanced until contamination is eliminated. The source of the contamination shall be determined and corrective action taken, such as cleaning the system or replacing contaminated portions;

(g) When the overflow HC concentration does not exceed 2 µmol/mol, this value shall be recorded as x_{HCinit} and it shall be used to correct for HC contamination as described in Annex 4 Appendix A.7 (molar based approach) or Annex 4, Appendix A.8 (mass based approach).

8.1.8.5.5. Propane check performance

(a) The propane check shall be performed as follows:

(i) For batch HC sampling, clean storage media, such as evacuated bags shall be connected;

(ii) HC measurement instruments shall be operated according to the instrument manufacturer's instructions;

(iii) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded;

(iv) Any integrating devices shall be zeroed;

(v) Sampling shall begin and any flow integrators shall be started;

(vi) C_3H_8 shall be released at the rate selected. If a reference flow rate of C_3H_8 is used, the integration of this flow rate shall be started;

(vii) C_3H_8 shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8;

(viii) The C_3H_8 cylinder shall be shut off and sampling shall continue until it has been accounted for time delays due to sample transport and analyser response;

(ix) Sampling shall be stopped and any integrators shall be stopped;

(b) In case the metering with a critical flow orifice is used, the following procedure may be used for the propane check as the alternative method of the previous sub- clause;

(i) For batch HC sampling, clean storage media, such as evacuated bags shall be connected;

(ii) HC measurement instruments shall be operated according to the instrument manufacturer's instructions;

(iii) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded;

(iv) Any integrating devices shall be zeroed;

(v) The contents of the C_3H_8 reference cylinder shall be released at the rate selected;

(vi) Sampling shall begin, and any flow integrators started after confirming that HC concentration is to be stable;

(vii) The cylinder's contents shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8;

(viii) Any integrators shall be stopped;

(ix) The C_3H_8 reference cylinder shall be shut off.

8.1.8.5.6. Evaluation of the propane check

Post-test procedure shall be performed as follows:

(a) If batch sampling has been used, batch samples shall be analysed as soon as practical;

(b) After analysing HC, contamination and background shall be corrected for;

(c) Total C_3H_8 mass based on the CVS and HC data shall be calculated as described in Appendices A.7-A.8, using the molar mass of C_3H_8, M_{C3H8}, instead the effective molar mass of HC, M_{HC};

(d) If a reference mass (gravimetric technique) is used, the cylinder's propane mass shall be determined within ±0.5 per cent and the C_3H_8 reference mass shall be determined by subtracting the empty cylinder propane mass from the full cylinder propane mass. If a critical flow orifice (metering with a critical flow orifice) is used, the propane mass shall be determined as flow rate multiplied by the test time;

(e) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±3.0 per cent of the reference mass, the CVS passes this verification.

8.1.8.5.7. PM secondary dilution system verification

When the propane check is to be repeated to verify the PM secondary dilution system, the following procedure from sub- clauses (a) to (d) shall be used for this verification:

(a) The HC sampling system shall be configured to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, HC may be sampled from the batch sampler pump's exhaust. Caution shall be used when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow-meter will cause a false failure of the propane check;

(b) The propane check shall be repeated as described in this clause, but HC shall be sampled from the batch sampler;

(c) C_3H_8 mass shall be calculated, taking into account any secondary dilution from the batch sampler;

(d) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±5 per cent of the reference mass, the batch sampler passes this verification. If not, corrective action shall be taken.

8.1.8.5.8. Sample dryer verification

If a humidity sensor for continuous monitoring of dew point at the sample dryer outlet is used this check does not apply, as long as it is ensured that the dryer outlet humidity is below the minimum values used for quench, interference, and compensation checks.

(a) If a sample dryer is used as allowed in clause 9.3.2.3.1. to remove water from the sample gas, the performance shall be verified upon installation, after major maintenance, for thermal chiller. For osmotic membrane dryers, the performance shall be verified upon installation, after major maintenance, and within 35 days of testing;

(b) Water can inhibit an analyser's ability to properly measure the exhaust component of interest and thus is sometimes removed before the sample gas reaches the analyser. For example water can negatively interfere with

a CLD's NO_x response through collisional quenching and can positively interfere with an NDIR analyser by causing a response similar to CO;

(c) The sample dryer shall meet the specifications as determined in clause 9.3.2.3.1. for dew point, T_{dew}, and absolute pressure, p_{total}, downstream of the osmotic-membrane dryer or thermal chiller;

(d) The following sample dryer verification procedure method shall be used to determine sample dryer performance, or good engineering judgment shall be used to develop a different protocol:

(i) PTFE or stainless steel tubing shall be used to make necessary connections;

(ii) N_2 or purified air shall be humidified by bubbling it through distilled water in a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling;

(iii) The humidified gas shall be introduced upstream of the sample dryer;

(iv) The humidified gas temperature downstream of the vessel shall be maintained at least 5 ºC above its dew point;

(v) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the inlet of the sample dryer to verify that the dew point is the highest that was estimated during emission sampling;

(vi) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the outlet of the sample dryer;

(vii) The sample dryer meets the verification if the result of sub-clauses (d) (vi) of this clause is less than the dew point corresponding to the sample dryer specifications as determined in clause 9.3.2.3.1. plus 2 °C or if the mol fraction from sub- clauses (d) (vi) is less than the corresponding sample dryer specifications plus 0.002 mol/mol or 0.2 volume per cent. Note for this verification, sample dew point is expressed in absolute temperature, Kelvin.

8.1.8.6. Periodic calibration of the partial flow PM and associated raw exhaust gas measurement systems

8.1.8.6.1. Specifications for differential flow measurement

For partial flow dilution systems to extract a proportional raw exhaust sample, the accuracy of the sample flow q_{mp} is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (8\text{-}1)$$

Where:

q_{mp} = sample mass flow rate of exhaust gas into partial flow dilution system

q_{mdw} = dilution air mass flow rate (on wet basis)

q_{mdew} = diluted exhaust gas mass flow rate on wet basis

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ±5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of q_{mp} can be obtained by either of the following methods:

(a) The absolute accuracies of q_{mdew} and q_{mdw} are ±0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios;

(b) Calibration of q_{mdw} relative to q_{mdew} is carried out such that the same accuracies for q_{mp} as in (a) are obtained. For details see clause 8.1.8.6.2;

(c) The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO_2. Accuracies equivalent to method (a) for q_{mp} are required;

(d) The absolute accuracy of q_{mdew} and q_{mdw} is within ±2 per cent of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0.2 per cent and the linearity error is within ±0.2 per cent of the highest q_{mdew} observed during the test.

8.1.8.6.2. Calibration of differential flow measurement

The partial flow dilution system to extract a proportional raw exhaust sample shall be periodically calibrated with an accurate flow-meter traceable to international and/or national standards. The flow-meter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow q_{mp} into the tunnel shall fulfil the accuracy requirements of clause 8.1.8.6.1.

(a) The flow-meter for q_{mdw} shall be connected in series to the flow-meter for q_{mdew}, the difference between the two flow-meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed;

(b) A calibrated flow device shall be connected in series to the flow-meter for q_{mdew} and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flow-meter for q_{mdw}, and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 15, relative to q_{mdew} used during the test;

(c) The transfer line TL (see Figure 9.2) shall be disconnected from the exhaust and a calibrated flow measuring device with a suitable range to measure q_{mp} shall be connected to the transfer line. q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 15. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and dilution air flow is passed through the corresponding meters as in the actual test;

(d) A tracer gas, shall be fed into the exhaust transfer line TL. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x. After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 15. The accuracy of the sample flow shall be determined from the dilution ratio r_d:

$$q_{mp} = q_{mdew} / r_d \quad (8\text{-}2)$$

The accuracies of the gas analysers shall be taken into account to guarantee the accuracy of q_{mp}.

8.1.8.6.3. Special requirements for differential flow measurement

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex 4, Appendix A.4 shall be applied. The carbon flow rates shall be calculated according to equations of Annex 4, Appendix A.4. All carbon flow rates shall agree to within 5 per cent.

8.1.8.6.3.1. Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way.

The accuracy of the flow-meters shall be checked by the same method as used for calibration (see clause 8.1.8.6.2.) for at least two points, including flow values of q_{mdw} that correspond to dilution ratios between 5 and 15 for the q_{mdew} value used during the test.

If it can be demonstrated by records of the calibration procedure under clause 8.1.8.6.2. that the flow-meter calibration is stable over a longer period of time, the pre-test check may be omitted.

8.1.8.6.3.2. Determination of the transformation time

The system settings for the transformation time evaluation shall be the same as during measurement of the test run. The transformation time, defined in Figure 1, shall be determined by the following method:

An independent reference flow-meter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flow-meter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system according to good engineering judgment. A step change shall be introduced to the exhaust flow (or air flow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90 per cent of full scale. The trigger for the step change shall be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flow-meter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50 per cent point of the flow-meter response. In a similar manner, the transformation times of the q_{mp} signal (i.e. sample flow of exhaust gas into partial flow dilution system) and of the $q_{mew,i}$ signal (i.e. the exhaust gas mass flow rate on wet basis supplied by the exhaust flow-meter) shall be determined. These

signals are used in the regression checks performed after each test (see clause 8.2.1.2.).

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 ms) of the reference flow-meter shall be subtracted from this value. In the case that the system in accordance with clause 8.2.1.2. requires the "look-ahead" method, this is the "look-ahead" value of the partial flow dilution system to be applied in accordance with clause 8.2.1.2.

8.1.8.7. Vacuum-side leak verification

8.1.8.7.1. Scope and frequency

Upon initial sampling system installation, after major maintenance such as pre-filter changes, and within 8 hours prior to each duty-cycle sequence, it shall be verified that there are no significant vacuum-side leaks using one of the leak tests described in this section. This verification does not apply to any full-flow portion of a CVS dilution system.

8.1.8.7.2. Measurement principles

A leak may be detected either by measuring a small amount of flow when there shall be zero flow, by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system or by measuring the pressure increase of an evacuated system.

8.1.8.7.3. Low-flow leak test

A sampling system shall be tested for low-flow leaks as follows:

(a) The probe end of the system shall be sealed by taking one of the following steps:

(i) The end of the sample probe shall be capped or plugged;

(ii) The transfer line shall be disconnected at the probe and the transfer line capped or plugged;

(iii) A leak-tight valve in-line between a probe and transfer line shall be closed;

(b) All vacuum pumps shall be operated. After stabilizing, it shall be verified that the flow through the vacuum-side of the sampling system is less than 0.5 per cent of the system's normal in-use flow rate. Typical analyser and bypass flows may be estimated as an approximation of the system's normal in-use flow rate.

8.1.8.7.4. Dilution-of-span-gas leak test

Any gas analyser may be used for this test. If a FID is used for this test, any HC contamination in the sampling system shall be corrected according to Appendices A.7 and A.8 on HC and NMHC determination. Misleading results shall be avoided by using only analysers that have a repeatability of 0.5 per cent or better at the span gas concentration used for this test. The vacuum side leak check shall be performed as follows:

(a) A gas analyser shall be prepared as it would be for emission testing;

(b) Span gas shall be supplied to the analyser port and it shall be verified that the span gas concentration is measured within its expected measurement accuracy and repeatability;

(c) Overflow span gas shall be routed to one of the following locations in the sampling system:

(i) The end of the sample probe;

(ii) The transfer line shall be disconnected at the probe connection, and the span gas overflown at the open end of the transfer line;

(iii) A three-way valve installed in-line between a probe and its transfer line;

(d) It shall be verified that the measured overflow span gas concentration is within ±0.5 per cent of the span gas concentration. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyser itself. A measured value higher than expected does not indicate a leak.

8.1.8.7.5. Vacuum-decay leak test

To perform this test a vacuum shall be applied to the vacuum-side volume of the sampling system and the leak rate of the system shall be observed as a decay in the applied vacuum. To perform this test the vacuum-side volume of the sampling system shall be known to within ±10 per cent of its true volume. For this test measurement instruments that meet the specifications of clauses 8.1. and 9.4. shall also be used.

A vacuum-decay leak test shall be performed as follows:

(a) The probe end of the system shall be sealed as close to the probe opening as possible by taking one of the following steps:

(i) The end of the sample probe shall be capped or plugged;

(ii) The transfer line at the probe shall be disconnected and the transfer line capped or plugged;

(iii) A leak-tight valve in-line between a probe and transfer line shall be closed;

(b) All vacuum pumps shall be operated. A vacuum shall be drawn that is representative of normal operating conditions. In the case of sample bags, it is recommended that the normal sample bag pump-down procedure be repeated twice to minimize any trapped volumes;

(c) The sample pumps shall be turned off and the system sealed. The absolute pressure of the trapped gas and optionally the system absolute temperature shall be measured and recorded. Sufficient time shall be allowed for any transients to settle and long enough for a leak at 0.5 per cent to have caused a pressure change of at least 10 times the resolution of the pressure transducer. The pressure and optionally temperature shall be recorded once again;

(d) The leak flow rate based on an assumed value of zero for pumped-down bag volumes and based on known values for the sample system volume, the initial and final pressures, optional temperatures, and elapsed time shall be calculated. It shall be verified that the vacuum-decay leak flow rate is less than 0.5 per cent of the system's normal in-use flow rate as follows:

$$q_{V\,\text{leak}} = \frac{V_{\text{vac}}}{R} \frac{\left(\frac{p_2}{T_2} - \frac{p_1}{T_1} \right)}{\left(t_2 - t_1 \right)} \quad \text{(8-3)}$$

Where:

$q_{V\text{leak}}$ = vacuum-decay leak rate [mol/s]

V_{vac} = geometric volume of the vacuum-side of the sampling system [m^3]

R = molar gas constant [J/(mol·K)]

p_2 = vacuum-side absolute pressure at time t_2 [Pa]

T_2 = vacuum-side absolute temperature at time t_2 [K]

p_1 = vacuum-side absolute pressure at time t_1 [Pa]

T_1 = vacuum-side absolute temperature at time t_1 [K]

t_2 = time at completion of vacuum-decay leak verification test [s]

t_1 = time at start of vacuum-decay leak verification test [s]

8.1.9. CO and CO_2 measurements

8.1.9.1. H_2O interference verification for CO_2 NDIR analysers

8.1.9.1.1. Scope and frequency

If CO_2 is measured using an NDIR analyser, the amount of H_2O interference shall be verified after initial analyser installation and after major maintenance.

8.1.9.1.2. Measurement principles

H_2O can interfere with an NDIR analyser's response to CO_2. If the NDIR analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyser interference verification.

8.1.9.1.3. System requirements

A CO_2 NDIR analyser shall have an H_2O interference that is within (0.0 ± 0.4) mmol/mol (of the expected mean CO_2 concentration).

8.1.9.1.4. Procedure

The interference verification shall be performed as follows:

(a) The CO_2 NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test;

(b) A humidified test gas shall be created by bubbling zero air that meets the specifications in clause 9.5.1. through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H_2O level at least as high as the level determined in clause 9.3.2.3.1.;

(c) The humidified test gas temperature shall be maintained at least 5 °C above its dew point downstream of the vessel;

(d) The humidified test gas shall be introduced into the sampling system. The humidified test gas may be introduced downstream of any sample dryer, if one is used during testing;

(e) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O};

(f) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyser;

(g) Time shall be allowed for the analyser response to stabilize. Stabilization time shall include time to purge the transfer line and to account for analyser response;

(h) While the analyser measures the sample's concentration, 30 s of sampled data shall be recorded. The arithmetic mean of this data shall be calculated. The analyser meets the interference verification if this value is within (0.0 ± 0.4) mmol/mol

8.1.9.2. H_2O and CO_2 interference verification for CO NDIR analysers

8.1.9.2.1. Scope and frequency

If CO is measured using an NDIR analyser, the amount of H_2O and CO_2 interference shall be verified after initial analyser installation and after major maintenance.

8.1.9.2.2. Measurement principles

H_2O and CO_2 can positively interfere with an NDIR analyser by causing a response similar to CO. If the NDIR analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyser interference verification.

8.1.9.2.3. System requirements

A CO NDIR analyser shall have combined H_2O and CO_2 interference that is within ±2 per cent of the expected mean concentration of CO.

8.1.9.2.4. Procedure

The interference verification shall be performed as follows:

(a) The CO NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test;

(b) A humidified CO_2 test gas shall be created by bubbling a CO_2 span gas through distilled water in a sealed vessel. If the sample is not passed through a dryer, the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in clause 8.1.8.5.8. A CO_2 span gas concentration shall be used at least as high as the maximum expected during testing;

(c) The humidified CO_2 test gas shall be introduced into the sampling system. The humidified CO_2 test gas may be introduced downstream of any sample dryer, if one is used during testing;

(d) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O};

(e) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyser;

(f) Time shall be allowed for the analyser response to stabilize;

(g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated;

(h) The analyser meets the interference verification if the result of sub-clause (g) of this section meets the tolerance in clause 8.1.9.2.3.;

(i) Interference procedures for CO_2 and H_2O may be also run separately. If the CO_2 and H_2O levels used are higher than the maximum levels expected during testing, each observed interference value shall be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference procedures concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the two scaled interference values shall meet the tolerance in clause 8.1.9.2.3.

8.1.10. Hydrocarbon measurements

8.1.10.1. FID optimization and verification

8.1.10.1.1. Scope and frequency

For all FID analysers, the FID shall be calibrated upon initial installation. The calibration shall be repeated as needed using good engineering judgment. The following steps shall be performed for a FID that measures HC:

(a) A FID's response to various hydrocarbons shall be optimized after initial analyser installation and after major maintenance. FID response to propylene and toluene shall be between 0.9 and 1.1 relative to propane;

(b) A FID's methane (CH_4) response factor shall be determined after initial analyser installation and after major maintenance as described in clause 8.1.10.1.4. of this section;

(c) Methane (CH_4) response shall be verified within 185 days before testing.

8.1.10.1.2. Calibration

Good engineering judgment shall be used to develop a calibration procedure, such as one based on the FID-analyser manufacturer's instructions and recommended frequency for calibrating the FID. For a FID that measures HC, it shall be calibrated using C_3H_8 calibration gases that meet the specifications of clause 9.5.1. For a FID that measures CH_4, it shall be calibrated using CH_4 calibration gases that meet the specifications of clause 9.5.1. Regardless of the calibration gas composition, it shall be calibrated on a carbon number basis of one (C_1).

8.1.10.1.3. HC FID response optimization

This procedure is only for FID analysers that measure HC.

(a) Instrument manufacturer requirements and good engineering judgment shall be used for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimized to meet the requirement of the hydrocarbon response factors and the oxygen interference check according to sub- clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2. at the most common analyser range expected during emission testing. Higher analyser range may be used according to the instrument manufacturer's recommendation and good engineering judgment in order to optimize FID accurately, if the common analyser range is lower than the minimum range for the optimization specified by the instrument manufacturer;

(b) Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimized at the most common analyser range expected during emission testing. With the fuel and airflow rates set at the manufacturer's recommendations, a span gas shall be introduced to the analyser;

(c) The following step from (1) to (4) or the procedure instructed by the instrument manufacturer shall be taken for optimization. The procedures outlined in SAE paper No. 770141 may be optionally used for optimization;

(i) The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response;

(ii) The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded;

(iii) The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to sub- clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2;

(iv) If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating sub- clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2 for each flow;

(d) The optimum flow rates and/or pressures for FID fuel and burner air shall be determined, and they shall be sampled and recorded for future reference.

8.1.10.1.4. HC FID CH_4response factor determination

This procedure is only for FID analysers that measure HC. Since FID analysers generally have a different response to CH_4 versus C_3H_8, each THC FID analyser's CH_4 response factor, $RF_{CH4[THC\text{-}FID]}$ shall be determined, after FID optimization. The most recent $RF_{CH4[THC\text{-}FID]}$ measured according to this clause shall be used in the calculations for HC determination described in Annex 4, Appendix A.7 (molar based approach) or Annex 4, Appendix A.8 (mass based approach) to compensate for CH_4 response. $RF_{CH4[THC\text{-}FID]}$ shall be determined as follows, noting that $RF_{CH4[THC\text{-}FID]}$ is not determined for FIDs that are calibrated and spanned using CH_4 with a non-methane cutter:

(a) A C_3H_8 span gas concentration shall be selected to span the analyser before emission testing. Only span gases that meet the specifications of clause 9.5.1. shall be selected and the C_3H_8 concentration of the gas shall be recorded;

(b) A CH_4 span gas that meets the specifications of clause 9.5.1. shall be selected and the CH_4 concentration of the gas shall be recorded;

(c) The FID analyser shall be operated according to the manufacturer's instructions;

(d) It shall be confirmed that the FID analyser has been calibrated using C_3H_8. Calibration shall be performed on a carbon number basis of one (C_1);

(e) The FID shall be zeroed with a zero gas used for emission testing;

(f) The FID shall be spanned with the selected C_3H_8 span gas;

(g) The selected CH_4 span gas shall be introduced at the sample port of the FID analyser, the CH_4 span gas that has been selected under sub-clause (b) of this clause;

(h) The analyser response shall be stabilized. Stabilization time may include time to purge the analyser and to account for its response;

(i) While the analyser measures the CH_4 concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these values shall be calculated;

(j) The mean measured concentration shall be divided by the recorded span concentration of the CH_4 calibration gas. The result is the FID analyser's response factor for CH_4, $RF_{CH4[THC\text{-}FID]}$.

8.1.10.1.5. HC FID methane (CH_4) response verification

This procedure is only for FID analysers that measure HC. If the value of $RF_{CH4[THC\text{-}FID]}$ from clause 8.1.10.1.4. is within ±5.0 per cent of its most recent previously determined value, the HC FID passes the methane response verification.

(a) It shall be first verified that the pressures and / or flow rates of FID fuel, burner air, and sample are each within ±0.5 per cent of their most recent previously recorded values, as described in clause 8.1.10.1.3. of this section. If these flow rates have to be adjusted, a new $RF_{CH4[THC\text{-}FID]}$ shall be determined as described in clause 8.1.10.1.4. of this section. It should

be verified that the value of $RF_{CH4[THC-FID]}$ determined is within the tolerance specified in this clause 8.1.10.1.5.;

(b) If $RF_{CH4[THC-FID]}$ is not within the tolerance specified in this clause 8.1.10.1.5., the FID response shall be re-optimized as described in clause 8.1.10.1.3. of this section;

(c) A new $RF_{CH4[THC-FID]}$ shall be determined as described in clause 8.1.10.1.4. of this section. This new value of $RF_{CH4[THC-FID]}$ shall be used in the calculations for HC determination, as described in Annex 4, Appendix A.7 (molar based approach) or Annex 4, Appendix A.8 (mass based approach).

8.1.10.2. Non-stoichiometric raw exhaust FID O_2 interference verification

8.1.10.2.1. Scope and frequency

If FID analysers are used for raw exhaust measurements, the amount of FID O_2 interference shall be verified upon initial installation and after major maintenance.

8.1.10.2.2. Measurement principles

Changes in O_2 concentration in raw exhaust can affect FID response by changing FID flame temperature. FID fuel, burner air, and sample flow shall be optimized to meet this verification. FID performance shall be verified with the compensation algorithms for FID O_2 interference that is active during an emission test.

8.1.10.2.3. System requirements

Any FID analyser used during testing shall meet the FID O_2 interference verification according to the procedure in this section.

8.1.10.2.4. Procedure

FID O_2 interference shall be determined as follows, noting that one or more gas dividers may be used to create reference gas concentrations that are required to perform this verification:

(a) Three span reference gases shall be selected that meet the specifications in clause 9.5.1. and contain C_3H_8 concentration used to span the analysers before emissions testing. Only span gases that meet the specifications in clause 9.5.1. CH_4 span reference gases may be used for FIDs calibrated on CH_4 with a non-methane cutter. The three balance gas concentrations shall be selected such that the concentrations of O_2 and N_2 represent the minimum and maximum and intermediate O_2 concentrations expected during testing. The requirement for using the average O_2 concentration can be removed if the FID is calibrated with span gas balanced with the average expected oxygen concentration;

(b) It shall be confirmed that the FID analyser meets all the specifications of clause 8.1.10.1.;

(c) The FID analyser shall be started and operated as it would be before an emission test. Regardless of the FID burner's air source during testing, zero air shall be used as the FID burner's air source for this verification;

(d) The analyser shall be set at zero;

(e) The analyser shall be spanned using a span gas that is used during emissions testing;

(f) The zero response shall be checked by using the zero gas used during emission testing. It shall be proceeded to the next step if the mean zero response of 30 s of sampled data is within ±0.5 per cent of the span reference value used in sub- clause (e) of this clause, otherwise the procedure shall be restarted at sub- clause (d) of this clause;

(g) The analyser response shall be checked using the span gas that has the minimum concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as $x_{O2minHC}$;

(h) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0.5 per cent of the span reference value used in sub- clause (e) of this clause, otherwise the procedure shall be restarted at sub- clause (d) of this clause;

(i) The analyser response shall be checked using the span gas that has the average concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as $x_{O2avgHC}$;

(j) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0.5 per cent of the span reference value used in clause (e) of this clause, otherwise the procedure shall be restarted at clause (d) of this clause;

(k) The analyser response shall be checked using the span gas that has the maximum concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as $x_{O2maxHC}$;

(l) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0.5 per cent of the span reference value used in clause (e) of this clause, otherwise the procedure at clause (d) of this clause shall be restarted;

(m) The percent difference between $x_{O2maxHC}$ and its reference gas concentration shall be calculated. The percent difference between $x_{O2avgHC}$ and its reference gas concentration shall be calculated. The percent difference between $x_{O2minHC}$ and its reference gas concentration shall be calculated. The maximum percent difference of the three shall be determined. This is the O_2 interference;

(n) If the O_2 interference is within ±3 per cent, the FID passes the O_2 interference verification; otherwise one or more of the following need to be performed to address the deficiency:

(i) The verification shall be repeated to determine if a mistake was made during the procedure;

(ii) The zero and span gases for emission testing shall be selected that contain higher or lower O_2 concentrations and the verification shall be repeated;

(iii) The FID burner air, fuel, and sample flow rates shall be adjusted. Note that if these flow rates are adjusted on a THC FID to meet the O_2 interference verification, the RF_{CH4} shall be reset for the next RF_{CH4} verification. The O_2 interference verification shall be repeated after adjustment and RF_{CH4} shall be determined;

(iv) The FID shall be repaired or replaced and the O_2 interference verification shall be repeated.

8.1.10.3. Non-methane cutter penetration fractions

8.1.10.3.1. Scope and frequency

If a FID analyser and a non-methane cutter (NMC) is used to measure methane (CH_4), the non-methane cutter's conversion efficiencies of methane, E_{CH4}, and ethane, E_{C2H6} shall be determined. As detailed in this clause, these conversion efficiencies may be determined as a combination of NMC conversion efficiencies and FID analyser response factors, depending on the particular NMC and FID analyser configuration.

This verification shall be performed after installing the non-methane cutter. This verification shall be repeated within 185 days of testing to verify that the catalytic activity of the cutter has not deteriorated.

8.1.10.3.2. Measurement principles

A non-methane cutter is a heated catalyst that removes non-methane hydrocarbons from the exhaust stream before the FID analyser measures the remaining hydrocarbon concentration. An ideal non-methane cutter would have a methane conversion efficiency E_{CH4} [-] of 0 (that is, a methane penetration fraction, PF_{CH4}, of 1.000), and the conversion efficiency for all other hydrocarbons would be 1.000, as represented by an ethane conversion efficiency E_{C2H6} [-] of 1 (that is, an ethane penetration fraction PF_{C2H6} [-] of 0). The emission calculations in Annex 4, Appendix A.7 or Annex 4, Appendix A.8 use this clause's measured values of conversion efficiencies E_{CH4} and E_{C2H6} to account for less than ideal NMC performance.

8.1.10.3.3. System requirements

NMC conversion efficiencies are not limited to a certain range. However, it is recommended that a non-methane cutter is optimized by adjusting its temperature to achieve a $E_{CH4} < 0.15$ and a $E_{C2H6} > 0.98$ ($PF_{CH4} > 0.85$ and $PF_{C2H6} < 0.02$) as determined by clause 8.1.10.3.4., as applicable. If adjusting NMC temperature does not result in achieving these specifications, it is recommended that the catalyst material is replaced. The most recently determined conversion values from this section shall be used to calculate HC emissions according to Appendices A.7-A.8 as applicable.

8.1.10.3.4. Procedure

Any one of the procedures specified in clauses 8.1.10.3.4.1., 8.1.10.3.4.2. and 8.1.10.3.4.3. is recommended. An alternative method recommended by the instrument manufacturer may be used.

8.1.10.3.4.1. Procedure for a FID calibrated with the NMC

If a FID is always calibrated to measure CH_4 with the NMC, then the FID shall be spanned with the NMC using a CH_4 span gas, the product of that FID's CH_4 response factor and CH_4 penetration fraction, $RFPF_{CH4[NMC-FID]}$, shall be set equal to 1.0 (i.e. efficiency E_{CH4} [-] is set to 0) for all emission calculations, and the combined ethane (C_2H_6) response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$ (and efficiency E_{C2H6} [-]) shall be determined as follows:

(a) Both a CH_4 gas mixture and a C_2H_6 analytical gas mixture shall be selected meeting the specifications of clause 9.5.1. Both a CH_4 concentration for spanning the FID during emission testing and a C_2H_6

concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to THC analyser's span value shall be selected;

(b) The non-methane cutter shall be started, operated, and optimized according to the manufacturer's instructions, including any temperature optimization;

(c) It shall be confirmed that the FID analyser meets all the specifications of clause 8.1.10.1.;

(d) The FID analyser shall be operated according to the manufacturer's instructions;

(e) CH_4 span gas shall be used to span the FID with the cutter. The FID shall be spanned on a C_1 basis. For example, if the span gas has a CH_4 reference value of 100 µmol/mol, the correct FID response to that span gas is 100 µmol/mol because there is one carbon atom per CH_4 molecule;

(f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter;

(g) The analyser response shall be stabilized. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response;

(h) While the analyser measures a stable concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these data points shall be calculated;

(i) The mean shall be divided by the reference value of C_2H_6, converted to a C_1 basis. The result is the C_2H_6 combined response factor and penetration fraction, $RFPF_{C2H6[NMC\text{-}FID]}$, equivalent to (1 - E_{C2H6} [-]). This combined response factor and penetration fraction and the product of the CH_4 response factor and CH_4 penetration fraction, $RFPF_{CH4[NMC\text{-}FID]}$, which is set equal to 1.0, in emission calculations shall be used according to Appendices A.7 or A.8, as applicable.

8.1.10.3.4.2. Procedure for a FID calibrated with propane bypassing the NMC

If a FID is used with an NMC that is calibrated with propane, C_3H_8, by bypassing the NMC, penetrations fractions $PF_{C2H6[NMC\text{-}FID]}$ and $PF_{CH4[NMC\text{-}FID]}$ shall be determined as follows:

(a) A CH_4 gas mixture and a C_2H_6 analytical gas mixture shall be selected meeting the specifications of clause 9.5.1. with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyser span value;

(b) The non-methane cutter shall be started and operated according to the manufacturer's instructions, including any temperature optimization;

(c) It shall be confirmed that the FID analyser meets all the specifications of clause 8.1.10.1.;

(d) The FID analyser shall be operated according to the manufacturer's instructions;

(e) The FID shall be zeroed and spanned as it would be during emission testing. The FID shall be spanned by bypassing the cutter and by using C_3H_8 span gas to span the FID. The FID shall be spanned on a C_1 basis;

(f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter at the same point the zero gas was introduced;

(g) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response;

(h) While the analyser measures a stable concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these data points shall be calculated;

(i) The flow path shall be rerouted to bypass the non-methane cutter, the C_2H_6 analytical gas mixture shall be introduced to the bypass, and the steps in sub- clauses (g) through (h) of this clause shall be repeated;

(j) The mean C_2H_6 concentration measured through the non-methane cutter shall be divided by the mean concentration measured after bypassing the non-methane cutter. The result is the C_2H_6 penetration fraction, $PF_{C2H6[NMC-FID]}$, that is equivalent to (1- E_{C2H6} [-]). This penetration fraction shall be used according to Appendices A.7 or A.8, as applicable;

(k) The steps in sub- clauses (f) through (j) of this clause shall be repeated, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $PF_{CH4[NMC-FID]}$ (equivalent to (1- E_{CH4} [-])). This penetration fraction shall be used according to Appendices A.7-A.8, as applicable.

8.1.10.3.4.3. Procedure for a FID calibrated with methane, bypassing the NMC

If a FID is used with an NMC that is calibrated with methane, CH_4, by bypassing the NMC, determine its combined ethane (C_2H_6) response factor and penetration fraction, $RFPF_{C2H6[NMC-FID]}$, as well as its CH_4 penetration fraction, $PF_{CH4[NMC-FID]}$, as follows:

(a) CH_4 and C_2H_6 analytical gas mixtures shall be selected that meet the specifications of clause 9.5.1., with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyser span value;

(b) The non-methane cutter shall be started and operated according to the manufacturer's instructions, including any temperature optimization;

(c) It shall be confirmed that the FID analyser meets all the specifications of clause 8.1.10.1.;

(d) The FID analyser shall be started and operated according to the manufacturer's instructions;

(e) The FID shall be zeroed and spanned as it would during emission testing. The FID shall be spanned with CH_4 span gas by bypassing the cutter. Note that the FID shall be spanned on a C_1 basis. For example, if the span gas has a methane reference value of 100 µmol/mol, the correct FID response to that span gas is 100 µmol/mol because there is one carbon atom per CH_4 molecule;

(f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter at the same point the zero gas was introduced;

(g) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response;

(h) 30 s of sampled data shall be recorded while the analyser measures a stable concentration. The arithmetic mean of these data points shall be calculated;

(i) The flow path to bypass the non-methane cutter shall be rerouted, the C_2H_6 analytical gas mixture shall be introduced to the bypass, and the steps in sub- clauses (g) and (h) of this clause shall be repeated;

(j) The mean C_2H_6 concentration measured through the non-methane cutter shall be divided by the mean concentration measured after bypassing the non-methane cutter. The result is the C_2H_6 combined response factor and penetration fraction, $RFPF_{C2H6[NMC\text{-}FID]}$. This combined response factor and penetration fraction shall be used according to Appendices A.7 and A.8, as applicable;

(k) The steps in sub- clauses (f) through (j) of this clause shall be repeated, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $PF_{CH4[NMC\text{-}FID]}$. This penetration fraction shall be used according to Appendices A.7 and A.8, as applicable.

8.1.11. NO_x measurements

8.1.11.1. CLD CO_2 and H_2O quench verification

8.1.11.1.1. Scope and frequency

If a CLD analyser is used to measure NO_x, the amount of H_2O and CO_2 quench shall be verified after installing the CLD analyser and after major maintenance.

8.1.11.1.2. Measurement principles

H_2O and CO_2 can negatively interfere with a CLD's NO_x response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_x. This procedure and the calculations in clause 8.1.11.2.3. determine quench and scale the quench results to the maximum mole fraction of H_2O and the maximum CO_2 concentration expected during emission testing. If the CLD analyser uses quench compensation algorithms that utilize H_2O and/or CO_2 measurement instruments, quench shall be evaluated with these instruments active and with the compensation algorithms applied.

8.1.11.1.3. System requirements

For dilute measurement a CLD analyser shall not exceed a combined H_2O and CO_2 quench of ±2 per cent. For raw measurement a CLD analyser shall not exceed a combined H_2O and CO_2 quench of ±2 per cent. Combined quench is the sum of the CO_2 quench determined as described in clause 8.1.11.1.4. and the H_2O quench as determined in clause 8.1.11.1.5. If these requirements are not met, corrective action shall be taken by repairing or replacing the analyser. Before running emission tests, it shall be verified that the corrective action have successfully restored the analyser to proper functioning.

8.1.11.1.4. CO_2quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine CO_2 quench by using a gas divider that blends binary span gases with zero gas as the diluent and meets the specifications in clause 9.4.5.6., or good engineering judgment shall be used to develop a different protocol:

(a) PTFE or stainless steel tubing shall be used to make necessary connections;

(b) The gas divider shall be configured such that nearly equal amounts of the span and diluent gases are blended with each other;

(c) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_x, the CLD analyser shall be operated in the NO-only operating mode;

(d) A CO_2 span gas that meets the specifications of clause 9.5.1. and a concentration that is approximately twice the maximum CO_2 concentration expected during emission testing shall be used;

(e) An NO span gas that meets the specifications of clause 9.5.1. and a concentration that is approximately twice the maximum NO concentration expected during emission testing shall be used. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(f) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from clause (e) of this clause through the gas divider. The NO span gas shall be connected to the span port of the gas divider; a zero gas shall be connected to the diluent port of the gas divider; the same nominal blend ratio shall be used as selected in sub- clause (b) of this clause; and the gas divider's output concentration of NO shall be used to span the CLD analyser. Gas property corrections shall be applied as necessary to ensure accurate gas division;

(g) The CO_2 span gas shall be connected to the span port of the gas divider;

(h) The NO span gas shall be connected to the diluents port of the gas divider;

(i) While flowing NO and CO_2 through the gas divider, the output of the gas divider shall be stabilized. The CO_2 concentration from the gas divider output shall be determined, applying gas property correction as necessary to ensure accurate gas division. This concentration, x_{CO2act}, shall be recorded and it shall be used in the quench verification calculations in clause 8.1.11.2.3. As an alternative to using a gas divider, another simple gas blending device may be used. In this case an analyser shall be used to determine CO_2 concentration. If a NDIR is used together with a simple gas blending device, it shall meet the requirements of this section and it shall be spanned with the CO_2 span gas from sub- clause (d) of this section. The linearity of the NDIR analyser has to be checked before over the whole range up to twice of the expected maximum CO_2 concentration expected during testing;

(j) The NO concentration shall be measured downstream of the gas divider with the CLD analyser. Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 s. The arithmetic mean concentration shall be calculated from these data, x_{NOmeas}. x_{NOmeas} shall be recorded and it shall be used in the quench verification calculations in clause 8.1.11.2.3.;

(k) The actual NO concentration shall be calculated at the gas divider's outlet, x_{NOact}, based on the span gas concentrations and x_{CO2act} according to equation (8-5). The calculated value shall be used in the quench verification calculations in equation (8-4);

(l) The values recorded according to clauses 8.1.11.1.4. and 8.1.11.1.5. of this section shall be used to calculate quench as described in clause 8.1.11.2.3.

8.1.11.1.5. H_2O quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine H_2O quench, or good engineering judgment shall be used to develop a different protocol:

(a) PTFE or stainless steel tubing shall be used to make necessary connections;

(b) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_x, the CLD analyser shall be operated in the NO-only operating mode;

(c) A NO span gas shall be used that meets the specifications of clause 9.5.1. and a concentration that is near the maximum concentration expected during emission testing. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(d) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from clause (c) of this clause, the span gas concentration shall be recorded as x_{NOdry}, and it shall be used in the quench verification calculations in clause 8.1.11.2.3.;

(e) The NO span gas shall be humidified by bubbling it through distilled water in a sealed vessel. If the humidified NO span gas sample does not pass through a sample dryer for this verification test, the vessel temperature shall be controlled to generate an H_2O level approximately equal to the maximum mole fraction of H_2O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in clause 8.1.11.2.3. scale the measured H_2O quench to the highest mole fraction of H_2O expected during emission testing. If the humidified NO span gas sample passes through a dryer for this verification test, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in clause 9.3.2.3.1. For this case, the quench verification

calculations in clause 8.1.11.2.3. do not scale the measured H_2O quench;

(f) The humidified NO test gas shall be introduced into the sample system. It may be introduced upstream or downstream of a sample dryer that is used during emission testing. Depending on the point of introduction, the respective calculation method of sub-clause (e) shall be selected. Note that the sample dryer shall meet the sample dryer verification check in clause 8.1.8.5.8.;

(g) The mole fraction of H_2O in the humidified NO span gas shall be measured. In case a sample dryer is used, the mole fraction of H_2O in the humidified NO span gas shall be measured downstream of the sample dryer, $x_{H2Omeas}$. It is recommended to measure $x_{H2Omeas}$ as close as possible to the CLD analyser inlet. $x_{H2Omeas}$ may be calculated from measurements of dew point, T_{dew}, and absolute pressure, p_{total};

(h) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where $x_{H2Omeas}$ is measured to the analyser. It is recommended that the system is designed so the wall temperatures in the transfer lines, fittings, and valves from the point where $x_{H2Omeas}$ is measured to the analyser are at least 5 ºC above the local sample gas dew point;

(i) The humidified NO span gas concentration shall be measured with the CLD analyser. Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 seconds. The arithmetic mean shall be calculated of these data, x_{NOwet}. x_{NOwet} shall be recorded and used in the quench verification calculations in clause 8.1.11.2.3.

8.1.11.2. CLD quench verification calculations

CLD quench-check calculations shall be performed as described in this clause.

8.1.11.2.1. Amount of water expected during testing

The maximum expected mole fraction of water during emission testing, x_{H2Oexp} shall be estimated. This estimate shall be made where the humidified NO span gas was introduced in sub- clause (f) of clause 8.1.11.1.5. When estimating the maximum expected mole fraction of water, the maximum expected water content in combustion air, fuel combustion products, and dilution air (if applicable) shall be considered. If the humidified NO span gas is introduced into the sample system upstream of a sample dryer during the verification test, it is not needed to estimate the maximum expected mole fraction of water and x_{H2Oexp} shall be set equal to $x_{H2Omeas}$.

8.1.11.2.2. Amount of CO_2 expected during testing

The maximum expected CO_2 concentration during emission testing, x_{CO2exp} shall be estimated. This estimate shall be made at the sample system location where the blended NO and CO_2 span gases are introduced according to sub- clause (j) of clause 8.1.11.1.4. When estimating the maximum expected CO_2 concentration, the maximum expected CO_2 content in fuel combustion products and dilution air shall be considered.

8.1.11.2.3. Combined H_2O and CO_2 quench calculations

Combined H_2O and CO_2 quench shall be calculated as follows:

$$quench = \left[\left(\frac{\frac{x_{NOwet}}{1 - x_{H2Omeas}}}{x_{NOdry}} - 1 \right) \cdot \frac{x_{H20exp}}{x_{H2Omeas}} + \left(\frac{x_{NOmeas}}{x_{NOact}} - 1 \right) \cdot \frac{x_{CO2exp}}{x_{CO2act}} \right] \cdot 100\% \quad (8\text{-}4)$$

Where:

quench = amount of CLD quench

x_{NOdry} = measured concentration of NO upstream of a bubbler, according to sub- clause (d) of clause 8.1.11.1.5.

x_{NOwet} = measured concentration of NO downstream of a bubbler, according to sub- clause (i) of clause 8.1.11.1.5.

x_{H2Oexp} = maximum expected mole fraction of water during emission testing according to clause 8.1.11.2.1.

$x_{H2Omeas}$ = measured mole fraction of water during the quench verification according to sub- clause (g) of clause 8.1.11.1.5.

x_{NOmeas} = measured concentration of NO when NO span gas is blended with CO_2 span gas, according to sub- clause (j) of clause 8.1.11.1.4.

x_{NOact} = actual concentration of NO when NO span gas is blended with CO_2 span gas, according to sub-clause (k) of clause 8.1.11.1.4. and calculated according to equation (8-5)

x_{CO2exp} = maximum expected concentration of CO_2 during emission testing, according to clause 8.1.11.2.2.

x_{CO2act} = actual concentration of CO_2 when NO span gas is blended with CO_2 span gas, according to sub- clause (i) of clause 8.1.11.1.4.

$$x_{NOact} = \left(1 - \frac{x_{CO2act}}{x_{CO2span}} \right) \cdot x_{NOspan} \quad (8\text{-}5)$$

Where:

x_{NOspan} = the NO span gas concentration input to the gas divider, according to sub- clause (e) of clause 8.1.11.1.4.

$x_{CO2span}$ = the CO_2 span gas concentration input to the gas divider, according to sub-clause (d) of clause 8.1.11.1.4.

8.1.11.3. NDUV analyser HC and H_2O interference verification

8.1.11.3.1. Scope and frequency

If NO_x is measured using an NDUV analyser, the amount of H_2O and hydrocarbon interference shall be verified after initial analyser installation and after major maintenance.

8.1.11.3.2. Measurement principles

Hydrocarbons and H_2O can positively interfere with a NDUV analyser by causing a response similar to NO_x. If the NDUV analyser uses compensation algorithms that utilize measurements of other gases to meet this interference

verification, simultaneously such measurements shall be conducted to test the algorithms during the analyser interference verification.

8.1.11.3.3. System requirements

A NO_x NDUV analyser shall have combined H_2O and HC interference within ±2 per cent of the mean concentration of NO_x.

8.1.11.3.4. Procedure

The interference verification shall be performed as follows:

(a) The NO_x NDUV analyser shall be started, operated, zeroed, and spanned according to the instrument manufacturer's instructions;

(b) It is recommended to extract engine exhaust to perform this verification. A CLD shall be used that meets the specifications of clause 9.4. to quantify NO_x in the exhaust. The CLD response shall be used as the reference value. Also HC shall be measured in the exhaust with a FID analyser that meets the specifications of clause 9.4. The FID response shall be used as the reference hydrocarbon value;

(c) Upstream of any sample dryer, if one is used during testing, the engine exhaust shall be introduced into the NDUV analyser;

(d) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyser response;

(e) While all analysers measure the sample's concentration, 30 s of sampled data shall be recorded, and the arithmetic means for the three analysers calculated;

(f) The CLD mean shall be subtracted from the NDUV mean;

(g) This difference shall be multiplied by the ratio of the expected mean HC concentration to the HC concentration measured during the verification. The analyser meets the interference verification of this clause if this result is within ±2 per cent of the NO_x concentration expected at the standard:

$$\left|\overline{x}_{\mathrm{NOx,CLD,meas}} - \overline{x}_{\mathrm{NOx,NDUV,meas}}\right| \cdot \left(\frac{\overline{x}_{\mathrm{HC,exp}}}{\overline{x}_{\mathrm{HC,meas}}}\right) \leq 2\% \cdot \left(\overline{x}_{\mathrm{NOx,exp}}\right)$$

(8-6)

Where:

$\overline{x}_{\mathrm{NOx,CLD,meas}}$ = the mean concentration of NO_x measured by CLD [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{NOx,NDUV,meas}}$ = the mean concentration of NO_x measured by NDUV [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{HC,meas}}$ = the mean concentration of HC measured [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{HC,exp}}$ = the mean concentration of HC expected at the standard [µmol/mol] or [ppm]

$\bar{x}_{NOx,exp}$ = the mean concentration of NO_x expected at the standard [µmol/mol] or [ppm]

8.1.11.3.5. Cooling bath (chiller) requirements

It shall be demonstrated that for the highest expected water vapour concentration H_m, the water removal technique maintains CLD humidity at ≤ 5 g water/kg dry air (or about 0.8 volume per cent H_2O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

8.1.11.4. Cooling bath (chiller) NO_2 penetration

8.1.11.4.1. Scope and frequency

If a cooling bath (chiller) is used to dry a sample upstream of a NO_x measurement instrument, but no NO_2-to-NO converter is used upstream of the cooling bath, this verification shall be performed for cooling bath NO_2 penetration. This verification shall be performed after initial installation and after major maintenance.

8.1.11.4.2. Measurement principles

A cooling bath (chiller) removes water, which can otherwise interfere with a NO_x measurement. However, liquid water remaining in an improperly designed cooling bath can remove NO_2 from the sample. If a cooling bath is used without an NO_2-to-NO converter upstream, it could therefore remove NO_2 from the sample prior NO_x measurement.

8.1.11.4.3. System requirements

The chiller shall allow for measuring at least 95 per cent of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.4.4. Procedure

The following procedure shall be used to verify chiller performance:

(a) Instrument setup. The analyser and chiller manufacturers' start-up and operating instructions shall be followed. The analyser and chiller shall be adjusted as needed to optimize performance;

(b) Equipment setup and data collection.

(i) The total NO_x gas analyser(s) shall be zeroed and spanned as it would be before emission testing;

(ii) NO_2 calibration gas (balance gas of dry air) that has an NO_2 concentration that is near the maximum expected during testing shall be selected. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO_2 concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(iii) This calibration gas shall be overflowed at the gas sampling system's probe or overflow fitting. Time shall be allowed for stabilization of the total NO_x response, accounting only for transport delays and instrument response;

(iv) The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as x_{NOxref};

(v) The flowing the NO_2 calibration gas shall be stopped;

(vi) Next the sampling system shall be saturated by overflowing a dew point generator's output, set at a dew point of 50 °C, to the gas sampling system's probe or overflow fitting. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water;

(vii) It shall be immediately switched back to overflowing the NO_2 calibration gas used to establish x_{NOxref}. It shall be allowed for stabilization of the total NO_x response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as $x_{NOxmeas}$;

(viii) $x_{NOxmeas}$ shall be corrected to x_{NOxdry} based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure;

(c) Performance evaluation. If x_{NOxdry} is less than 95 per cent of x_{NOxref}, the chiller shall be repaired or replaced.

8.1.11.5. NO_2-to-NO converter conversion verification

8.1.11.5.1. Scope and frequency

If an analyser is used that measures only NO to determine NO_x, an NO_2-to-NO converter shall be used upstream of the analyser. This verification shall be performed after installing the converter, after major maintenance and within 35 days before an emission test. This verification shall be repeated at this frequency to verify that the catalytic activity of the NO_2-to-NO converter has not deteriorated.

8.1.11.5.2. Measurement principles

An NO_2-to-NO converter allows an analyser that measures only NO to determine total NO_x by converting the NO_2 in exhaust to NO.

8.1.11.5.3. System requirements

An NO_2-to-NO converter shall allow for measuring at least 95 per cent of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.5.4. Procedure

The following procedure shall be used to verify the performance of a NO_2-to-NO converter:

(a) For the instrument setup the analyser and NO_2-to-NO converter manufacturers' start-up and operating instructions shall be followed. The analyser and converter shall be adjusted as needed to optimize performance;

(b) An ozonator's inlet shall be connected to a zero-air or oxygen source and its outlet shall be connected to one port of a 3-way tee fitting. An NO span gas shall be connected to another port and the NO_2-to-NO converter inlet shall be connected to the last port;

(c) The following steps shall be taken when performing this check:

(i) The ozonator air shall be set off and the ozonator power shall be turned off and the NO_2-to-NO converter shall be set to the bypass mode (i.e., NO mode). Stabilization shall be allowed for, accounting only for transport delays and instrument response;

(ii) The NO and zero-gas flows shall be adjusted so the NO concentration at the analyser is near the peak total NO_x concentration expected during testing. The NO_2 content of the gas mixture shall be less than 5 per cent of the NO concentration. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOref}. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(iii) The ozonator O_2 supply shall be turned on and the O_2 flow rate adjusted so that the NO indicated by the analyser is about 10 percent less than x_{NOref}. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value recorded as $x_{NO+O2mix}$;

(iv) The ozonator shall be switched on and the ozone generation rate adjusted so that the NO measured by the analyser is approximately 20 percent of x_{NOref}, while maintaining at least 10 per cent unreacted NO. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOmeas};

(v) The NO_x analyser shall be switched to NO_x mode and total NO_x measured. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as $x_{NOxmeas}$;

(vi) The ozonator shall be switched off but gas flow through the system shall be maintained. The NO_x analyser will indicate the NO_x in the NO + O_2 mixture. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as $x_{NOx+O2mix}$;

(vii) O_2 supply shall be turned off. The NO_x analyser will indicate the NO_x in the original NO-in-N_2 mixture. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOxref}. This value shall be no more than 5 per cent above the x_{NOref} value;

(d) Performance evaluation. The efficiency of the NO_x converter shall be calculated by substituting the concentrations obtained into the following equation:

$$Efficiency[\%] = \left(1 + \frac{x_{NOxmeas} - x_{NOx+O2mix}}{x_{NO+O2mix} - x_{NOmeas}}\right) \cdot 100 \qquad (8\text{-}7)$$

(e) If the result is less than 95 per cent, the NO_2-to-NO converter shall be repaired or replaced.

8.1.12. PM measurements

8.1.12.1. PM balance verifications and weighing process verification

8.1.12.1.1. Scope and frequency

This clause describes three verifications.

(a) Independent verification of PM balance performance within 370 days prior to weighing any filter;

(b) Zero and span of the balance within 12 h prior to weighing any filter;

(c) Verification that the mass determination of reference filters before and after a filter weighing session be less than a specified tolerance.

8.1.12.1.2. Independent verification

The balance manufacturer (or a representative approved by the balance manufacturer) shall verify the balance performance within 370 days of testing in accordance with internal audit procedures.

8.1.12.1.3. Zeroing and spanning

Balance performance shall be verified by zeroing and spanning it with at least one calibration weight, and any weights that are used shall meet the specifications in clause 9.5.2. to perform this verification. A manual or automated procedure shall be used:

(a) A manual procedure requires that the balance shall be used in which the balance shall be zeroed and spanned with at least one calibration weight. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of PM measurements, the same process shall be used to verify balance performance;

(b) An automated procedure is carried out with internal calibration weights that are used automatically to verify balance performance. These internal calibration weights shall meet the specifications in clause 9.5.2. to perform this verification.

8.1.12.1.4. Reference sample weighing

All mass readings during a weighing session shall be verified by weighing reference PM sample media (e.g. filters) before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre- and post-test mass readings. Successive mass determinations of each reference PM sample media shall return the same value within ±10 µg or ±10 per cent of the expected total PM mass, whichever is higher. Should successive PM sample filter weighing events fail this criterion, all individual test filter mass readings mass readings occurring between the successive reference filter mass determinations shall be invalidated. These filters may be re-weighed in another weighing session. Should a post-test filter be invalidated then the test interval is void. This verification shall be performed as follows:

(a) At least two samples of unused PM sample media shall be kept in the PM-stabilization environment. These shall be used as references. Unused filters of the same material and size shall be selected for use as references;

(b) References shall be stabilized in the PM stabilization environment. References shall be considered stabilized if they have been in the PM-

stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of clause 9.3.4.4. for at least the preceding 60 min;

(c) The balance shall be exercised several times with a reference sample without recording the values;

(d) The balance shall be zeroed and spanned. A test mass shall be placed on the balance (e.g. calibration weight) and then removed ensuring that the balance returns to an acceptable zero reading within the normal stabilization time;

(e) Each of the reference media (e.g. filters) shall be weighed and their masses recorded. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of reference media (e.g. filters) masses, the same process shall be used to measure mean values of sample media (e.g. filters) masses;

(f) The balance environment dew point, ambient temperature, and atmospheric pressure shall be recorded;

(g) The recorded ambient conditions shall be used to correct results for buoyancy as described in clause 8.1.12.2. The buoyancy-corrected mass of each of the references shall be recorded;

(h) Each of the reference media's (e.g. filter's) buoyancy-corrected reference mass shall be subtracted from its previously measured and recorded buoyancy-corrected mass;

(i) If any of the reference filters' observed mass changes by more than that allowed under this clause, all PM mass determinations made since the last successful reference media (e.g. filter) mass validation shall be invalidated. Reference PM filters maybe discarded if only one of the filters mass has changed by more than the allowable amount and a special cause for that filter's mass change can be positively identified which would not have affected other in-process filters. Thus the validation can be considered a success. In this case, the contaminated reference media shall not be included when determining compliance with sub-clause (j) of this clause, but the affected reference filter shall be discarded and replaced;

(j) If any of the reference masses change by more than that allowed under this clause 8.1.12.1.4., all PM results that were determined between the two times that the reference masses were determined shall be invalidated. If reference PM sample media is discarded according to sub-clause (i) of this clause, at least one reference mass difference that meets the criteria in this clause 8.1.12.1.4. shall be available. Otherwise, all PM results that were determined between the two times that the reference media (e.g. filters) masses were determined shall be invalidated.

8.1.12.2. PM sample filter buoyancy correction

8.1.12.2.1. General

PM sample filter shall be corrected for their buoyancy in air. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10) per cent of the total weight. A

correction to this small fraction of mass would be at the most 0.010 per cent. The buoyancy-corrected values are the tare masses of the PM samples. These buoyancy-corrected values of the pre-test filter weighing are subsequently subtracted from the buoyancy-corrected values of the post-test weighing of the corresponding filter to determine the mass of PM emitted during the test.

8.1.12.2.2. PM sample filter density

Different PM sample filter have different densities. The known density of the sample media shall be used, or one of the densities for some common sampling media shall be used, as follows:

(a) For PTFE-coated borosilicate glass, a sample media density of 2,300 kg/m^3 shall be used;

(b) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95 per cent of the media mass, a sample media density of 920 kg/m^3 shall be used;

(c) For PTFE membrane (film) media with an integral support ring of PTFE, a sample media density of 2,144 kg/m^3 shall be used.

8.1.12.2.3. Air density

Because a PM balance environment shall be tightly controlled to an ambient temperature of (22 ± 1) °C and a dew point of (9.5 ± 1) °C, air density is primarily function of atmospheric pressure. Therefore a buoyancy correction is specified that is only a function of atmospheric pressure.

8.1.12.2.4. Calibration weight density

The stated density of the material of the metal calibration weight shall be used.

8.1.12.2.5. Correction calculation

The PM sample filter shall be corrected for buoyancy using the following equations:

$$m_{cor} = m_{uncor} \cdot \left(\frac{1 - \frac{\rho_{air}}{\rho_{weight}}}{1 - \frac{\rho_{air}}{\rho_{media}}} \right) \quad (8\text{-}8)$$

Where:

m_{cor} = PM sample filter mass corrected for buoyancy

m_{uncor} = PM sample filter mass uncorrected for buoyancy

ρ_{air} = density of air in balance environment

ρ_{weight} = density of calibration weight used to span balance

ρ_{media} = density of PM sample filter

$$\rho_{air} = \frac{p_{abs} \cdot M_{mix}}{R \cdot T_{amb}} \quad (8\text{-}9)$$

Where:

p_{abs} = absolute pressure in balance environment

M_{mix} = molar mass of air in balance environment

R = molar gas constant

T_{amb} = absolute ambient temperature of balance environment

8.2. Instrument validation for test

8.2.1. Validation of proportional flow control for batch sampling and minimum dilution ratio for PM batch sampling

8.2.1.1. Proportionality criteria for CVS

8.2.1.1.1. Proportional flows

For any pair of flow-meters, the recorded sample and total flow rates or their 1 Hz means shall be used with the statistical calculations in Annex 4, Appendix A.2, clause A.2.9. The standard error of the estimate, SEE, of the sample flow rate versus the total flow rate shall be determined. For each test interval, it shall be demonstrated that SEE was less than or equal to 3.5 per cent of the mean sample flow rate.

8.2.1.1.2. Constant flows

For any pair of flow-meters, the recorded sample and total flow rates or their 1 Hz means shall be used to demonstrate that each flow rate was constant within ±2.5 per cent of its respective mean or target flow rate. The following options may be used instead of recording the respective flow rate of each type of meter:

(a) Critical-flow venturi option. For critical-flow venturis, the recorded venturi-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the venturi inlet was constant within ±2.5 per cent of the mean or target density over each test interval. For a CVS critical-flow venturi, this may be demonstrated by showing that the absolute temperature at the venturi inlet was constant within ±4 per cent of the mean or target absolute temperature over each test interval;

(b) Positive-displacement pump option. The recorded pump-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the pump inlet was constant within ±2.5 per cent of the mean or target density over each test interval. For a CVS pump, this may be demonstrated by showing that the absolute temperature at the pump inlet was constant within ±2 per cent of the mean or target absolute temperature over each test interval.

8.2.1.1.3. Demonstration of proportional sampling

For any proportional batch sample such as a bag or PM filter, it shall be demonstrated that proportional sampling was maintained using one of the following, noting that up to 5 per cent of the total number of data points may be omitted as outliers.

Using good engineering judgment, it shall be demonstrated with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, CFVs may be used for both sample flow and total flow if it is demonstrated that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

Measured or calculated flows and/or tracer gas concentrations (e.g. CO_2) shall be used to determine the minimum dilution ratio for PM batch sampling over the test interval.

8.2.1.2. Partial flow dilution system validation

For the control of a partial flow dilution system to extract a proportional raw exhaust sample, a fast system response is required; this is identified by the promptness of the partial flow dilution system. The transformation time for the system shall be determined by the procedure in clause 8.1.8.6. and the related Figure 1. The actual control of the partial flow dilution system shall be based on the current measured conditions. If the combined transformation time of the exhaust flow measurement and the partial flow system is ≤ 0.3 s, online control shall be used. If the transformation time exceeds 0.3 s, look-ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$(sample flow of exhaust gas into partial flow dilution system), proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$versus $q_{mew,i}$ (exhaust gas mass flow rate on wet basis) shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

(a) The correlation coefficient r^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$shall not be less than 0.95;

(b) The standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 per cent of q_{mp} maximum;

(c) q_{mp} intercept of the regression line shall not exceed ±2 per cent of q_{mp} maximum.

Look-ahead control is required if the combined transformation times of the particulate system, $t_{50,P}$ and of the exhaust mass flow signal, $t_{50,F}$ are > 0.3 s. In this case, a pre-test shall be run and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pre-test, which controls q_{mp}, is shifted by a "look-ahead" time of $t_{50,P} + t_{50,F}$.

For establishing the correlation between $q_{mp,i}$ and $q_{mew,i}$ the data taken during the actual test shall be used, with $q_{mew,i}$ time aligned by $t_{50,F}$ relative to $q_{mp,i}$ (no contribution from $t_{50,P}$ to the time alignment). The time shift between q_{mew} and q_{mp} is the difference between their transformation times that were determined in clause 8.1.8.6.3.2.

8.2.2. Gas analyser range validation, drift validation and drift correction

8.2.2.1. Range validation

If an analyser operated above 100 per cent of its range at any time during the test, the following steps shall be performed:

8.2.2.1.1. Batch sampling

For batch sampling, the sample shall be re-analysed using the lowest analyser range that results in a maximum instrument response below 100 per cent. The result shall be reported from the lowest range from which the analyser operates below 100 per cent of its range for the entire test.

8.2.2.1.2. Continuous sampling

For continuous sampling, the entire test shall be repeated using the next higher analyser range. If the analyser again operates above 100 per cent of its range, the test shall be repeated using the next higher range. The test shall be continued to be repeated until the analyser always operates at less than 100 per cent of its range for the entire test.

8.2.2.2. Drift validation and drift correction

If the drift is within ±1 per cent, the data can be either accepted without any correction or accepted after correction. If the drift is greater than ±1 per cent, two sets of brake specific emission results shall be calculated for each pollutant, or the test shall be voided. One set shall be calculated using data before drift correction and another set of data calculated after correcting all the data for drift according to Appendix A.7.2 or Appendix A.8.2 of Appendices A.7. or A.8. The comparison shall be made as a percentage of the uncorrected results. The difference between the uncorrected and the corrected brake-specific emission values shall be within ±4 per cent of the uncorrected brake-specific emission values. If not, the entire test is void.

8.2.3. PM sampling media (e.g. filters) preconditioning and tare weighing

Before an emission test, the following steps shall be taken to prepare PM sample filter media and equipment for PM measurements:

8.2.3.1. Periodic verifications

It shall be made sure that the balance and PM-stabilization environments meet the periodic verifications in clause 8.1.12. The reference filter shall be weighed just before weighing test filters to establish an appropriate reference point (see section details of the procedure in clause 8.1.12.1.). The verification of the stability of the reference filters shall occur after the post-test stabilization period, immediately before the post-test weighing.

8.2.3.2. Visual Inspection

The unused sample filter media shall be visually inspected for defects, defective filters shall be discarded.

8.2.3.3. Grounding

Electrically grounded tweezers or a grounding strap shall be used to handle PM filters as described in clause 9.3.4.

8.2.3.4. Unused sample media

Unused sample media shall be placed in one or more containers that are open to the PM-stabilization environment. If filters are used, they may be placed in the bottom half of a filter cassette.

8.2.3.5. Stabilization

Sample media shall be stabilized in the PM-stabilization environment. An unused sample medium can be considered stabilized as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of clause 9.3.4.

8.2.3.6. Weighing

The sample media shall be weighed automatically or manually, as follows:

(a) For automatic weighing, the automation system manufacturer's instructions shall be followed to prepare samples for weighing;

(b) For manual weighing, good engineering judgment shall be used;

(c) Optionally, substitution weighing is permitted (see clause 8.2.3.10.);

(d) Once a filter is weighed it shall be returned to the Petri dish and covered.

8.2.3.7. Buoyancy correction

The measured weight shall be corrected for buoyancy as described in clause 8.1.12.2.

8.2.3.8. Repetition

The filter mass measurements may be repeated to determine the average mass of the filter using good engineering judgement and to exclude outliers from the calculation of the average.

8.2.3.9. Tare-weighing

Unused filters that have been tare-weighed shall be loaded into clean filter cassettes and the loaded cassettes shall be placed in a covered or sealed container before they are taken to the test cell for sampling.

8.2.3.10. Substitution weighing

Substitution weighing is an option and, if used, involves measurement of a reference weight before and after each weighing of a PM sampling medium (e.g. filter). While substitution weighing requires more measurements, it corrects for a balance's zero-drift and it relies on balance linearity only over a small range. This is most appropriate when quantifying total PM masses that are less than 0.1 per cent of the sample medium's mass. However, it may not be appropriate when total PM masses exceed 1 per cent of the sample medium's mass. If substitution weighing is used, it shall be used for both pre-test and post-test weighing. The same substitution weight shall be used for both pre-test and post-test weighing. The mass of the substitution weight shall be corrected for buoyancy if the density of the substitution weight is less than 2.0 g/cm^3. The following steps are an example of substitution weighing:

(a) Electrically grounded tweezers or a grounding strap shall be used, as described in clause 9.3.4.6.;

(b) A static neutralizer shall be used as described in clause 9.3.4.6. to minimize static electric charge on any object before it is placed on the balance pan;

(c) A substitution weight shall be selected that meets the specifications for calibration weights in clause 9.5.2. The substitution weight shall also have the same density as the weight that is used to span the microbalance, and shall be similar in mass to an unused sample medium (e.g. filter). If filters are used, the weight's mass should be about (80 to 100) mg for typical 47 mm diameter filters;

(d) The stable balance reading shall be recorded and then the calibration weight shall be removed;

(e) An unused sampling medium (e.g. a new filter) shall be weighed, the stable balance reading recorded and the balance environment's dew point, ambient temperature, and atmospheric pressure recorded;

(f) The calibration weight shall be reweighed and the stable balance reading recorded;

(g) The arithmetic mean of the two calibration-weight readings that were recorded immediately before and after weighing the unused sample shall be calculated. That mean value shall be subtracted from the unused sample reading, then the true mass of the calibration weight as stated on the calibration-weight certificate shall be added. This result shall be recorded. This is the unused sample's tare weight without correcting for buoyancy;

(h) These substitution-weighing steps shall be repeated for the remainder of the unused sample media;

(i) The instructions given in clause 8.2.3.7. through 8.2.3.9. of this section shall be followed once weighing is completed.

8.2.4. PM sample post-conditioning and total weighing

8.2.4.1. Periodic verification

It shall be assured that the weighing and PM-stabilization environments have met the periodic verifications in clause 8.1.12.1. After testing is complete, the filters shall be returned to the weighing and PM-stabilization environment. The weighing and PM-stabilization environment shall meet the ambient conditions requirements in clause 9.3.4.4., otherwise the test filters shall be left covered until proper conditions have been met.

8.2.4.2. Removal from sealed containers

In the PM-stabilization environment, the PM samples shall be removed from the sealed containers. Filters may be removed from their cassettes before or after stabilization. When a filter is removed from a cassette, the top half of the cassette shall be separated from the bottom half using a cassette separator designed for this purpose.

8.2.4.3. Electrical grounding

To handle PM samples, electrically grounded tweezers or a grounding strap shall be used, as described in clause 9.3.4.5. below.

8.2.4.4. Visual inspection

The collected PM samples and the associated filter media shall be inspected visually. If the conditions of either the filter or the collected PM sample appear to have been compromised, or if the particulate matter contacts any surface other than the filter, the sample may not be used to determine particulate emissions. In the case of contact with another surface; the affected surface shall be cleaned before proceeding.

8.2.4.5. Stabilization of PM samples

To stabilize PM samples, they shall be placed in one or more containers that are open to the PM-stabilization environment, which is described in clause 9.3.4.3. A PM sample is stabilized as long as it has been in the PM-stabilization environment for one of the following durations, during which the stabilization environment has been within the specifications of clause 9.3.4.3. below:

(a) If it is expected that a filter's total surface concentration of PM will be greater than 0.353 µg/mm^2, assuming a 400 µg loading on a 38 mm diameter filter stain area, the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing;

(b) If it is expected that a filter's total surface concentration of PM will be less than 0.353 µg/mm^2, the filter shall be exposed to the stabilization environment for at least 30 minutes before weighing;

(c) If a filter's total surface concentration of PM to be expected during the test is unknown, the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing.

8.2.4.6. Determination of post-test filter mass

The procedures in clause 8.2.3. shall be repeated (clauses 8.2.3.6. through 8.2.3.9.) to determine the post-test filter mass.

8.2.4.7. Total mass

Each buoyancy-corrected filter tare mass shall be subtracted from its respective buoyancy-corrected post-test filter mass. The result is the total mass, m_{total}, which shall be used in emission calculations in Appendices A.7 and A.8.

9. MEASUREMENT EQUIPMENT

9.1. Engine dynamometer specification

9.1.1. Shaft work

An engine dynamometer shall be used that has adequate characteristics to perform the applicable duty cycle including the ability to meet appropriate cycle validation criteria. The following dynamometers may be used:

(a) Eddy-current or water-brake dynamometers;

(b) Alternating-current or direct-current motoring dynamometers;

(c) One or more dynamometers.

9.1.2. Transient cycle

Load cell or in-line torque meter may be used for torque measurements.

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

9.1.3. Engine accessories

The work of engine accessories required to fuel, lubricate, or heat the engine, circulate liquid coolant to the engine, or to operate after-treatment devices shall be accounted for and they shall be installed in accordance with clause 6.3.

9.2. Dilution procedure (if applicable)

9.2.1. Diluent conditions and background concentrations

Gaseous constituents may be measured raw or dilute whereas PM measurement generally requires dilution. Dilution may be accomplished by a full flow or partial flow dilution system. When dilution is applied then the exhaust may be diluted with ambient air, synthetic air, or nitrogen. For gaseous emissions measurement the diluent shall be at least 15 °C. For PM sampling the temperature of the diluent is specified in clauses 9.2.2. for CVS and 9.2.3. for PFD with varying dilution ratio. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and

sampling systems. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. The dilution tunnel walls may be heated or insulated as well as the bulk stream tubing downstream of the tunnel to prevent aqueous condensation.

Before a diluent is mixed with exhaust, it may be preconditioned by increasing or decreasing its temperature or humidity. Constituents may be removed from the diluent to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

(a) Constituent concentrations in the diluent may be measured and compensated for background effects on test results. See Appendices A.7-A.8 for calculations that compensate for background concentrations;

(b) To account for background PM the following options are available:

(i) For removing background PM, the diluent shall be filtered with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99.97 per cent (see clause 2.1.38. of this Part for procedures related to HEPA filtration efficiencies);

(ii) For correcting for background PM without HEPA filtration, the background PM shall not contribute more than 50 per cent of the net PM collected on the sample filter;

(iii) Background correction of net PM with HEPA filtration is permitted without restriction.

9.2.2. Full flow system

Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flow-meter within the limits. For non constant flow the flow shall be measured directly to allow for proportional sampling. The system shall be designed as follows (see Figure 9.1):

(a) A tunnel with inside surfaces of stainless steel shall be used. The entire dilution tunnel shall be electrically grounded;

(b) The exhaust system backpressure shall not be artificially lowered by the dilution air inlet system. The static pressure at the location where raw exhaust is introduced into the tunnel shall be maintained within ±1.2 kPa of atmospheric pressure;

(c) To support mixing the raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. A fraction of dilution air maybe introduced radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls;

(d) Diluent. For PM sampling the temperature of the diluents (ambient air, synthetic air, or nitrogen as quoted in clause 9.2.1.) shall be maintained between 293 and 325 K (20 to 52°C) in close proximity to the entrance into the dilution tunnel.

(e) The Reynolds number, *Re*, shall be at least 4,000 for the diluted exhaust stream, where *Re* is based on the inside diameter of the dilution tunnel. *Re* is defined in Appendices A.7-A.8. Verification of adequate mixing shall be performed while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyser response indicates

any deviation exceeding ±2 per cent of the mean measured concentration, the CVS shall be operated at a higher flow rate or a mixing plate or orifice shall be installed to improve mixing;

(f) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:

(i) Flow straighteners, pulsation dampeners, or both of these maybe used;

(ii) A filter maybe used;

(iii) A heat exchanger maybe used to control the temperature upstream of any flow-meter but steps shall be taken to prevent aqueous condensation;

(g) Aqueous condensation. To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow-meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow-meter inlet measured. The dilution tunnel walls or bulk stream tubing downstream of the tunnel may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel. Certain exhaust components can be diluted or eliminated by the presence of moisture;

For PM sampling, the already proportional flow coming from CVS goes through secondary dilution (one or more) to achieve the requested overall dilution ratio as shown in Figure 9.2 and mentioned in clause 9.2.3.2.;

(h) The minimum overall dilution ratio shall be within the range of 5:1 to 7:1 and at least 2:1 for the primary dilution stage based on the maximum engine exhaust flow rate during the test cycle or test interval;

(i) The overall residence time in the system shall be between 0.5 and 5 s, as measured from the point of diluent introduction to the filter holder(s);

(j) The residence time in the secondary dilution system, if present, shall be at least 0.5 s, as measured from the point of secondary diluent introduction to the filter holder(s).

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a gravimetric balance, and a temperature and humidity controlled weighing chamber, are required.

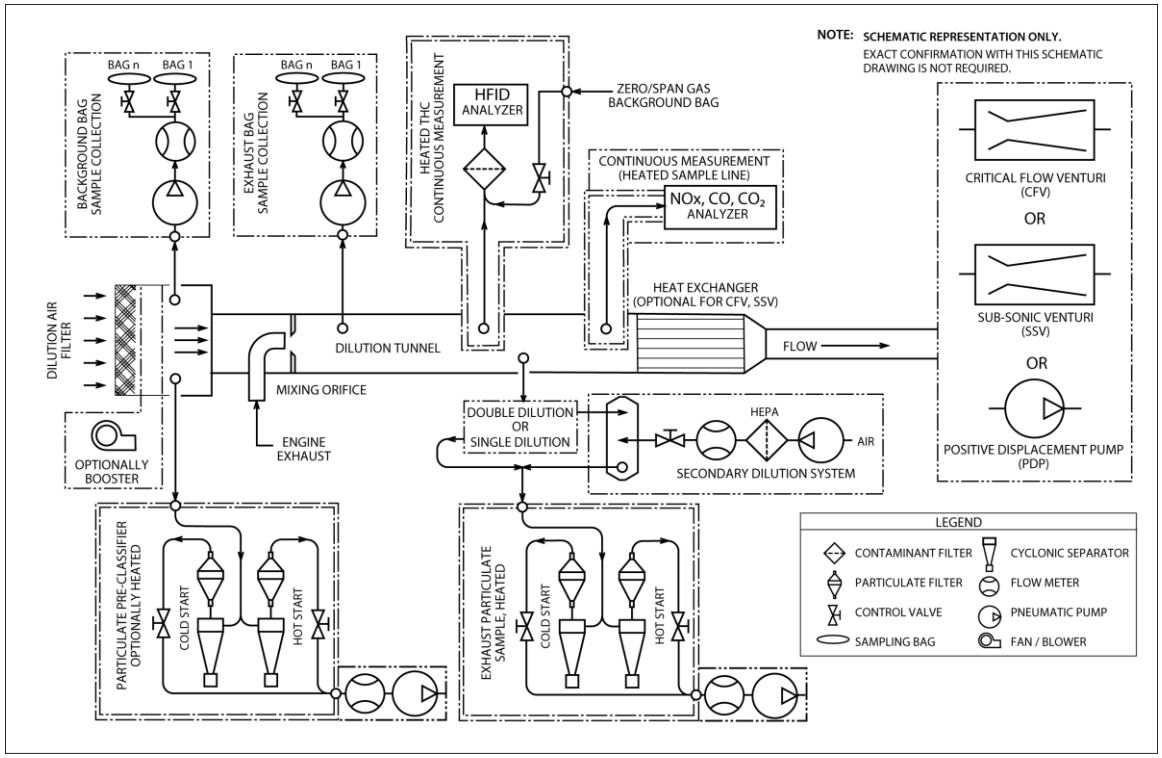


Figure 9.1
Examples of Full-Flow Dilution Sampling Configurations

9.2.3. Partial flow dilution (PFD) system

9.2.3.1. Description of partial flow system

A schematic of a PFD system is shown in Figure 9.2. It is a general schematic showing principles of sample extraction, dilution and PM sampling. It is not meant to indicate that all the components described in the figure are necessary for other possible sampling systems that satisfy the intent of sample collection. Other configurations which do not match these schematics are allowed under the condition that they serve the same purpose of sample collection, dilution, and PM sampling. These need to satisfy other criteria such as in clauses 8.1.8.6. (periodic calibration) and 8.2.1.2. (validation) for varying dilution PFD, and clause 8.1.4.5. as well as Table 8.2 (linearity verification) and clause 8.1.8.5.7. (verification) for constant dilution PFD.

As shown in Figure 9.2, the raw exhaust gas or the primary diluted flow is transferred from the exhaust pipe EP or from CVS respectively to the dilution tunnel DT through the sampling probe SP and the transfer line TL. The total flow through the tunnel is adjusted with a flow controller and the sampling pump P of the particulate sampling system (PSS). For proportional raw exhaust sampling, the dilution air flow is controlled by the flow controller FC1, which may use q_{mew} (exhaust gas mass flow rate on wet basis) or q_{maw} (intake air mass flow rate on wet basis) and q_{mf} (fuel mass flow rate) as command signals, for the desired exhaust split. The sample flow into the dilution tunnel DT is the difference of the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1, the total flow rate with

the flow measurement device of the particulate sampling system. The dilution ratio is calculated from these two flow rates. For sampling with a constant dilution ratio of raw or diluted exhaust versus exhaust flow (e.g.: secondary dilution for PM sampling), the dilution air flow rate is usually constant and controlled by the flow controller FC1 or dilution air pump.

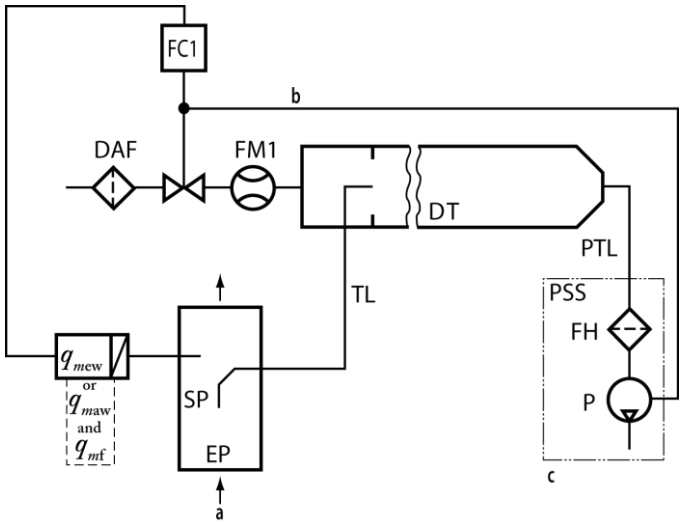


Figure 9.2
Schematic of Partial Flow Dilution System (Total Sampling Type)

a = engine exhaust or primary diluted flow
b = optional c = PM sampling

Components of Figure 9.2:

DAF	=	Dilution air filter – The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency PM air (HEPA) filter.
DT	=	Dilution tunnel or secondary dilution system
EP	=	Exhaust pipe or primary dilution system
FC1	=	Flow controller
FH	=	Filter holder
FM1	=	Flow measurement device measuring the dilution air flow rate
P	=	Sampling pump
PSS	=	PM sampling system
PTL	=	PM transfer line
SP	=	Raw or dilute exhaust gas sampling probe
TL	=	Transfer line

Mass flow rates applicable only for proportional raw exhaust sampling PFD:

q_{mew} = Exhaust gas mass gas flow rate on wet basis

q_{maw} = Intake air mass flow rate on wet basis

q_{mf} = Fuel mass flow rate

9.2.3.2. Dilution

The temperature of the diluents (ambient air, synthetic air, or nitrogen as quoted in clause 9.2.1.) shall be maintained between 293 and 325 K (20 to 52 °C) in close proximity to the entrance into the dilution tunnel.

De-humidifying the dilution air before entering the dilution system is permitted. The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature at the test filter as prescribed by clause 9.3.3.4.3. For this it is essential that the dilution ratio be determined such that the accuracy requirements of clause 8.1.8.6.1. are fulfilled.

To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow-meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow-meter inlet measured. The PFD system may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel.

The minimum dilution ratio shall be within the range of 5:1 to 7:1 based on the maximum engine exhaust flow rate during the test cycle or test interval.

The residence time in the system shall be between 0.5 and 5 s, as measured from the point of diluent introduction to the filter holder(s).

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a gravimetric balance, and a temperature and humidity controlled weighing chamber, are required.

9.2.3.3. Applicability

PFD may be used to extract a proportional raw exhaust sample for any batch or continuous PM and gaseous emission sampling over any transient duty cycle, any steady-state duty cycle or any ramped-modal duty cycle.

The system may be used also for a previously diluted exhaust where, via a constant dilution-ratio, an already proportional flow is diluted (see Figure 9.2). This is the way of performing secondary dilution from a CVS tunnel to achieve the necessary overall dilution ratio for PM sampling.

9.2.3.4. Calibration

The calibration of the PFD to extract a proportional raw exhaust sample is considered in clause 8.1.8.6.

9.3. Sampling procedures

9.3.1 General sampling requirements

9.3.1.1. Probe design and construction

A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that it's inside and outside surfaces are

in contact with the exhaust. A sample is transported out of a probe into a transfer line.

Sample probes shall be made with inside surfaces of stainless steel or, for raw exhaust sampling, with any non-reactive material capable of withstanding raw exhaust temperatures. Sample probes shall be located where constituents are mixed to their mean sample concentration and where interference with other probes is minimized. It is recommended that all probes remain free from influences of boundary layers, wakes, and eddies – especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Purging or back-flushing of a probe shall not influence another probe during testing. A single probe to extract a sample of more than one constituent may be used as long as the probe meets all the specifications for each constituent.

9.3.1.2. Transfer lines

Transfer lines that transport an extracted sample from a probe to an analyser, storage medium, or dilution system shall be minimized in length by locating analysers, storage media, and dilution systems as close to the probes as practical. The number of bends in transfer lines shall be minimized and that the radius of any unavoidable bend shall be maximized.

9.3.1.3. Sampling methods

For continuous and batch sampling, introduced in clause 7.2., the following conditions apply:

(a) When extracting from a constant flow rate, the sample shall also be carried out at a constant flow rate;

(b) When extracting from a varying flow rate, the sample flow rate shall be varied in proportion to the varying flow rate;

(c) Proportional sampling shall be validated as described in clause 8.2.1.

9.3.2. Gas sampling

9.3.2.1. Sampling probes

Either single-port or multi-port probes are used for sampling gaseous emissions. The probes may be oriented in any direction relative to the raw or diluted exhaust flow. For some probes, the sample temperatures shall be controlled, as follows:

(a) For probes that extract NO_x from diluted exhaust, the probe's wall temperature shall be controlled to prevent aqueous condensation;

(b) For probes that extract hydrocarbons from the diluted exhaust, a probe wall temperature is recommended to be controlled approximately 190 ºC to minimize contamination.

9.3.2.2. Transfer lines

Transfer lines with inside surfaces of stainless steel, PTFE, Viton™, or any other material that has better properties for emission sampling shall be used. A non-reactive material capable of withstanding exhaust temperatures shall be used. In-line filters may be used if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:

(a) For NO_x transfer lines upstream of either an NO_2-to-NO converter that meets the specifications of clause 8.1.11.5. or a chiller that meets the

specifications of clause 8.1.11.4. a sample temperature that prevents aqueous condensation shall be maintained;

(b) For THC transfer lines a wall temperature tolerance throughout the entire line of (191 ± 11) °C shall be maintained. If sampled from raw exhaust, an unheated, insulated transfer line may be connected directly to a probe. The length and insulation of the transfer line shall be designed to cool the highest expected raw exhaust temperature to no lower than 191 °C, as measured at the transfer line outlet. For dilute sampling a transition zone between the probe and transfer line of up to 0.92 m in length is allowed to transition the wall temperature to (191 ± 11) °C.

9.3.2.3. Sample-conditioning components

9.3.2.3.1. Sample dryers

9.3.2.3.1.1. Requirements

The instrument that is used for removing moisture shall meet the minimum requirements in the following clause. The moisture content of 0.8 volume per cent H_2O is used in equation (A.8-14).

For the highest expected water vapour concentration H_m, the water removal technique shall maintain CLD humidity at ≤ 5 g water/kg dry air (or about 0.8 volume per cent H_2O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

9.3.2.3.1.2. Type of sample dryers allowed and procedure to estimate moisture content after the dryer

Either type of sample dryer described in this clause to decrease the effects of water on gaseous emission measurements may be used.

(a) If an osmotic-membrane dryer upstream of any gaseous analyser or storage medium is used, it shall meet the temperature specifications in clause 9.3.2.2. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer shall be monitored. The amount of water shall be calculated as specified in Annexes A.7-A.8 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the dryer's lowest absolute pressure expected during testing;

(b) A thermal chiller upstream of a THC measurement system for compression-ignition engines may not be used. If a thermal chiller upstream of an NO_2-to-NO converter or in a sampling system without an NO_2-to-NO converter is used, the chiller shall meet the NO_2 loss-performance check specified in clause 8.1.11.4. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller shall be monitored. The amount of water shall be calculated as specified in Appendices A.7-A.8 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the thermal chiller's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, T_{dew} based on the

known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$ may be calculated. If values of $T_{chiller}$ are not continuously recorded, its peak value observed during a test, or its alarm set point, may be used as a constant value to determine a constant amount of water according to Appendices A.7-A.8. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, $T_{chiller}$ may be used in lieu of T_{dew} according to Appendices A.7-A.8. If it is valid to assume a constant temperature offset between $T_{chiller}$ and T_{dew}, due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, this assumed temperature offset value may be factored in into emission calculations. The validity of any assumptions allowed by this clause shall be shown by engineering analysis or by data.

9.3.2.3.2. Sample pumps

Sample pumps upstream of an analyser or storage medium for any gas shall be used. Sample pumps with inside surfaces of stainless steel, PTFE, or any other material having better properties for emission sampling shall be used. For some sample pumps, temperatures shall be controlled, as follows:

(a) If a NO_x sample pump upstream of either an NO_2-to-NO converter that meets clause 8.1.11.5. or a chiller that meets clause 8.1.11.4. is used, it shall be heated to prevent aqueous condensation;

(b) If a THC sample pump upstream of a THC analyser or storage medium is used, its inner surfaces shall be heated to a tolerance of (191 ± 11) °C.

9.3.2.4. Sample storage media

In the case of bag sampling, gas volumes shall be stored in sufficiently clean containers that minimally off-gas or allow permeation of gases. Good engineering judgment shall be used to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, it may be repeatedly purged and evacuated and may be heated. A flexible container (such as a bag) within a temperature-controlled environment, or a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement, shall be used. Containers meeting the specifications in the following Table 9.1 shall be used.

Table 9.1
Gaseous Batch Sampling Container Materials

CO, CO_2, O_2, CH_4, C_2H_6, C_3H_8, NO, NO_2[1]	polyvinyl fluoride (PVF)[2] for example Tedlar™, polyvinylidene fluoride[2] for example Kynar™, polytetrafluoroethylene[3] for example Teflon™, or stainless steel[3]
THC, NMHC	polytetrafluoroethylene[4] or stainless steel[4]

[1] As long as aqueous condensation in storage container is prevented.
[2] Up to 40 °C.
[3] Up to 202 °C.
[4] At (191 ± 11) °C.

9.3.3. PM sampling

9.3.3.1. Sampling probes

PM probes with a single opening at the end shall be used. PM probes shall be oriented to face directly upstream.

The PM probe may be shielded with a hat that conforms with the requirements in Figure 9.3. In this case the pre-classifier described in clause 9.3.3.3. shall not be used.

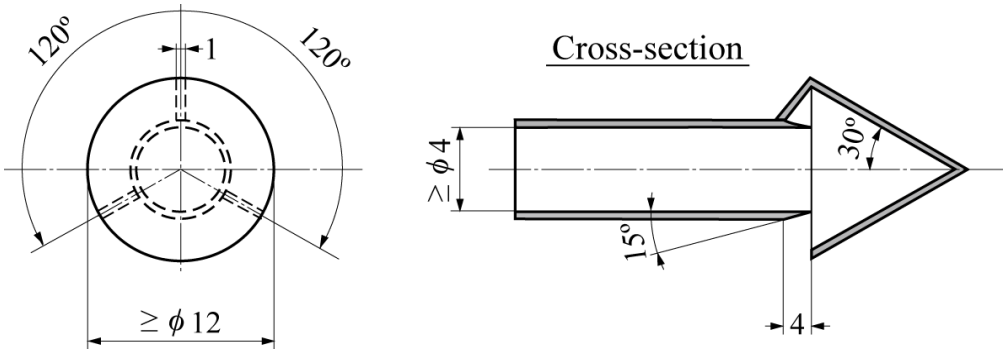


Figure 9.3
Scheme of a Sampling Probe with a Hat-Shaped Pre-Classifier

9.3.3.2. Transfer lines

Insulated or heated transfer lines or a heated enclosure are recommended to minimize temperature differences between transfer lines and exhaust constituents. Transfer lines that are inert with respect to PM and are electrically conductive on the inside surfaces shall be used. It is recommended using PM transfer lines made of stainless steel; any material other than stainless steel will be required to meet the same sampling performance as stainless steel. The inside surface of PM transfer lines shall be electrically grounded.

9.3.3.3. Pre-classifier

The use of a PM pre-classifier to remove large-diameter particles is permitted that is installed in the dilution system directly before the filter holder. Only one

pre-classifier is permitted. If a hat shaped probe is used (see Figure 9.3), the use of a pre-classifier is prohibited.

The PM pre-classifier may be either an inertial impactor or a cyclonic separator. It shall be constructed of stainless steel. The pre-classifier shall be rated to remove at least 50 per cent of PM at an aerodynamic diameter of 10 µm and no more than 1 per cent of PM at an aerodynamic diameter of 1 µm over the range of flow rates for which it is used. The pre-classifier outlet shall be configured with a means of bypassing any PM sample filter so that the pre-classifier flow can be stabilized before starting a test. PM sample filter shall be located within 75 cm downstream of the pre-classifier's exit.

9.3.3.4. Sample filter

The diluted exhaust shall be sampled by a filter that meets the requirements of clauses 9.3.3.4.1. to 9.3.3.4.4. during the test sequence.

9.3.3.4.1. Filter specification

All filter types shall have a 0.3 µm DOP (di-octylphthalate) collection efficiency of at least 99.7 per cent. The sample filter manufacturer's measurements reflected in their product ratings may be used to show this requirement. The filter material shall be either:

(a) Fluorocarbon (PTFE) coated glass fibre; or

(b) Fluorocarbon (PTFE) membrane.

If the expected net PM mass on the filter exceeds 400 µg, a filter with a minimum initial collection efficiency of 98 per cent may be used.

9.3.3.4.2. Filter size

The nominal filter size shall be 46.50 mm ± 0.6 mm diameter.

9.3.3.4.3. Dilution and temperature control of PM samples

PM samples shall be diluted at least once upstream of transfer lines in case of a CVS system and downstream in case of PFD system (see clause 9.3.3.2. relating to transfer lines). Sample temperature is to be controlled to a (47 ± 5) °C tolerance, as measured anywhere within 200 mm upstream or 200 mm downstream of the PM storage media. The PM sample is intended to be heated or cooled primarily by dilution conditions as specified in sub- clause (a) of clause 9.2.1.

9.3.3.4.4. Filter face velocity

A filter face velocity shall be between 0.90 and 1.00 m/s with less than 5 per cent of the recorded flow values exceeding this range. If the total PM mass exceeds 400 µg, the filter face velocity may be reduced. The face velocity shall be measured as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter face, divided by the filter's exposed area. The exhaust stack or CVS tunnel pressure shall be used for the upstream pressure if the pressure drop through the PM sampler up to the filter is less than 2 kPa.

9.3.3.4.5 Filter holder

To minimize turbulent deposition and to deposit PM evenly on a filter, a 12.5° (from centre) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face shall be used. Stainless steel for this transition shall be used.

9.3.4. PM-stabilization and weighing environments for gravimetric analysis

9.3.4.1. Environment for gravimetric analysis

This section describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space.

Both the stabilization and the weighing environments shall be kept free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples.

9.3.4.2. Cleanliness

The cleanliness of the PM-stabilization environment using reference filters shall be verified, as described in clause 8.1.12.1.4.

9.3.4.3. Temperature of the chamber

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 22 °C ± 1 °C during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 9.5 °C ± 1 °C and a relative humidity of 45 per cent ± 8 per cent. If the stabilization and weighing environments are separate, the stabilization environment shall be maintained at a tolerance of 22 °C ± 3 °C.

9.3.4.4. Verification of ambient conditions

When using measurement instruments that meet the specifications in clause 9.4 the following ambient conditions shall be verified:

(a) Dew point and ambient temperature shall be recorded. These values shall be used to determine if the stabilization and weighing environments have remained within the tolerances specified in clause 9.3.4.3. of this section for at least 60 min before weighing filters;

(b) Atmospheric pressure shall be continuously recorded within the weighing environment. An acceptable alternative is to use a barometer that measures atmospheric pressure outside the weighing environment, as long as it can be ensured that the atmospheric pressure at the balance is always at the balance within ±100 Pa of the shared atmospheric pressure. A means to record the most recent atmospheric pressure shall be provided when each PM sample is weighed. This value shall be used to calculate the PM buoyancy correction in clause 8.1.12.2.

9.3.4.5. Installation of balance

The balance shall be installed as follows:

(a) Installed on a vibration-isolation platform to isolate it from external noise and vibration;

(b) Shielded from convective airflow with a static-dissipating draft shield that is electrically grounded.

9.3.4.6. Static electric charge

Static electric charge shall be minimized in the balance environment, as follows:

(a) The balance is electrically grounded;

(b) Stainless steel tweezers shall be used if PM samples shall be handled manually;

(c) Tweezers shall be grounded with a grounding strap, or a grounding strap shall be provided for the operator such that the grounding strap shares a common ground with the balance;

(d) A static-electricity neutralizer shall be provided that is electrically grounded in common with the balance to remove static charge from PM samples.

9.4. Measurement instruments

9.4.1. Introduction

9.4.1.1. Scope

This clause specifies measurement instruments and associated system requirements related to emission testing. This includes laboratory instruments for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations (raw or diluted).

9.4.1.2. Instrument types

Any instrument mentioned in this annex shall be used as described in the annex itself (see Table 8.2 for measurement quantities provided by these instruments). Whenever an instrument mentioned in this annex is used in a way that is not specified, or another instrument is used in its place, the requirements for equivalency provisions shall apply as specified in clause 5.1.3. Where more than one instrument for a particular measurement is specified, one of them will be identified by the Test Agency upon application as the reference for showing that an alternative procedure is equivalent to the specified procedure.

9.4.1.3. Redundant systems

Data from multiple instruments to calculate test results for a single test may be used for all measurement instruments described in this clause, with prior approval of the Test Agency. Results from all measurements shall be recorded and the raw data shall be retained, as described in clause 5.3 of this Annex. This requirement applies whether or not the measurements are actually used in the calculations.

9.4.2. Data recording and control

The test system shall be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Data acquisition and control systems shall be used that can record at the specified minimum frequencies, as shown in Table 9.2 (this table does not apply to discrete mode testing).

Table 9.2
Data recording and control minimum frequencies

Applicable test protocol section	Measured values	Minimum command and control frequency	Minimum recording frequency
7.6.	Speed and torque during an engine step-map	1 Hz	1 mean value per step
7.6.	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
7.8.3.	Transient duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
7.8.2.	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
7.3.	Continuous concentrations of raw analysers	N/A	1 Hz
7.3.	Continuous concentrations of dilute analysers	N/A	1 Hz
7.3.	Batch concentrations of raw or dilute analysers	N/A	1 mean value per test interval
7.6. 8.2.1.	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
7.6. 8.2.1.	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
7.6. 8.2.1.	Intake-air or exhaust flow rate (for raw transient measurement)	N/A	1 Hz means
7.6. 8.2.1.	Dilution air if actively controlled	5 Hz	1 Hz means
7.6. 8.2.1.	Sample flow from a CVS with a heat exchanger	1 Hz	1 Hz
7.6. 8.2.1.	Sample flow from a CVS without a heat exchanger	5 Hz	1 Hz mean

9.4.3. Performance specifications for measurement instruments

9.4.3.1. Overview

The test system as a whole shall meet all the applicable calibrations, verifications, and test-validation criteria specified in clause 8.1., including the requirements of the linearity check of clauses 8.1.4. and 8.2. Instruments shall meet the specifications in Table 9.2 for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in Table 9.2 shall be kept.

9.4.3.2. Component requirements

Table 9.3 shows the specifications of transducers of torque, speed, and pressure, sensors of temperature and dew point, and other instruments. The overall system for measuring the given physical and/or chemical quantity shall meet the linearity verification in clause 8.1.4. For gaseous emissions measurements, analysers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the fuel properties for the specific engine test. Any compensation algorithm shall only provide offset compensation without affecting any gain (that is no bias).

Table 9.3
Recommended Performance Specifications for Measurement Instruments

Measurement instrument	Measured quantity symbol	Complete systemrise time	Recordingupdate frequency	Accuracy[a]	Repeatability[a]
Engine speed transducer	n	1 s	1 Hz means	2.0 % of pt. or0.5 % of max	1.0 % of pt. or0.25 % of max
Engine torque transducer	T	1 s	1 Hz means	2.0 % of pt. or1.0 % of max	1.0 % of pt. or0.5 % of max
Fuel flow-meter (Fuel totalizer)		5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or1.5 % of max	1.0 % of pt. or0.75 % of max
Total diluted exhaust meter (CVS) (With heat exchanger before meter)		1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or1.5 % of max	1.0 % of pt. or0.75 % of max
Dilution air, inlet air, exhaust, and sample flow-meters		1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or1.5 % of max	1.25 % of pt. or0.75 % of max
Continuous gas analyser raw	x	2.5 s	2 Hz	2.0 % of pt. or2.0 % of meas.	1.0 % of pt. or1.0 % of meas.
Continuous gas analyser dilute	x	5 s	1 Hz	2.0 % of pt. or2.0 % of meas.	1.0 % of pt. or1.0 % of meas.
Continuous gas analyser	x	5 s	1 Hz	2.0 % of pt. or2.0 % of meas.	1.0 % of pt. or1.0 % of meas.
Batch gas analyser	x	N/A	N/A	2.0 % of pt. or2.0 % of meas.	1.0 % of pt. or1.0 % of meas.
Gravimetric PM balance	m_{PM}	N/A	N/A	See 9.4.11.	0.5 µg

Inertial PM balance	m_{PM}	5 s	1 Hz	2.0 % of pt. or2.0 % of meas.	1.0 % of pt. or1.0 % of meas.

[a] Accuracy and repeatability are all determined with the same collected data, as described in 9.4.3., and based on absolute values. "pt." refers to the overall mean value expected at the emission limit; "max." refers to the peak value expected at the emission limit over the duty cycle , not the maximum of the instrument's range; "meas." refers to the actual mean measured over the duty cycle.

9.4.4. Measurement of engine parameters & ambient conditions

9.4.4.1. Speed and torque sensors

9.4.4.1.1. Application

Measurement instruments for work inputs and outputs during engine operation shall meet the specifications in this clause. Sensors, transducers, and meters meeting the specifications in Table 9.3 are recommended. Overall systems for measuring work inputs and outputs shall meet the linearity verifications in clause 8.1.4.

9.4.4.1.2. Shaft work

Work and power shall be calculated from outputs of speed and torque transducers according to clause 9.4.4.1. Overall systems for measuring speed and torque shall meet the calibration and verifications in clauses 8.1.7. and 8.1.4.

Torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for as needed, based on good engineering judgment.

9.4.4.2. Pressure transducers, temperature sensors, and dew point sensors

Overall systems for measuring pressure, temperature, and dew point shall meet the calibration in clause 8.1.7.

Pressure transducers shall be located in a temperature-controlled environment, or they shall compensate for temperature changes over their expected operating range. Transducer materials shall be compatible with the fluid being measured.

9.4.5. Flow-related measurements

For any type of flow-meter (of fuel, intake-air, raw exhaust, diluted exhaust, sample), the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, orifice plates (or pneumatic pulsation dampeners for the fuel flow-meter) to establish a steady and predictable velocity profile upstream of the meter.

9.4.5.1. Fuel flow-meter

Overall system for measuring fuel flow shall meet the calibration in clause 8.1.8.1. In any fuel flow measurement it shall be accounted for any fuel that bypasses the engine or returns from the engine to the fuel storage tank.

9.4.5.2. Intake-air flow-meter

Overall system for measuring intake-air flow shall meet the calibration in clause 8.1.8.2.

9.4.5.3. Raw exhaust flow-meter

9.4.5.3.1. Component requirements

The overall system for measuring raw exhaust flow shall meet the linearity requirements in clause 8.1.4. Any raw-exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

9.4.5.3.2. Flow-meter response time

For the purpose of controlling of a partial flow dilution system to extract a proportional raw exhaust sample, a flow-meter response time faster than indicated in Table 9.3 is required. For partial flow dilution systems with online control, the flow-meter response time shall meet the specifications of clause 8.2.1.2.

9.4.5.3.3. Exhaust cooling

Exhaust cooling upstream of the flow-meter is permitted with the following restrictions:

(a) PM shall not be sampled downstream of the cooling;

(b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC shall not be sampled downstream of the cooling;

(c) If cooling causes aqueous condensation, NO_x shall not be sampled downstream of the cooling unless the cooler meets the performance verification in clause 8.1.11.4.;

(d) If cooling causes aqueous condensation before the flow reaches a flow-meter, T_{dew} and pressure p_{total} shall be measured at the flow-meter inlet. These values shall be used in emission calculations according to Appendices A.7-A.8.

9.4.5.4. Dilution air and diluted exhaust flow-meters

9.4.5.4.1. Application

Instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval shall be determined by using a diluted exhaust flow-meter. Raw exhaust flow rates or total raw exhaust flow over a test interval may be calculated from the difference between a diluted exhaust flow-meter and a dilution air meter.

9.4.5.4.2. Component requirements

The overall system for measuring diluted exhaust flow shall meet the calibration and verifications in clauses 8.1.8.4. and 8.1.8.5. The following meters may be used:

(a) For constant-volume sampling (CVS) of the total flow of diluted exhaust, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow-meter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller by keeping the diluted exhaust temperature constant in a CVS system;

(b) For the Partial Flow Dilution (PFD) system the combination of any flow-meter with any active flow control system to maintain proportional sampling of exhaust constituents may be used. The total flow of diluted

exhaust, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

For any other dilution system, a laminar flow element, an ultrasonic flow-meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer may be used.

9.4.5.4.3. Exhaust cooling

Diluted exhaust upstream of a dilute flow-meter may be cooled, as long as all the following provisions are observed:

(a) PM shall not be sampled downstream of the cooling;

(b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC shall not be sampled downstream of the cooling;

(c) If cooling causes aqueous condensation, NO_x shall not be sampled downstream of the cooling unless the cooler meets the performance verification in clause 8.1.11.4.;

(d) If cooling causes aqueous condensation before the flow reaches a flow-meter, dew point, T_{dew} and pressure p_{total} shall be measured at the flow-meter inlet. These values shall be used in emission calculations according Appendices A.7-A.8.

9.4.5.5. Sample flow-meter for batch sampling

A sample flow-meter shall be used to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. The difference between two flow-meters may be used to calculate sample flow into a dilution tunnel e.g. for partial flow dilution PM measurement and secondary dilution flow PM measurement. Specifications for differential flow measurement to extract a proportional raw exhaust sample is given in clause 8.1.8.6.1. and the calibration of differential flow measurement is given in clause 8.1.8.6.2.

Overall system for the sample flow-meter shall meet the calibration in clause 8.1.8.

9.4.5.6. Gas divider

A gas divider may be used to blend calibration gases.

A gas divider shall be used that blends gases to the specifications of clause 9.5.1. and to the concentrations expected during testing. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division. The gas-divider system shall meet the linearity verification in clause 8.1.4.5. Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings used and the nominal value shall be compared to the measured concentration of the instrument.

9.4.6. CO and CO_2 measurements

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO_2 concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system shall meet the calibration and verifications in clause 8.1.9.1.

9.4.7. Hydrocarbon measurements

9.4.7.1. Flame-ionization detector

9.4.7.1.1. Application

A heated flame-ionization detector (FID) analyser shall be used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Hydrocarbon concentrations shall be determined on a carbon number basis of one, C_1. Methane and non-methane hydrocarbon values shall be determined as described in clause 9.4.7.1.4. Heated FID analysers shall maintain all surfaces that are exposed to emissions at a temperature of 191 ± 11 °C.

9.4.7.1.2. Component requirements

The FID-based system for measuring THC or CH_4 shall meet all of the verifications for hydrocarbon measurement in clause 8.1.10.

9.4.7.1.3. FID fuel and burner air

FID fuel and burner air shall meet the specifications of clause 9.5.1. The FID fuel and burner air shall not mix before entering the FID analyser to ensure that the FID analyser operates with a diffusion flame and not a premixed flame.

9.4.7.1.4. Methane

FID analysers measure total hydrocarbons (THC). To determine non-methane hydrocarbons (NMHC), methane, CH_4, shall be quantified either with a non-methane cutter and a FID analyser as described in clause 9.4.7.2., or with a gas chromatograph as described in clause 9.4.7.3. For a FID analyser used to determine NMHC, its response factor to CH_4, RF_{CH4}, shall be determined as described in clause 8.1.10.1. NMHC-related calculations are described in Appendix A.7-A.8.

9.4.7.1.5. Assumption on methane

Instead of measuring methane, it is allowed to assume that 2 per cent of measured total hydrocarbons is methane, as described in Appendix A.7-A.8.

9.4.7.2. Non-methane cutter

9.4.7.2.1. Application

A non-methane cutter may be used to measure CH_4 with a FID analyser. A non-methane cutter oxidizes all non-methane hydrocarbons to CO_2 and H_2O. A non-methane cutter may be used for raw or diluted exhaust for batch or continuous sampling.

9.4.7.2.2. System performance

Non-methane-cutter performance shall be determined as described in clause 8.1.10.3. and the results shall be used to calculate NMHC emission in Appendices A.7 and A.8.

9.4.7.2.3. Configuration

The non-methane cutter shall be configured with a bypass line for the verification described in clause 8.1.10.3.

9.4.7.2.4. Optimization

A non-methane cutter may be optimised to maximize the penetration of CH_4 and the oxidation of all other hydrocarbons. A sample may be humidified and a sample may be diluted with purified air or oxygen (O_2) upstream of non-methane cutter to optimize its performance. Any sample humidification and dilution shall be accounted for in emission calculations.

9.4.7.3. Gas chromatograph

Application: A gas chromatograph may be used to measure CH_4 concentrations of diluted exhaust for batch sampling. While also a non-methane cutter may be used to measure CH_4, as described in clause 9.4.7.2. a reference procedure based on a gas chromatograph shall be used for comparison with any proposed alternate measurement procedure under clause 5.1.3. of this Annex.

9.4.8. NO_x measurements

Two measurement instruments are specified for NO_x measurement and either instrument may be used provided it meets the criteria specified in clause 9.4.8.1. or 9.4.8.2., respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure under clause 5.1.3. of this Annex.

9.4.8.1. Chemiluminescent detector

9.4.8.1.1. Application

A chemiluminescent detector (CLD) coupled with an NO_2-to-NO converter is used to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.1.2. Component requirements

The CLD-based system shall meet the quench verification in clause 8.1.11.1. A heated or unheated CLD may be used, and a CLD that operates at atmospheric pressure or under a vacuum may be used.

9.4.8.1.3. NO_2-to-NO converter

An internal or external NO_2-to-NO converter that meets the verification in clause 8.1.11.5. shall be placed upstream of the CLD, while the converter shall be configured with a bypass to facilitate this verification.

9.4.8.1.4. Humidity effects

All CLD temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, one of the following configurations shall be used:

(a) A CLD connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in clause 8.1.11.5.;

(b) A CLD connected downstream of any dryer or thermal chiller that meets the verification in clause 8.1.11.4.

9.4.8.1.5. Response time

A heated CLD may be used to improve CLD response time.

9.4.8.2. Non-dispersive ultraviolet analyser

9.4.8.2.1. Application

A non-dispersive ultraviolet (NDUV) analyser is used to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.2.2. Component requirements

The NDUV-based system shall meet the verifications in clause 8.1.11.3.

9.4.8.2.3. NO_2-to-NO converter

If the NDUV analyser measures only NO, an internal or external NO_2-to-NO converter that meets the verification in clause 8.1.11.5. shall be placed upstream of the NDUV analyser. The converter shall be configured with a bypass to facilitate this verification.

9.4.8.2.4. Humidity effects

The NDUV temperature shall be maintained to prevent aqueous condensation, unless one of the following configurations is used:

(a) An NDUV shall be connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in clause 8.1.11.5;

(b) An NDUV shall be connected downstream of any dryer or thermal chiller that meets the verification in clause 8.1.11.4.

9.4.9. O_2 measurements

A paramagnetic detection (PMD) or magneto pneumatic detection (MPD) analyser shall be used to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.10. Air-to-fuel ratio measurements

A Zirconia (ZrO_2) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O_2 measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to Appendices A.7-A.8.

9.4.11. PM measurements with gravimetric balance

A balance shall be used to weigh net PM collected on sample filter media.

The minimum requirement on the balance resolution shall be equal or lower than the repeatability of 0.5 microgram recommended in Table 9.3. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights shall meet the specifications in clause 9.5.2.

The balance shall be configured for optimum settling time and stability at its location.

9.5. Analytical gases and mass standards

9.5.1. Analytical gases

Analytical gases shall meet the accuracy and purity specifications of this section.

9.5.1.1. Gas specifications

The following gas specifications shall be considered:

(a) Purified gases shall be used to zero measurement instruments and to blend with calibration gases. Gases with contamination no higher than the

highest of the following values in the gas cylinder or at the outlet of a zero-gas generator shall be used:

(i) 2 per cent contamination, measured relative to the mean concentration expected at the standard. For example, if a CO concentration of 100.0 µmol/mol is expected, then it would be allowed to use a zero gas with CO contamination less than or equal to 2.000 µmol/mol;

(ii) Contamination as specified in Table 9.4, applicable for raw or dilute measurements;

(iii) Contamination as specified in Table 9.5, applicable for raw measurements.

Table 9.4
Contamination Limits, Applicable for Raw or Dilute Measurements
[µmol/mol = ppm (3.2.)]

Constituent	**Purified synthetic air[a]**	**Purified N_2[a]**
THC (C_1 equivalent)	≤ 0.05 µmol/mol	≤ 0.05 µmol/mol
CO	≤ 1 µmol/mol	≤ 1 µmol/mol
CO_2	≤ 10 µmol/mol	≤ 10 µmol/mol
O_2	0.205 to 0.215 mol/mol	≤ 2 µmol/mol
NO_x	≤ 0.02 µmol/mol	≤ 0.02 µmol/mol
[a] It is not required that these levels of purity are international and/or national recognized standards-traceable.		

Table 9.5
Contamination Limits, Applicable for Raw Measurements
[µmol/mol = ppm (3.2.)]

Constituent	Purified synthetic air[a]	Purified N_2[a]
THC (C_1 equivalent)	≤ 1 µmol/mol	≤ 1 µmol/mol
CO	≤ 1 µmol/mol	≤ 1 µmol/mol
CO_2	≤ 400 µmol/mol	≤ 400 µmol/mol
O_2	0.18 to 0.21 mol/mol	-
NO_x	≤ 0.1 µmol/mol	≤ 0.1 µmol/mol
[a] It is not required that these levels of purity are international and/or national recognized standards-traceable.		

(b) The following gases shall be used with a FID analyser:

(i) FID fuel shall be used with an H_2 concentration of (0.39 to 0.41) mol/mol, balance He. The mixture shall not contain more than 0.05 µmol/mol THC;

(ii) FID burner air shall be used that meets the specifications of purified air in clause (a) of this clause;

(iii) FID zero gas.Flame-ionization detectors shall be zeroed with purified gas that meets the specifications in clause (a) of this clause, except that the purified gas O_2 concentration may be any value;

(iv) FID propane span gas. The THC FID shall be spanned and calibrated with span concentrations of propane, C_3H_8. It shall be calibrated on a carbon number basis of one (C_1);

(v) FID methane span gas. If a CH_4 FID is always spanned and calibrated with a non-methane cutter, then the FID shall be spanned and calibrated with span concentrations of methane, CH_4. It shall be calibrated on a carbon number basis of one (C_1);

(c) The following gas mixtures shall be used, with gases traceable within ±1.0 per cent of the international and/or national recognized standards true value or of other gas standards that are approved:

(i) CH_4, balance purified synthetic air and/or N_2 (as applicable);

(ii) C_2H_6, balance purified synthetic air and/or N_2 (as applicable);

(iii) C_3H_8, balance purified synthetic air and/or N_2 (as applicable);

(iv) CO, balance purified N_2;

(v) CO_2, balance purified N_2;

(vi) NO, balance purified N_2;

(vii) NO_2, balance purified synthetic air;

(viii) O_2, balance purified N_2;

(ix) C_3H_8, CO, CO_2, NO, balance purified N_2;

(x) C_3H_8, CH_4, CO, CO_2, NO, balance purified N_2.

(d) Gases for species other than those listed in sub- clause (c) of this clause may be used (such as methanol in air, which may be used to determine response factors), as long as they are traceable to within ±3.0 per cent of the international and/or national recognized standards true value, and meet the stability requirements of clause 9.5.1.2.;

(e) Own calibration gases may be generated using a precision blending device, such as a gas divider, to dilute gases with purified N_2 or purified synthetic air. If the gas dividers meet the specifications in clause 9.4.5.6., and the gases being blended meet the requirements of sub- clauses (a) and (c) of this clause, the resulting blends are considered to meet the requirements of this clause 9.5.1.1.

9.5.1.2. Concentration and expiration date

The concentration of any calibration gas standard and its expiration date specified by the gas supplier shall be recorded.

(a) No calibration gas standard may be used after its expiration date, except as allowed by sub- clause (b) of this clause.

(b) Calibration gases may be relabelled and used after their expiration date if it is approved in advance by Test Agency.

9.5.1.3. Gas transfer

Gases shall be transferred from their source to analysers using components that are dedicated to controlling and transferring only those gases.

The shelf life of all calibration gases shall be respected. The expiration date of the calibration gases stated by the manufacturer shall be recorded.

9.5.2. Mass standards

PM balance calibration weights that are certified as international and/or national recognized standards-traceable within 0.1 per cent uncertainty shall be used. Calibration weights may be certified by any calibration lab that maintains international and/or national recognized standards-traceability. It shall be made sure that the lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium. The calibration report shall also state the density of the weights.

ANNEX 4 - APPENDIX A.1

RESERVED

ANNEX 4 - APPENDIX A.2

STATISTICS

A.2.1. ARITHMETIC MEAN

The arithmetic mean, $\bar{y}$, shall be calculated as follows:

$$\bar{y} = \frac{\sum_{i=1}^{N} y_i}{N} \tag{A.2-1}$$

A.2.2. STANDARD DEVIATION

The standard deviation for a non-biased (*e.g.*, *N*–1) sample, σ, shall be calculated as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{N} \left(y_i - \bar{y}\right)^2}{\left(N-1\right)}} \tag{A.2-2}$$

A.2.3. ROOT MEAN SQUARE

The root mean square, rms_y, shall be calculated as follows:

$$rms_y = \sqrt{\frac{1}{N}\sum_{i=1}^{N} y_i^2} \tag{A.2-3}$$

A.2.4. t-TEST

It shall be determined if the data passes a *t*-test by using the following equations and tables:

(a) For an unpaired *t*-test, the *t* statistic and its number of degrees of freedom, *v*, shall be calculated as follows:

$$t = \frac{\left|\bar{y}_{ref} - \bar{y}\right|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}} \tag{A.2-4}$$

$$v = \frac{\left(\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}\right)^2}{\frac{\left(\sigma_{ref}^2/N_{ref}\right)^2}{N_{ref}-1} + \frac{\left(\sigma_y^2/N\right)^2}{N-1}} \tag{A.2-5}$$

(b) For a paired *t*-test, the *t* statistic and its number of degrees of freedom, *v*, shall be calculated as follows, noting that the ε_i are the errors (*e.g.*, differences) between each pair of y_{refi} and y_i:

$$t = \frac{\left|\bar{\varepsilon}\right| \cdot \sqrt{N}}{\sigma_\varepsilon} \qquad v = N - 1 \tag{A.2-6}$$

(c) Table A.2.1 of this clause shall be used to compare t to the t_{crit} values tabulated versus the number of degrees of freedom. If t is less than t_{crit}, then t passes the t-test.

Table A.2.1

Critical t values versus number of degrees of freedom, ν

ν	**Confidence**	
	90 per cent	95 per cent
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
18	1.734	2.101

ν	Confidence	
	90 per cent	95 per cent
20	1.725	2.086
22	1.717	2.074
24	1.711	2.064
26	1.706	2.056
28	1.701	2.048
30	1.697	2.042
35	1.690	2.030
40	1.684	2.021
50	1.676	2.009
70	1.667	1.994
100	1.660	1.984
1000+	1.645	1.960

Linear interpolation shall be used to establish values not shown here.

A.2.5. F-TEST

The *F* statistic shall be calculated as follows:

$$F_y = \frac{\sigma_y^2}{\sigma_{\text{ref}}^2} \qquad \text{(A.2-7)}$$

(a) For a 90 per cent confidence *F*-test, Table A.2.2 of this clause is used to compare *F* to the F_{crit90} values tabulated versus (N−1) and (N_{ref}−1). If *F* is less than F_{crit90}, then *F* passes the *F*-test at 90 per cent confidence;

(b) For a 95 per cent confidence F-test, Table A.2.3 of this clause is used to compare F to the Fcrit95 values tabulated versus (N−1) and (Nref−1). If F is less than Fcrit95, then F passes the F-test at 95 per cent confidence.

Table A.2.2

Critical F values, F_{crit90}, versus N-1 and N_{ref}-1 at 90 per cent confidence

N-1 / N_{ref}-1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000
1	39.8	49.5	53.5	55.8	57.2	58.2	58.9	59.4	59.8	60.1	60.7	61.2	61.7	62.0	62.2	62.5	62.7	63.0	63.32
2	8.52	9.00	9.16	9.24	9.29	9.32	9.34	9.36	9.38	9.39	9.40	9.42	9.44	9.45	9.45	9.46	9.47	9.48	9.491
3	5.53	5.46	5.39	5.34	5.30	5.28	5.26	5.25	5.24	5.23	5.21	5.20	5.18	5.17	5.16	5.16	5.15	5.14	5.134
4	4.54	4.32	4.19	4.10	4.05	4.01	3.97	3.95	3.93	3.92	3.89	3.87	3.84	3.83	3.81	3.80	3.79	3.77	3.761
5	4.06	3.78	3.61	3.52	3.45	3.40	3.36	3.33	3.31	3.29	3.26	3.23	3.20	3.19	3.17	3.15	3.14	3.12	3.105
6	3.77	3.46	3.28	3.18	3.10	3.05	3.01	2.98	2.95	2.93	2.90	2.87	2.83	2.81	2.80	2.78	2.76	2.74	2.722
7	3.58	3.25	3.07	2.96	2.88	2.82	2.78	2.75	2.72	2.70	2.66	2.63	2.59	2.57	2.55	2.53	2.51	2.49	2.471
8	3.45	3.11	2.92	2.80	2.72	2.66	2.62	2.58	2.56	2.53	2.50	2.46	2.42	2.40	2.38	2.36	2.33	2.31	2.293
9	3.36	3.00	2.81	2.69	2.61	2.55	2.50	2.46	2.44	2.41	2.37	2.34	2.29	2.27	2.25	2.23	2.20	2.18	2.159
10	3.28	2.92	2.72	2.60	2.52	2.46	2.41	2.37	2.34	2.32	2.28	2.24	2.20	2.17	2.15	2.13	2.10	2.08	2.055
11	3.22	2.86	2.66	2.53	2.45	2.38	2.34	2.30	2.27	2.24	2.20	2.16	2.12	2.10	2.07	2.05	2.02	2.00	1.972
12	3.17	2.80	2.60	2.48	2.39	2.33	2.28	2.24	2.21	2.18	2.14	2.10	2.06	2.03	2.01	1.98	1.96	1.93	1.904
13	3.13	2.76	2.56	2.43	2.34	2.28	2.23	2.19	2.16	2.13	2.09	2.05	2.00	1.98	1.95	1.93	1.90	1.87	1.846
14	3.10	2.72	2.52	2.39	2.30	2.24	2.19	2.15	2.12	2.09	2.05	2.01	1.96	1.93	1.91	1.88	1.85	1.82	1.797
15	3.07	2.69	2.49	2.36	2.27	2.20	2.15	2.11	2.08	2.05	2.01	1.97	1.92	1.89	1.87	1.84	1.81	1.78	1.755
16	3.04	2.66	2.46	2.33	2.24	2.17	2.12	2.08	2.05	2.02	1.98	1.94	1.89	1.86	1.83	1.81	1.78	1.75	1.718
17	3.02	2.64	2.43	2.30	2.21	2.15	2.10	2.06	2.02	2.00	1.95	1.91	1.86	1.83	1.80	1.78	1.75	1.71	1.686
18	3.00	2.62	2.41	2.28	2.19	2.13	2.07	2.03	2.00	1.97	1.93	1.88	1.83	1.81	1.78	1.75	1.72	1.69	1.657
19	2.99	2.60	2.39	2.26	2.17	2.10	2.05	2.01	1.98	1.95	1.91	1.86	1.81	1.78	1.75	1.73	1.69	1.66	1.631

20	2.97	2.58	2.38	2.24	2.15	2.09	2.04	1.99	1.96	1.93	1.89	1.84	1.79	1.76	1.73	1.70	1.67	1.64	1.607
21	2.96	2.57	2.36	2.23	2.14	2.07	2.02	1.98	1.94	1.92	1.87	1.82	1.77	1.74	1.71	1.68	1.65	1.62	1.586
22	2.94	2.56	2.35	2.21	2.12	2.06	2.00	1.96	1.93	1.90	1.85	1.81	1.75	1.73	1.70	1.67	1.63	1.60	1.567
23	2.93	2.54	2.33	2.20	2.11	2.04	1.99	1.95	1.91	1.89	1.84	1.79	1.74	1.71	1.68	1.65	1.62	1.58	1.549
24	2.92	2.53	2.32	2.19	2.10	2.03	1.98	1.94	1.90	1.87	1.83	1.78	1.73	1.70	1.67	1.64	1.60	1.57	1.533
25	2.91	2.52	2.31	2.18	2.09	2.02	1.97	1.92	1.89	1.86	1.82	1.77	1.71	1.68	1.65	1.62	1.59	1.55	1.518
26	2.90	2.51	2.30	2.17	2.08	2.01	1.96	1.91	1.88	1.85	1.80	1.76	1.70	1.67	1.64	1.61	1.58	1.54	1.504
27	2.90	2.51	2.29	2.16	2.07	2.00	1.95	1.90	1.87	1.84	1.79	1.74	1.69	1.66	1.63	1.60	1.56	1.53	1.491
28	2.89	2.50	2.29	2.15	2.06	1.99	1.94	1.90	1.86	1.83	1.79	1.74	1.68	1.65	1.62	1.59	1.55	1.52	1.478
29	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.89	1.85	1.82	1.78	1.73	1.67	1.64	1.61	1.58	1.54	1.50	1.467
30	2.88	2.48	2.27	2.14	2.04	1.98	1.92	1.88	1.84	1.81	1.77	1.72	1.66	1.63	1.60	1.57	1.53	1.49	1.456
40	2.83	2.44	2.22	2.09	1.99	1.92	1.87	1.82	1.79	1.76	1.71	1.66	1.60	1.57	1.54	1.50	1.46	1.42	1.377
60	2.79	2.39	2.17	2.04	1.94	1.87	1.81	1.77	1.73	1.70	1.65	1.60	1.54	1.51	1.47	1.43	1.39	1.34	1.291
120	2.74	2.34	2.13	1.99	1.89	1.82	1.76	1.72	1.68	1.65	1.60	1.54	1.48	1.44	1.40	1.36	1.32	1.26	1.193
1000+	2.70	2.30	2.08	1.94	1.84	1.77	1.71	1.67	1.63	1.59	1.54	1.48	1.42	1.38	1.34	1.29	1.24	1.16	1.000

Table A.2.3

Critical *F* values, F_{crit95}, versus *N*-1 and N_{ref}-1 at 95 per cent confidence

N-1 / N_{ref}-1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000
1	161.	199.	215.	224.	230.	233.	236.	238.	240.	241.	243.	245.	248.	249.	250.	251.	252.	253.	254.3
2	18.5	19.0	19.1	19.2	19.2	19.3	19.3	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.49
3	10.1	9.55	9.27	9.11	9.01	8.94	8.88	8.84	8.81	8.78	8.74	8.70	8.66	8.63	8.61	8.59	8.57	8.54	8.526
4	7.70	6.94	6.59	6.38	6.25	6.16	6.09	6.04	5.99	5.96	5.91	5.85	5.80	5.77	5.74	5.71	5.68	5.65	5.628
5	6.60	5.78	5.41	5.19	5.05	4.95	4.87	4.81	4.77	4.73	4.67	4.61	4.55	4.52	4.49	4.46	4.43	4.39	4.365
6	5.98	5.14	4.75	4.53	4.38	4.28	4.20	4.14	4.09	4.06	4.00	3.93	3.87	3.84	3.80	3.77	3.74	3.70	3.669
7	5.59	4.73	4.34	4.12	3.97	3.86	3.78	3.72	3.67	3.63	3.57	3.51	3.44	3.41	3.37	3.34	3.30	3.26	3.230
8	5.31	4.45	4.06	3.83	3.68	3.58	3.50	3.43	3.38	3.34	3.28	3.21	3.15	3.11	3.07	3.04	3.00	2.96	2.928
9	5.11	4.25	3.86	3.63	3.48	3.37	3.29	3.23	3.17	3.13	3.07	3.00	2.93	2.90	2.86	2.82	2.78	2.74	2.707
10	4.96	4.10	3.70	3.47	3.32	3.21	3.13	3.07	3.02	2.97	2.91	2.84	2.77	2.73	2.70	2.66	2.62	2.58	2.538
11	4.84	3.98	3.58	3.35	3.20	3.09	3.01	2.94	2.89	2.85	2.78	2.71	2.64	2.60	2.57	2.53	2.49	2.44	2.405
12	4.74	3.88	3.49	3.25	3.10	2.99	2.91	2.84	2.79	2.75	2.68	2.61	2.54	2.50	2.46	2.42	2.38	2.34	2.296
13	4.66	3.80	3.41	3.17	3.02	2.91	2.83	2.76	2.71	2.67	2.60	2.53	2.45	2.42	2.38	2.33	2.29	2.25	2.206
14	4.60	3.73	3.34	3.11	2.95	2.84	2.76	2.69	2.64	2.60	2.53	2.46	2.38	2.34	2.30	2.26	2.22	2.17	2.131
15	4.54	3.68	3.28	3.05	2.90	2.79	2.70	2.64	2.58	2.54	2.47	2.40	2.32	2.28	2.24	2.20	2.16	2.11	2.066
16	4.49	3.63	3.23	3.00	2.85	2.74	2.65	2.59	2.53	2.49	2.42	2.35	2.27	2.23	2.19	2.15	2.10	2.05	2.010
17	4.45	3.59	3.19	2.96	2.81	2.69	2.61	2.54	2.49	2.45	2.38	2.30	2.23	2.19	2.14	2.10	2.05	2.01	1.960

18	4.41	3.55	3.16	2.92	2.77	2.66	2.57	2.51	2.45	2.41	2.34	2.26	2.19	2.15	2.10	2.06	2.01	1.96	1.91
19	4.38	3.52	3.12	2.89	2.74	2.62	2.54	2.47	2.42	2.37	2.30	2.23	2.15	2.11	2.07	2.02	1.98	1.93	1.87
20	4.35	3.49	3.09	2.86	2.71	2.59	2.51	2.44	2.39	2.34	2.27	2.20	2.12	2.08	2.03	1.99	1.94	1.89	1.84
21	4.32	3.46	3.07	2.84	2.68	2.57	2.48	2.42	2.36	2.32	2.25	2.17	2.09	2.05	2.01	1.96	1.91	1.86	1.81
22	4.30	3.44	3.04	2.81	2.66	2.54	2.46	2.39	2.34	2.29	2.22	2.15	2.07	2.02	1.98	1.93	1.88	1.83	1.78
23	4.27	3.42	3.02	2.79	2.64	2.52	2.44	2.37	2.32	2.27	2.20	2.12	2.04	2.00	1.96	1.91	1.86	1.81	1.75
24	4.26	3.40	3.00	2.77	2.62	2.50	2.42	2.35	2.30	2.25	2.18	2.10	2.02	1.98	1.93	1.89	1.84	1.79	1.73
25	4.24	3.38	2.99	2.75	2.60	2.49	2.40	2.33	2.28	2.23	2.16	2.08	2.00	1.96	1.91	1.87	1.82	1.76	1.71
26	4.22	3.36	2.97	2.74	2.58	2.47	2.38	2.32	2.26	2.22	2.14	2.07	1.99	1.94	1.90	1.85	1.80	1.74	1.69
27	4.21	3.35	2.96	2.72	2.57	2.45	2.37	2.30	2.25	2.20	2.13	2.05	1.97	1.93	1.88	1.83	1.78	1.73	1.67
28	4.19	3.34	2.94	2.71	2.55	2.44	2.35	2.29	2.23	2.19	2.11	2.04	1.95	1.91	1.86	1.82	1.76	1.71	1.65
29	4.18	3.32	2.93	2.70	2.54	2.43	2.34	2.27	2.22	2.17	2.10	2.02	1.94	1.90	1.85	1.80	1.75	1.69	1.63
30	4.17	3.31	2.92	2.69	2.53	2.42	2.33	2.26	2.21	2.16	2.09	2.01	1.93	1.88	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.83	2.60	2.45	2.33	2.24	2.18	2.12	2.07	2.00	1.92	1.83	1.79	1.74	1.69	1.63	1.57	1.50
60	4.00	3.15	2.75	2.52	2.36	2.25	2.16	2.09	2.04	1.99	1.91	1.83	1.74	1.70	1.64	1.59	1.53	1.46	1.38
120	3.92	3.07	2.68	2.44	2.29	2.17	2.08	2.01	1.95	1.91	1.83	1.75	1.65	1.60	1.55	1.49	1.42	1.35	1.25
1000	3.84	2.99	2.60	2.37	2.21	2.09	2.01	1.93	1.88	1.83	1.75	1.66	1.57	1.51	1.45	1.39	1.31	1.22	1.00

A.2.6. SLOPE

The least-squares regression slope, a_{1y}, shall be calculated as follows:

$$a_{1y} = \frac{\sum_{i=1}^{N}\left(y_i - \bar{y}\right)\cdot\left(y_{refi} - \bar{y}_{ref}\right)}{\sum_{i=1}^{N}\left(y_{refi} - \bar{y}_{ref}\right)^2} \quad \text{(A.2-8)}$$

A.2.7. INTERCEPT

The least-squares regression intercept, a_{0y}, shall be calculated as follows:

$$a_{0y} = \bar{y} - \left(a_{1y}\cdot\bar{y}_{ref}\right) \quad \text{(A.2-9)}$$

A.2.8. STANDARD ESTIMATE OF ERROR

The standard estimate of error, *SEE*, shall be calculated as follows:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^{N}\left[y_i - a_{0y} - \left(a_{1y}\cdot y_{refi}\right)\right]^2}{N-2}} \quad \text{(A.2-10)}$$

A.2.9. COEFFICIENT OF DETERMINATION

The coefficient of determination, r^2, shall be calculated as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^{N}\left[y_i - a_{0y} - \left(a_{1y}\cdot y_{refi}\right)\right]^2}{\sum_{i=1}^{N}\left[y_i - \bar{y}\right]^2} \quad \text{(A.2-11)}$$

ANNEX 4 - APPENDIX A.3

1980 INTERNATIONAL GRAVITY FORMULA

The acceleration of Earth's gravity, a_g, varies depending on the location and a_g is calculated for a respective latitude, as follows:

$$a_g = 9.7803267715\left[1 + 5.2790414\times10^{-3}\sin^2\theta + 2.32718\times10^{-5}\sin^4\theta + 1.262\times10^{-7}\sin^6\theta + 7\times10^{-10}\sin^8\theta\right] \quad \text{(A.3-1)}$$

Where:

θ = Degrees north or south latitude

ANNEX 4 - APPENDIX A.4

CARBON FLOW CHECK

A.4.1. INTRODUCTION

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO_2. This is the basis for a system verification check based on CO_2 measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO_2 concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure A.4.1 shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given in the following clauses.

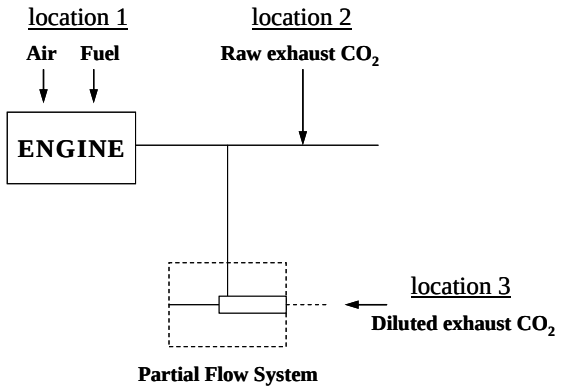


Figure A.4.1
Measuring Points for Carbon Flow Check

A.4.2. CARBON FLOW RATE INTO THE ENGINE (LOCATION 1)

The carbon mass flow rate into the engine q_{mCf} [kg/s] for a fuel CHαOε is given by:

$$q_{mCf} = \frac{12.011}{12.011 + \alpha + 15.9994 \cdot \varepsilon} \cdot q_{mf} \qquad \text{(A.4-1)}$$

Where:

q_{mf} = uel mass flow rate [kg/s]

A.4.3. CARBON FLOW RATE IN THE RAW EXHAUST (LOCATION 2)

The carbon mass flow rate in the exhaust pipe of the engine $q_{m\mathrm{Ce}}$ [kg/s] shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{m\mathrm{Ce}} = \left(\frac{c_{\mathrm{CO2,r}} - c_{\mathrm{CO2,a}}}{100} \right) \cdot q_{m\mathrm{ew}} \cdot \frac{12.011}{M_{\mathrm{e}}} \qquad \text{(A.4-2)}$$

Where:

$c_{\mathrm{CO2,r}}$ = wet CO_2 concentration in the raw exhaust gas [per cent]

$c_{\mathrm{CO2,a}}$ = wet CO_2 concentration in the ambient air [per cent]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on wet basis [kg/s]

M_{e} = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to clause A.7.3.2. of Appendix A.7 or A.8.2.2. of Appendix A.8.

A.4.4. CARBON FLOW RATE IN THE DILUTION SYSTEM (LOCATION 3)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate in an equivalent dilution system $q_{m\mathrm{Cp}}$ [kg/s] (with equivalent meaning equivalent to a full flow system where the total flow is diluted) shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate; the new equation is identical to equation A.4-2, being only supplemented by the dilution factor $q_{m\mathrm{dew}} / q_{m\mathrm{p}}$.

$$q_{m\mathrm{Cp}} = \left(\frac{c_{\mathrm{CO2,d}} - c_{\mathrm{CO2,a}}}{100} \right) \cdot q_{m\mathrm{ew}} \cdot \frac{12.011}{M_{\mathrm{e}}} \cdot \frac{q_{m\mathrm{dew}}}{q_{m\mathrm{p}}} \qquad \text{(A.4-3)}$$

Where:

$c_{\mathrm{CO2,d}}$ = wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel [per cent]

$c_{\mathrm{CO2,a}}$ = wet CO_2 concentration in the ambient air [per cent]

$q_{m\mathrm{dew}}$ = diluted sample flow in the partial flow dilution system [kg/s]

$q_{m\mathrm{ew}}$ = exhaust gas mass flow rate on wet basis [kg/s]

$q_{m\mathrm{p}}$ = sample flow of exhaust gas into partial flow dilution system [kg/s]

M_{e} = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis, it shall be converted to wet basis according to clause A.7.3.2. of Appendix A.7 or A.8.2.2. of Appendix A.8.

A.4.5. CALCULATION OF THE MOLAR MASS OF THE EXHAUST GAS

The molar mass of the exhaust gas shall be calculated according to equation (A.8-15) (see clause A.8.2.4.2.) of Appendix A.8

Alternatively, the following exhaust gas molar masses may be used:

M_{e} (diesel) = 28.9 g/mol

ANNEX 4 - APPENDIX A.5

(RESERVED)

ANNEX 4 - APPENDIX A.6

(RESERVED)

ANNEX 4 - APPENDIX A.7

MOLAR BASED EMISSION CALCULATIONS

A.7.0. SYMBOL CONVERSION

A.7.0.1. General symbols

Appendix A.7[1]	Appendix A.8	Unit	Quantity
A		m^2	Area
A_t		m^2	Venturi throat cross-sectional area
a_0	b, D_0	t.b.d.[7]	y intercept of the regression line, PDP calibration intercept
a_1	m	t.b.d.[7]	Slope of the regression line
β	r_D	m/m	Ratio of diameters
C		-	Coefficient
C_d	C_d	-	Discharge coefficient
C_f		-	Flow coefficient
d	d	m	Diameter
DR	r_d	-	Dilution ratio[2]
e	e	g/kWh	Brake specific basis
e_{gas}	e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	e_{PM}	g/kWh	Specific emission of particulates
f		Hz	Frequency
f_n	n	min^{-1}, s^{-1}	Rotational frequency (shaft)
γ		-	Ratio of specific heats
K			Correction factor
K_s	X_0	s/rev	PDP slip correction factor
k_{Dr}	k_{Dr}	-	Downward adjustment factor
	k_h		Humidity correction factor for NO_x
k_r	k_r	-	Multiplicative regeneration factor
k_{Ur}	k_{Ur}	-	Upward adjustment factor
μ	μ	kg/(m·s)	Dynamic viscosity
M	M	g/mol	Molar mass[3]
M_{gas}[4]	M_{gas}	g/mol	Molar mass of gaseous components

Appendix A.7[1]	Appendix A.8	Unit	Quantity
m	m	kg	Mass
$\dot{m}$	q_m	kg/s	Mass rate
v		m^2/s	Kinematic viscosity
N			Total number in series
n		mol	Amount of substance
$\dot{n}$		mol/s	Amount of substance rate
P	P	kW	Power
p	p	kPa	Pressure
p_{abs}	p_p	kPa	Absolute pressure
p_{H2O}	p_r	kPa	Water vapour pressure
PF	$1 – E$	per cent	Penetration fraction (E = conversion efficiency)
$\dot{V}$	q_V	m^3/s	Volume flow rate
ρ	ρ	kg/m^3	Mass density
r		-	Ratio of pressures
Ra		µm	Average surface roughness
$Re^{\#}$	Re	-	Reynolds number
$RH\%$	RH	per cent	Relative humidity
σ	σ	-	Standard deviation
S		K	Sutherland constant
T	T_a	K	Absolute temperature
T	T	°C	Temperature
T		N·m	Engine torque
t	t	s	Time
Δt	Δt	s	Time interval
V	V	m^3	Volume
$\dot{V}$	q_V	m^3/s	Volume rate
W	W	kWh	Work
W_{act}	W_{act}	kWh	Actual cycle work of the test cycle
WF	WF	-	Weighing factor

Appendix A.7[1]	Appendix A.8	Unit	Quantity
w	w	g/g	Mass fraction
X[5]	c	mol/mol, per cent vol	Amount of substance mole fraction[6] / concentration (also in µmol/mol = ppm)
$\overline{x}$		mol/mol	Flow-weighted mean concentration
y		-	Generic variable
$\overline{y}$		-	Arithmetic mean
Z		-	Compressibility factor

[1] See subscripts; e.g.: $\dot{m}_{air}$ for mass rate of dry air or $\dot{m}_{fuel}$ for fuel mass rate.

[2] Dilution ratio r_d in Appendix A.8 and DR in Appendix A.7: different symbols but same meaning and same equations. Dilution factor D in Appendix A.8 and $x_{dil/exh}$ in Appendix A.7: different symbols but same physical meaning; equation (A.7-47) shows the relationship between $x_{dil/exh}$ and DR.

[3] See clause A.7.1.1. of this section for the values to use for molar masses. In the cases of NO_x and HC, the Parts specify effective molar masses based on assumed speciation rather than actual speciation.

[4] See symbols and abbreviations for the chemical components.

[5] See specific symbols in the table of chemical balance.

[6] The mole fractions for THC and NMHC are expressed on a C1 equivalent basis.

[7] t.b.d.= to be defined.

A.7.0.2. Subscripts

Appendix A.7	Appendix A.8[1]	Quantity
abs		Absolute quantity
act	act	Actual quantity
air		Air, dry
atmos		Atmospheric
bkgnd		Background
C		Carbon
cal		Calibration quantity
CFV		Critical flow venturi
cor		Corrected quantity
dil		Dilution air
dexh		Diluted exhaust
dry		Dry quantity

Appendix A.7	**Appendix A.8[1]**	**Quantity**
exh		Raw exhaust
exp		Expected quantity
eq		Equivalent quantity
fuel		Fuel
	i	Instantaneous measurement (e.g.: 1 Hz)
i		An individual of a series
idle		Condition at idle
in		Quantity in
init		Initial quantity, typically before an emission test
max		Maximum (i.e. peak) value
meas		Measured quantity
min		Minimum value
mix		Molar mass of air
out		Quantity out
part		Partial quantity
PDP		Positive displacement pump
raw		Raw exhaust
ref		Reference quantity
rev		Revolution
sat		Saturated condition
slip		PDP slip
smpl		Sampling
span		Span quantity
SSV		Subsonic venturi
std		Standard quantity
test		Test quantity
total		Total quantity
uncor		Uncorrected quantity
vac		Vacuum quantity
weight		Calibration weight

Appendix A.7	Appendix A.8[1]	Quantity
wet		Wet quantity
zero		Zero quantity

[1] In Appendix A.8 the meaning of subscript is determined by the associated quantity; for example, the subscript "d" can indicate a dry basis as in "c_d = concentration on dry basis", dilution air as in "p_d = saturation vapour pressure of the dilution air" or "$k_{w,d}$ = dry to wet correction factor for the dilution air", dilution ratio as in "r_d". This is the reason why the column of Appendix A.8 is nearly empty.

A.7.0.3. Symbols and abbreviations for the chemical components (used also as a subscript)

Appendix A.7	Appendix A.8	Quantity
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH_4	CH_4	Methane
C_2H_6	C_2H_6	Ethane
C_3H_8	C_3H_8	Propane
CO	CO	Carbon monoxide
CO_2	CO_2	Carbon dioxide
DOP	DOP	Di-octylphthalate
H		Atomic hydrogen
H_2		Molecular hydrogen
HC	HC	Hydrocarbon
H_2O	H_2O	Water
He		Helium
N		Atomic nitrogen
N_2		Molecular nitrogen
NMHC	NMHC	Non-methane hydrocarbon
NO_x	NO_x	Oxides of nitrogen
NO	NO	Nitric oxide
NO_2	NO_2	Nitrogen dioxide
O		Atomic oxygen
PM	PM	Particulate matter

Appendix A.7	Appendix A.8	Quantity
S		Sulphur

A.7.0.4. Symbols and abbreviations for the fuel composition

Appendix A.7[1]	Appendix A.8[2]	Quantity
w_C[4]	w_C[4]	Carbon content of fuel, mass fraction [g/g] or [per cent mass]
w_H	w_H	Hydrogen content of fuel, mass fraction [g/g] or [per cent mass]
w_N	w_N	Nitrogen content of fuel, mass fraction [g/g] or [per cent mass]
w_O	w_O	Oxygen content of fuel, mass fraction [g/g] or [per cent mass]
w_S	w_S	Sulphur content of fuel, mass fraction [g/g] or [per cent mass]
α	α	Atomic hydrogen-to-carbon ratio (H/C)
β	ε	Atomic oxygen-to-carbon ratio (O/C)[3]
γ	γ	Atomic sulphur-to-carbon ratio (S/C)
δ	δ	Atomic nitrogen-to-carbon ratio (N/C)

[1] Referred to a fuel with chemical formula $CH_\alpha O_\beta S_\gamma N_\delta$
[2] Referred to a fuel with chemical formula $CH_\alpha O_\varepsilon N_\delta S_\gamma$
[3] Attention should be paid to the different meaning of symbol β in the two emissions calculation annexes: in Appendix A.8 it refers to a fuel having the chemical formula $CH_\alpha S_\gamma N_\delta O_\varepsilon$ (i.e. the formula $C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon$ where $\beta = 1$, assuming one carbon atom per molecule), while in Appendix A.7 it refers to the oxygen-to-carbon ratio with $CH_\alpha O_\beta S_\gamma N_\delta$. Then $\beta$of Appendix A.7 corresponds to ε of Appendix A.8.
[4] Mass fraction *w* accompanied by the symbol of the chemical component as a subscript.

A.7.0.5. Symbols for chemical balance used in Appendix A.7

$x_{dil/exh}$ = Amount of dilution gas or excess air per mole of exhaust

x_{H2Oexh} = Amount of water in exhaust per mole of exhaust

$x_{Ccombdry}$ = Amount of carbon from fuel in the exhaust per mole of dry exhaust

$x_{H2Oexhdry}$ = Amount of water in exhaust per dry mole of dry exhaust

$x_{prod/intdry}$ = Amount of dry stoichiometric products per dry mole of intake air

$x_{dil/exhdry}$ = Amount of dilution gas and/or excess air per mole of dry exhaust

$x_{int/exhdry}$ = Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust

$x_{raw/exhdry}$ = Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust

$x_{O2intdry}$ = Amount of intake air O_2 per mole of dry intake air

$x_{CO2intdry}$ = Amount of intake air CO_2 per mole of dry intake air

$x_{H2Ointdry}$ = Amount of intake air H_2O per mole of dry intake air

x_{CO2int} = Amount of intake air CO_2 per mole of intake air

x_{CO2dil} = Amount of dilution gas CO_2 per mole of dilution gas

$x_{CO2dildry}$ = Amount of dilution gas CO_2 per mole of dry dilution gas

$x_{H2Odildry}$ = Amount of dilution gas H_2O per mole of dry dilution gas

x_{H2Odil} = Amount of dilution gas H_2O per mole of dilution gas

$x_{[emission]meas}$ = Amount of measured emission in the sample at the respective gas analyser

$x_{[emission]dry}$ = Amount of emission per dry mole of dry sample

$x_{H2O[emission]meas}$ = Amount of water in sample at emission-detection location

x_{H2Oint} = Amount of water in the intake air, based on a humidity measurement of intake air

A.7.1. BASIC PARAMETERS AND RELATIONSHIPS

A.7.1.1. Dry air and chemical species

This Appendix uses the following values for dry air composition:

$x_{O2airdry} = 0.209445\,\text{mol/mol}$

$x_{CO2airdry} = 0.000375\ \text{mol/mol}$

This Appendix uses the following molar masses or effective molar masses of chemical species:

M_{air} = 28.96559 g/mol (dry air)

M_{Ar} = 39.948 g/mol (argon)

M_{C} = 12.0107 g/mol (carbon)

M_{CO} = 28.0101 g/mol (carbon monoxide)

M_{CO2} = 44.0095 g/mol (carbon dioxide)

M_{H} = 1.00794 g/mol (atomic hydrogen)

M_{H2} = 2.01588 g/mol (molecular hydrogen)

M_{H2O} = 18.01528 g/mol (water)

M_{He} = 4.002602 g/mol (helium)

M_{N} = 14.0067 g/mol (atomic nitrogen)

M_{N2} = 28.0134 g/mol (molecular nitrogen)

M_{NMHC} = 13.875389 g/mol (non-methane hydrocarbon[(a)])

M_{NOx} = 46.0055 g/mol (oxides of nitrogen[(b)])

M_{O} = 15.9994 g/mol (atomic oxygen)

M_{O2} = 31.9988 g/mol (molecular oxygen)

M_{C3H8} = 44.09562 g/mol (propane)

M_S = 32.065 g/mol (sulphur)

M_{THC} = 13.875389 g/mol (total hydrocarbon[(a)])

(a) The effective molar masses of THC and NMHC are defined by an atomic hydrogen-to-carbon ratio, α, of 1.85;

(b) The effective molar mass of NO_x is defined by the molar mass of nitrogen dioxide, NO_2.

This Appendix uses the following molar gas constant R for ideal gases:

$$R = 8.314472\,\mathrm{J}/(\mathrm{mol}\cdot\mathrm{K})$$

This Appendix uses the following ratios of specific heats γ $[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]/[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]$ for dilution air and diluted exhaust:

γ_{air} = 1.399 (ratio of specific heats for intake air or dilution air)

γ_{dil} = 1.399 (ratio of specific heats for diluted exhaust)

γ_{dil} = 1.385 (ratio of specific heats for raw exhaust)

A.7.1.2. Wet air

This section describes how to determine the amount of water in an ideal gas:

A.7.1.2.1. Vapour pressure of water

The vapour pressure of water p_{H2O} [kPa] for a given saturation temperature condition, T_{sat} [K], shall be calculated as follows:

(a) For humidity measurements made at ambient temperatures from 0 to 100 °C or for humidity measurements made over super-cooled water at ambient temperatures from –50 to 0 °C:

$$\log_{10}(p_{H2O}) = 10.79574\cdot\left(1-\frac{273.16}{T_{sat}}\right) - 5.02800\cdot\log_{10}\left(\frac{T_{sat}}{273.16}\right) +$$
$$+1.50475\cdot10^{-4}\cdot\left(1-10^{-8.2969\cdot\left(\frac{T_{sat}}{273.16}-1\right)}\right) + 0.42873\cdot10^{-3}\cdot\left(10^{4.76955\cdot\left(1-\frac{273.16}{T_{sat}}\right)}-1\right) - 0.2138602 \quad \text{(A.7-1)}$$

Where:

p_{H2O} = vapour pressure of water at saturation temperature condition [kPa]

T_{sat} = saturation temperature of water at measured condition [K]

(b) For humidity measurements made over ice at ambient temperatures from (-100 to 0) °C:

$$\log_{10}(p_{sat}) = -9.096853\cdot\left(\frac{273.16}{T_{sat}}-1\right) - 3.566506\cdot\log_{10}\left(\frac{273.16}{T_{sat}}\right) + 0.876812\cdot\left(1-\frac{T_{sat}}{273.16}\right) - 0.2138602 \quad \text{(A.7-2)}$$

Where:

T_{sat} = saturation temperature of water at measured condition [K]

A.7.1.2.2. Dew point

If humidity is measured as a dew point, the amount of water in an ideal gas x_{H2O} [mol/mol] shall be obtained as follows:

$$x_{H2O} = \frac{p_{H2O}}{p_{abs}} \quad \text{(A.7-3)}$$

Where:

x_{H2O} = amount of water in an ideal gas [mol/mol]

p_{H2O} = vapour pressure of water at the measured dew point, $T_{sat}=T_{dew}$ [kPa]

p_{abs} = wet static absolute pressure at the location of dew point measurement [kPa]

A.7.1.2.3. Relative humidity

If humidity is measured as a relative humidity *RH%*, the amount of water of an ideal gas x_{H2O} [mol/mol] is calculated as follows:

$$x_{H2O} = \frac{RH\%}{100} \cdot \frac{p_{H2O}}{p_{abs}} \quad \text{(A.7-4)}$$

Where:

RH% = relative humidity [per cent]

p_{H2O} = water vapour pressure at 100 per cent relative humidity at the location of relative humidity measurement, $T_{sat}=T_{amb}$ [kPa]

p_{abs} = wet static absolute pressure at the location of relative humidity measurement [kPa]

A.7.1.3. Fuel properties

The general chemical formula of fuel is $CH_\alpha O_\beta S_\gamma N_\delta$ with α atomic hydrogen-to-carbon ratio (H/C), *β*atomic oxygen-to-carbon ratio (O/C), *γ*atomic sulphur-to-carbon ratio (S/C) and *δ* atomic nitrogen-to-carbon ratio (N/C). Based on this formula the carbon mass fraction of fuel w_C can be calculated. In case of diesel fuel the simple formula CHαOβ may be used. Default values for fuel composition may be used as follows:

Table A.7.1
Default Values of Atomic Hydrogen-to-Carbon Ratio, α, Atomic Oxygen-to-Carbon Ratio, β, and Carbon Mass Fraction of Fuel, w_C for Diesel Fuels

Fuel	Atomic hydrogen and oxygen-to-carbon ratios $CH_\alpha O_\beta$	Carbon mass concentration, w_C [g/g]
Diesel	$CH_{1.85}O_0$	0.866

A.7.1.4. Total HC and non-methane HC concentration

A.7.1.4.1. THC determination and THC/CH_4 initial contamination corrections

(a) If THC emissions are required to be determined, $x_{THC[THC\text{-}FID]}$ shall be calculated by using the initial THC contamination concentration $x_{THC[THC\text{-}FID]init}$ from clause 7.3.1.2. of this Annex as follows:

$$x_{THC[THC\text{-}FID]cor} = x_{THC[THC\text{-}FID]uncorr} - x_{THC[THC\text{-}FID]init} \quad \text{(A.7-5)}$$

Where:

$x_{THC[THC\text{-}FID]cor}$ = THC concentration corrected for contamination [mol/mol]

$x_{THC[THC\text{-}FID]uncorr}$ = THC uncorrected concentration [mol/mol]

$x_{THC[THC\text{-}FID]init}$ = initial THC contamination concentration [mol/mol]

(b) For the NMHC determination described in clause A.7.1.4.2., $x_{THC[THC\text{-}FID]}$ shall be corrected for initial HC contamination using equation (A.7-5). The initial contamination of the CH_4 sample train may be corrected using equation (A.7-5), substituting in CH_4 concentrations for THC.

A.7.1.4.2. NMHC determination

To determine NMHC concentration, x_{NMHC}, one of the following shall be used:

(a) If CH_4 is not measured, NMHC concentrations may be determined as follows:

The background corrected mass of NMHC shall be compared to background corrected mass of THC. If the background corrected mass of NMHC is greater than 0.98 times the background corrected mass of THC, the background corrected mass of NMHC shall be taken as 0.98 times the background corrected mass of THC. If the NMHC calculations are omitted, the background corrected mass of NMHC shall be taken as 0.98 times the background corrected mass of THC;

(b) For non-methane cutters, x_{NMHC} shall be calculated using the non-methane cutter's penetration fractions (*PF*) of CH_4 and C_2H_6 from clause 8.1.10.3. of this Annex, and using the HC contamination and dry-to-wet corrected THC concentration $x_{THC[THC\text{-}FID]cor}$ as determined in sub-clause (a) of clause of A.7.1.4.1.:

(i) The following equation for penetration fractions determined using an NMC configuration as outlined in clause 8.1.10.3.4.1. shall be used:

$$x_{NMHC} = \frac{x_{THC[THC\text{-}FID]cor} - x_{THC[NMC\text{-}FID]} \cdot RF_{CH4[THC\text{-}FID]}}{1 - RFPF_{C2H6[NMC\text{-}FID]} \cdot RF_{CH4[THC\text{-}FID]}} \quad \text{(A.7-6)}$$

Where:

x_{NMHC} = concentration of NMHC

$x_{THC[THC\text{-}FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC

$x_{THC[NMC\text{-}FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC

$RF_{CH4[THC\text{-}FID]}$ = response factor of THC FID to CH4, according to clause 8.1.10.1.4.

$RFPF_{C2H6[NMC\text{-}FID]}$ = non-methane cutter combined ethane response factor and penetration fraction, according to clause 8.1.10.3.4.1.

(ii) For penetration fractions determined using an NMC configuration as outlined in clause 8.1.10.3.4.2., the following equation shall be used:

$$x_{NMHC} = \frac{x_{THC[THC\text{-}FID]cor} \cdot PF_{CH4[NMC\text{-}FID]} - x_{THC[NMC\text{-}FID]}}{PF_{CH4[NMC\text{-}FID]} - PF_{C2H6[NMC\text{-}FID]}} \quad \text{(A.7-7)}$$

Where:

x_{NMHC} = concentration of NMHC

$x_{THC[THC\text{-}FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC

$PF_{CH4[NMC\text{-}FID]}$ = non-methane cutter CH_4 penetration fraction, according to clause 8.1.10.3.4.2.

$x_{THC[NMC\text{-}FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC

$PF_{C2H6[NMC\text{-}FID]}$ = non-methane cutter ethane penetration fraction, according to clause 8.1.10.3.4.2.

(iii) For penetration fractions determined using an NMC configuration as outlined in clause 8.1.10.3.4.3., the following equation shall be used:

$$x_{NMHC} = \frac{x_{THC[THC\text{-}FID]cor} \cdot PF_{CH4[NMC\text{-}FID]} - x_{THC[NMC\text{-}FID]} \cdot RF_{CH4[THC\text{-}FID]}}{PF_{CH4[NMC\text{-}FID]} - RFPF_{C2H6[NMC\text{-}FID]} \cdot RF_{CH4[THC\text{-}FID]}}$$

(A.7-8)

Where:

x_{NMHC} = concentration of NMHC

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC

$PF_{CH4[NMC-FID]}$ = non-methane cutter CH_4 penetration fraction, according to clause 8.1.10.3.4.3.

$x_{THC[NMC-FID]}$ = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC

$RFPF_{C2H6[NMC-FID]}$ = non-methane cutter CH_4 combined ethane response factor and penetration fraction, according to clause 8.1.10.3.4.3.

$RF_{CH4[THC-FID]}$ = response factor of THC FID to CH_4, according to clause 8.1.10.1.4.

(c) For a gas chromatograph, x_{NMHC} shall be calculated using the THC analyser's response factor (RF) for CH_4, from clause 8.1.10.1.4., and the HC contamination and dry-to-wet corrected initial THC concentration $x_{THC[THC-FID]cor}$ as determined in clause (a) above as follows:

$$x_{NMHC} = x_{THC[THC-FID]cor} - RF_{CH4[THC-FID]} \cdot x_{CH4} \quad \text{(A.7-9)}$$

Where:

x_{NMHC} = concentration of NMHC

$x_{THC[THC-FID]cor}$ = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID

x_{CH4} = concentration of CH_4, HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID

$RF_{CH4[THC-FID]}$ = response factor of THC-FID to CH_4

A.7.1.4.3. Approximation of NMHC from THC

NMHC (non-methane hydrocarbon) emissions can be approximated as 98 percent of THC (total hydrocarbon).

A.7.1.5. Flow-weighted mean concentration

In some clauses of this Annex, it may be necessary to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust molar flow rate, divided by the sum of the recorded flow rate values. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. A certain flow-weighted mean concentration of an emission at its standard might be already expected based on previous testing with similar engines or testing with similar equipment and instruments.

A.7.2. CHEMICAL BALANCES OF FUEL, INTAKE AIR, AND EXHAUST

A.7.2.1. General

Chemical balances of fuel, intake air and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. With one flow rate of either fuel, intake air or exhaust, chemical balances may be used to determine the flows of the other two. For example, chemical balances along with either intake air or fuel flow to determine raw exhaust flow may be used.

A.7.2.2. Procedures that require chemical balances

Chemical balances are required to determine the following:

(a) The amount of water in a raw or diluted exhaust flow, x_{H2Oexh}, when the amount of water to correct for the amount of water removed by a sampling system is not measured;

(b) The flow-weighted mean fraction of dilution air in diluted exhaust, $x_{dil/exh,}$ when dilution air flow is not measured to correct for background emissions. It has to be noted that if chemical balances are used for this purpose, the exhaust is assumed to be stoichiometric, even if it is not.

A.7.2.3. Chemical balance procedure

The calculations for a chemical balance involve a system of equations that require iteration. The initial values of up to three quantities shall be guessed: the amount of water in the measured flow, x_{H2Oexh}, fraction of dilution air in diluted exhaust (or excess air in the raw exhaust), $x_{dil/exh}$, and the amount of products on a C1 basis per dry mole of dry measured flow, $x_{Ccombdry}$. Time-weighted mean values of combustion air humidity and dilution air humidity in the chemical balance may be used; as long as combustion air and dilution air humidity remain within tolerances of ± 0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x, and amount of water x_{H2Oexh}, it shall be determined their completely dry concentrations, x_{dry} and $x_{H2Oexhdry}$. It shall also be used fuel's atomic hydrogen-to-carbon ratio, α, oxygen-to-carbon ratio, β, and carbon mass fraction of fuel, w_C. For the test fuel, α, and β, or the default values in Table 7.1 may be used.

Use the following steps to complete a chemical balance:

(a) Measured concentrations such as, $x_{CO2meas}$, x_{NOmeas}, and x_{H2Oint}, shall be converted to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{H2OxCO2meas}$, $x_{H2OxNOmeas}$, and x_{H2Oint}. If the amount of water present during a "wet" measurement is the same as the unknown amount of water in the exhaust flow, x_{H2Oexh}, it has to be iteratively solved for that value in the system of equations. If only total NO_x are measured and not NO and NO_2 separately, good engineering judgement shall be used to estimate a split in the total NO_x concentration between NO and NO_2 for the chemical balances. The molar concentration of NO_x, x_{NOx}, may be assumed to be 75 per cent NO and 25 per cent NO_2. For NO_2 storage aftertreatment systems, x_{NOx} may be assumed to be 25 per cent NO and 75 per cent NO_2. For calculating the mass of NO_x emissions, the molar mass of NO_2 for the effective molar mass of all NO_x species, regardless of the actual NO_2 fraction of NO_x, shall be used;

(b) Equations (A.7-10 to A.7-26) in clause (d) of this clause A.7.2.3. have to be entered into a computer program to iteratively solve for x_{H2Oexh}, $x_{Ccombdry}$ and $x_{dil/exh}$. Good engineering judgment shall be used to guess initial values for x_{H2Oexh}, $x_{Ccombdry}$, and $x_{dil/exh}$. Guessing an initial amount of water that is about twice the amount of water in the intake or dilution air is recommended. Guessing an initial value of $x_{Ccombdry}$ as the sum of the measured CO_2, CO, and THC values is recommended. Guessing an initial x_{dil} between 0.75 and 0.95 ($0.75 < x_{dil} < 0.95$), such as 0.8 is also recommended. Values in the system of equations shall be iterated until the most recently updated guesses are all within ±1 per cent of their respective most recently calculated values;

(c) The following symbols and subscripts are used in the equation system of sub- clause (c) of this clausewhere *x* unit is mol/mol:

Symbol	Description
$x_{dil/exh}$	Amount of dilution gas or excess air per mole of exhaust
x_{H2Oexh}	Amount of H_2O in exhaust per mole of exhaust
$x_{Ccombdry}$	Amount of carbon from fuel in the exhaust per mole of dry exhaust
$x_{H2Oexhdry}$	Amount of water in exhaust per dry mole of dry exhaust
$x_{prod/intdry}$	Amount of dry stoichiometric products per dry mole of intake air
$x_{dil/exhdry}$	Amount of dilution gas and/or excess air per mole of dry exhaust
$x_{int/exhdry}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust
$x_{raw/exhdry}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust
$x_{O2intdry}$	Amount of intake air O_2 per mole of dry intake air; $x_{O2intdry}$ = 0.209445 mol/mol may be assumed

Symbol	Description
$x_{CO2intdry}$	Amount of intake air CO_2 per mole of dry intake air. $x_{CO2intdry}$ = 375 µmol/mol may be used, but measuring the actual concentration in the intake air is recommended
$x_{H2Ointdry}$	Amount of the intake air H_2O per mole of dry intake air
x_{CO2int}	Amount of intake air CO_2 per mole of intake air
x_{CO2dil}	Amount of dilution gas CO_2 per mole of dilution gas
$x_{CO2dildry}$	Amount of dilution gas CO_2 per mole of dry dilution gas. If air is used as diluent, $x_{CO2dildry}$ = 375 µmol/mol may be used, but measuring the actual concentration in the intake air is recommended
$x_{H2Odildry}$	Amount of dilution gas H_2O per mole of dry dilution gas
x_{H2Odil}	Amount of dilution gas H_2O per mole of dilution gas
$x_{[emission]meas}$	Amount of measured emission in the sample at the respective gas analyser
$x_{[emission]dry}$	Amount of emission per dry mole of dry sample
$x_{H2O[emission]meas}$	Amount of water in sample at emission-detection location. These values shall be measured or estimated according to clause 9.3.2.3.1. of this Annex.
x_{H2Oint}	Amount of water in the intake air, based on a humidity measurement of intake air
α	Atomic hydrogen-to-carbon ratio of the mixture of fuel(s) ($CH_\alpha O_\beta$) being combusted, weighted by molar consumption
β	Atomic oxygen-to-carbon ratio of the mixture of fuel(s) ($CH_\alpha O_\beta$) being combusted, weighted by molar consumption

(d) The following equations shall be used to iteratively solve for $x_{dil/exh}$, x_{H2Oexh} and $x_{Ccombdry}$:

$$x_{dil/exh} = 1 - \frac{x_{raw/exhdry}}{1 + x_{H2Oexhdry}} \quad \text{(A.7-10)}$$

$$x_{H2Oexh} = \frac{x_{H2Oexhdry}}{1 + x_{H2Oexhdry}} \quad \text{(A.7-11)}$$

$$x_{Ccombdry} = x_{CO2dry} + x_{COdry} + x_{THCdry} - x_{CO2dil} \cdot x_{dil/exhdry} - x_{CO2int} \cdot x_{int/exhdry} \quad \text{(A.7-12)}$$

$$x_{\mathrm{H2Oexhdry}} = \frac{\alpha}{2}\left(x_{\mathrm{Ccombdry}} - x_{\mathrm{THCdry}}\right) + x_{\mathrm{H2Odil}} \cdot x_{\mathrm{dil/exhdry}} + x_{\mathrm{H2Oint}} \cdot x_{\mathrm{int/exhdry}} \quad \text{(A.7-13)}$$

$$x_{\mathrm{dil/exhdry}} = \frac{x_{\mathrm{dil/exh}}}{1 - x_{\mathrm{H2Oexh}}} \quad \text{(A.7-14)}$$

$$x_{\mathrm{int/exhdry}} = \frac{1}{2 \cdot x_{\mathrm{O2int}}}\left[\left(\frac{\alpha}{2} - \beta + 2\right)\left(x_{\mathrm{Ccombdry}} - x_{\mathrm{THCdry}}\right) - \left(x_{\mathrm{COdry}} - x_{\mathrm{NOdry}} - 2x_{\mathrm{NO2dry}}\right)\right] \quad \text{(A.7-15)}$$

$$x_{\mathrm{raw/exhdry}} = \frac{1}{2}\left[\left(\frac{\alpha}{2} + \beta\right)\left(x_{\mathrm{Ccombdry}} - x_{\mathrm{THCdry}}\right) + \left(2x_{\mathrm{THCdry}} + x_{\mathrm{COdry}} - x_{\mathrm{NO2dry}}\right)\right] + x_{\mathrm{int/exhdry}} \quad \text{(A.7-16)}$$

$$x_{\mathrm{O2int}} = \frac{0.209820 - x_{\mathrm{CO2intdry}}}{1 + x_{\mathrm{H2Ointdry}}} \quad \text{(A.7-17)}$$

$$x_{\mathrm{CO2int}} = \frac{x_{\mathrm{CO2intdry}}}{1 + x_{\mathrm{H2Ointdry}}} \quad \text{(A.7-18)}$$

$$x_{\mathrm{H2Ointdry}} = \frac{x_{\mathrm{H2Oint}}}{1 - x_{\mathrm{H2Oint}}} \quad \text{(A.7-19)}$$

$$x_{\mathrm{CO2dil}} = \frac{x_{\mathrm{CO2dildry}}}{1 + x_{\mathrm{H2Odildry}}} \quad \text{(A.7-20)}$$

$$x_{\mathrm{H2Odildry}} = \frac{x_{\mathrm{H2Odil}}}{1 - x_{\mathrm{H2Odil}}} \quad \text{(A.7-21)}$$

$$x_{\mathrm{COdry}} = \frac{x_{\mathrm{COmeas}}}{1 - x_{\mathrm{H2OCOmeas}}} \quad \text{(A.7-22)}$$

$$x_{\mathrm{CO2dry}} = \frac{x_{\mathrm{CO2meas}}}{1 - x_{\mathrm{H2OCO2meas}}} \quad \text{(A.7-23)}$$

$$x_{\mathrm{NOdry}} = \frac{x_{\mathrm{NOmeas}}}{1 - x_{\mathrm{H2ONOmeas}}} \quad \text{(A.7-24)}$$

$$x_{\mathrm{NO2dry}} = \frac{x_{\mathrm{NO2meas}}}{1 - x_{\mathrm{H2ONO2meas}}} \quad \text{(A.7-25)}$$

$$x_{\mathrm{THCdry}} = \frac{x_{\mathrm{THCmeas}}}{1 - x_{\mathrm{H2OTHCmeas}}} \quad \text{(A.7-26)}$$

At the end of the chemical balance, the molar flow rate $\dot{n}_{exh}$ is calculated as specified in clauses A.7.3.3. and A.7.4.3.

A.7.2.4. NO_x correction for humidity

All the NO_x concentrations, including dilution air background concentrations, shall be corrected for intake-air humidity using the following equation:

$$x_{NOxcor} = x_{NOxuncor} \cdot \left(9.953 \cdot x_{H2O} + 0.832\right) \quad \text{(A.7-27)}$$

Where:

$x_{NOxuncor}$ = uncorrected NO_x molar concentration in the exhaust gas [µmol/mol]

x_{H2O} = amount of water in the intake air [mol/mol]

A.7.3. RAW GASEOUS EMISSIONS

A.7.3.1. Mass of gaseous emissions

To calculate the total mass per test of gaseous emission m_{gas} [g/test], its molar concentration shall be multiplied by its respective molar flow and by exhaust gas molar mass; then integration over test cycle shall be performed:

$$m_{gas} = M_{gas} \cdot \int \dot{n}_{exh} \cdot x_{gas} \cdot \mathrm{d}t \quad \text{(A.7-28)}$$

Where:

M_{gas} = molar mass of the generic gaseous emission [g/mol]

$\dot{n}_{exh}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gas} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

t = time [s]

Since equation (A.7-28) has to be solved by numerical integration, it is transformed in:

$$m_{gas} = M_{gas} \cdot \int \dot{n}_{exh} \cdot x_{gas} \cdot \mathrm{d}t \quad \Rightarrow m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi} \quad \text{(A.7-29)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gasi} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

General equation may be modified according to which measurement system is used, batch or continuous sampling, and if a varying rather than a constant flow rate is sampled.

(a) For continuous sampling, in the general case of varying flow rate, the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of the following equation:

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi} \quad \text{(A.7-30)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gasi} = instantaneous gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(b) Still for continuous sampling but in the particular case of constant flow rate the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of the following equation:

$$m_{gas} = M_{gas} \cdot \dot{n}_{exh} \cdot \bar{x}_{gas} \cdot \Delta t \quad \text{(A.7-31)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exh}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(c) For the batch sampling, regardless the flow rate is varying or constant, the equation (A.7-30) can be simplified as follows:

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \bar{x}_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \quad \text{(A.7-32)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

F = data sampling rate [Hz]

N = number of measurements [-]

A.7.3.2. Dry-to-wet concentration conversion

Parameters of this clause are obtained from the results of the chemical balance calculated in clause A.7.2. The following relation exists between gas molar concentrations in the measured flow x_{gasdry} and x_{gas} [mol/mol] expressed on a dry and wet basis respectively:

$$x_{gasdry} = \frac{x_{gas}}{1 - x_{H2O}} \quad \text{(A.7-33)}$$

$$x_{gas} = \frac{x_{gasdry}}{1 + x_{H2Odry}} \quad \text{(A.7-34)}$$

Where:

x_{H2O} = molar fraction of water in the measured flow on a wet basis [mol/mol]

x_{H2Odry} = molar fraction of water in the measured flow on a dry basis [mol/mol]

For gaseous emissions a removed water correction shall be performed for the generic concentration x [mol/mol] as follows:

$$x = x_{[emission]meas}\left[\frac{(1 - x_{H2Oexh})}{1 - x_{H2O[emission]meas}}\right] \quad \text{(A.7-35)}$$

Where:

$x_{[emission]meas}$ = molar fraction of emission in the measured flow at measurement location [mol/mol]

$x_{H2O[emission]meas}$ = amount of water in the measured flow at the concentration measurement [mol/mol]

x_{H2Oexh} = amount of water at the flow-meter [mol/mol]

A.7.3.3. Exhaust gas molar flow rate

The flow rate of the raw exhaust gases can be directly measured or can be calculated based on the chemical balance of clause A.7.2.3. Calculation of raw exhaust molar flow rate is performed from measured intake air molar flow rate or fuel mass flow rate. The raw exhaust molar flow rate can be calculated from the sampled emissions, $\dot{n}_{exh}$, based on the measured intake air molar flow rate, $\dot{n}_{int}$, or the measured fuel mass flow rate, $\dot{m}_{fuel}$, and the values calculated using the chemical balance in clause A.7.2.3. It shall be solved for the chemical balance in clause A.7.2.3. at the same frequency that $\dot{n}_{int}$ or $\dot{m}_{fuel}$ is updated and recorded.

(a) Crankcase flow rate. The raw exhaust flow can be calculated based on $\dot{n}_{int}$ or $\dot{m}_{fuel}$ only if at least one of the following is true about crankcase emission flow rate:

(i) The test engine has a production emission-control system with a closed crankcase that routes crankcase flow back to the intake air, downstream of intake air flow-meter;

(ii) During emission testing open crankcase flow are routed to the exhaust according to clause 6.10;

(iii) Open crankcase emissions and flow are measured and added brake-specific emission calculations;

(iv) Using emission data or an engineering analysis, it can be demonstrated that neglecting the flow rate of open crankcase emissions does not adversely affect compliance with the applicable standards;

(b) Molar flow rate calculation based on intake air.

Based on $\dot{n}_{int}$, exhaust gas molar flow rate $\dot{n}_{exh}$ [mol/s] shall be calculated as follows:

$$\dot{n}_{exh} = \frac{\dot{n}_{int}}{\left[1 + \frac{\left(x_{int/exhdry} - x_{raw/exhdry}\right)}{\left(1 + x_{H2Oexhdry}\right)}\right]} \quad \text{(A.7-36)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured [mol/s]

$\dot{n}_{int}$ = intake air molar flow rate including humidity in intake air [mol/s]

$x_{int/exhdry}$ = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust [mol/mol]

$x_{raw/exhdry}$ = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust [mol/mol]

$x_{H2Oexhdry}$ = amount of water in exhaust per mole of dry exhaust [mol/mol]

(c) Molar flow rate calculation based on fuel mass flow rate

Based on $\dot{m}_{fuel}$, $\dot{n}_{exh}$ [mol/s] shall be calculated as follows:

$$\dot{n}_{exh} = \frac{\dot{m}_{fuel} \cdot w_C \cdot \left(1 + x_{H2Oexhdry}\right)}{M_C \cdot x_{Ccombdry}} \quad \text{(A.7-37)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured

$\dot{m}_{fuel}$ = fuel flow rate including humidity in intake air [g/s]

w_C = carbon mass fraction for the given fuel [g/g]

$x_{H2Oexhdry}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_C = molecular mass of carbon 12.0107 g/mol

$x_{Ccombdry}$ = amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]

A.7.4. DILUTED GASEOUS EMISSIONS

A.7.4.1. Emission mass calculation and background correction

Equations for the calculation of gaseous emissions mass m_{gas} [g/test] as a function of molar emissions flow rates are as follows:

(a) Continuous sampling, varying flow rate

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi} \quad \text{(see A.7-29)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

m_{gasi} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

Continuous sampling, constant flow rate

$$m_{gas} = M_{gas} \cdot \dot{n}_{exh} \cdot \overline{x}_{gas} \cdot \Delta t \quad \text{(see A.7-31)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exh}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(b) Batch sampling, regardless varying flow or constant rate is the following equation shall be used:

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \overline{x}_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \quad \text{(see A.7-32)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(c) In case of diluted exhaust gases calculated values for mass of the pollutants shall be corrected by subtracting the mass of background emissions, due to dilution air:

(i) Firstly, the molar flow rate of dilution air $\dot{n}_{airdil}$ [mol/s] shall be determined over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust flow and the flow-weighted mean fraction of dilution air in diluted exhaust, $\bar{x}_{dil/exh}$;

(ii) The total flow of dilution air n_{airdil} [mol] shall be multiplied by the mean concentration of background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of n_{airdil} and the mean concentration of a background emission is the total amount of a background emission;

(iii) If the result is a molar quantity, it shall be converted to a mass of the background emissionm_{bkgnd} [g] by multiplying it by emission molar mass, M_{gas} [g/mol];

(iv) Total background mass shall be subtracted from total mass to correct for background emissions;

(v) The total flow of dilution air may be determined by a direct flow measurement. In this case, the total mass of background shall be calculated, using the dilution air flow, n_{airdil}. The background mass shall be subtracted from the total mass. The result shall be used in brake-specific emission calculations;

(vi) The total flow of dilution air may be determined from the total flow of diluted exhaust and a chemical balance of the fuel, intake air, and exhaust as described in clause A.7.2. In this case, the total mass of background shall be calculated, using the total flow of diluted exhaust, n_{dexh}. Then this result shall be multiplied by the flow-weighted mean fraction of dilution air in diluted exhaust, $\bar{x}_{dil/exh}$.

Considering the two cases (v) and (vi), the following equations shall be used:

$$m_{bkgnd} = M_{gas} \cdot x_{gasdil} \cdot n_{airdil} \quad \text{or} \quad m_{bkgnd} = M_{gas} \cdot \bar{x}_{dil/exh} \cdot \bar{x}_{bkgnd} \cdot n_{dexh} \quad \text{(A.7-38)}$$

$$m_{gascor} = m_{gas} - m_{bkgnd} \quad \text{(A.7-39)}$$

Where:

m_{gas} = total mass of the gaseous emission [g]

m_{bkgnd} = total background masses [g]

m_{gascor} = mass of gas corrected for background emissions [g]

M_{gas} = molecular mass of generic gaseous emission [g/mol]

x_{gasdil} = gaseous emission concentration in dilution air [mol/mol]

n_{airdil} = dilution air molar flow [mol]

$\overline{x}_{dil/exh}$ = flow-weighted mean fraction of dilution air in diluted exhaust [mol/mol]

$\overline{x}_{bkgnd}$ = gas fraction of background [mol/mol]

n_{dexh} = total flow of diluted exhaust [mol]

A.7.4.2. Dry-to wet concentration conversion

The same relations for raw gases (clause A.7.3.2.) shall be used for dry-to-wet conversion on diluted samples. For dilution air a humidity measurement shall be performed with the aim to calculate its water vapour fraction $x_{H2Odildry}$ [mol/mol]:

$$x_{H2Odildry} = \frac{x_{H2Odil}}{1 - x_{H2Odil}} \quad \text{(see A.7-21)}$$

Where:

x_{H2Odil} = water molar fraction in the dilution air flow [mol/mol]

A.7.4.3. Exhaust molar flow rate

(a) Calculation via chemical balance;

The molar flow rate $\dot{n}_{exh}$ [mol/s] can be calculated based on fuel mass flow rate $\dot{m}_{fuel}$:

$$\dot{n}_{exh} = \frac{\dot{m}_{fuel} \cdot w_C \cdot \left(1 + x_{H2Oexhdry}\right)}{M_C \cdot x_{Ccombdry}} \quad \text{(see A.7-37)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured

$\dot{m}_{fuel}$ = fuel flow rate including humidity in intake air [g/s]

w_C = carbon mass fraction for the given fuel [g/g]

$x_{H2Oexhdry}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_C = molecular mass of carbon 12.0107 g/mol

$x_{Ccombdry}$ = amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]

(b) Measurement

The exhaust gas molar flow rate may be measured by means of three systems:

(i) PDP molar flow rate. Based upon the speed at which the Positive Displacement Pump (PDP) operates for a test interval, the corresponding slope a_1, and intercept, a_0 [-], as calculated with the calibration procedure of Appendix A.7.1 to this Annex, shall be used to calculate molar flow rate $\dot{n}$ [mol/s] as follows:

$$\dot{n} = f_{\text{n,PDP}} \cdot \frac{p_{\text{in}} \cdot V_{\text{rev}}}{R \cdot T_{\text{in}}} \quad \text{(A.7-40)}$$

Where:

$$V_{\text{rev}} = \frac{a_1}{f_{\text{n,PDP}}} \cdot \sqrt{\frac{p_{\text{out}} - p_{\text{in}}}{p_{\text{in}}}} + a_0 \quad \text{(A.7-41)}$$

Where:

a_1 = calibration coefficient [m^3/s]

a_0 = calibration coefficient [m^3/rev]

p_{in}, p_{out} = inlet/outlet pressure [Pa]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

V_{rev} = PDP pumped volume [m^3/rev]

$f_{\text{n.,PDP}}$ = PDP speed [rev/s]

(ii) SSV molar flow rate. Based on the C_{d} versus $R_{\text{e}}^{\#}$ equation determined according to Appendix A.7.1 of this Annex, the Sub-Sonic Venturi (SSV) molar flow rate during an emission test $\dot{n}$ [mol/s] shall be calculated as follows:

$$\dot{n} = C_{\text{d}} \cdot C_{\text{f}} \cdot \frac{A_{\text{t}} \cdot p_{\text{in}}}{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}} \quad \text{(A.7-42)}$$

Where:

p_{in} = inlet pressure [Pa]

A_{t} = Venturi throat cross-sectional area [m^2]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

Z = compressibility factor

M_{mix} = molar mass of diluted exhaust [kg/mol]

C_{d} = discharge coefficient of the SSV [-]

C_{f} = flow coefficient of the SSV [-]

(iii) CFV molar flow rate. To calculate the molar flow rate through one venturi or one combination of venturis, its respective mean C_{d} and

other constants, determined according to the Appendix A.7.1 of this Annex, shall be used. The calculation of its molar flow rate $\dot{n}$ [mol/s] during an emission test follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{(A.7-43)}$$

Where:

p_{in}	=	inlet pressure [Pa]
A_t	=	Venturi throat cross-sectional area [m^2]
R	=	molar gas constant [J/(mol K)]
T_{in}	=	inlet temperature [K]
Z	=	compressibility factor
M_{mix}	=	molar mass of diluted exhaust [kg/mol]
C_d	=	discharge coefficient of the CFV [-]
C_f	=	flow coefficient of the CFV [-]

A.7.4.4. Determination of particulates

A.7.4.4.1. Sampling

(a) Sampling from a varying flow rate:

If a batch sample from a changing exhaust flow rate is collected, a sample proportional to the changing exhaust flow rate shall be extracted. The flow rate shall be integrated over a test interval to determine the total flow. The mean PM concentration $\overline{M}_{PM}$ (which is already in units of mass per mole of sample) shall be multiplied by the total flow to obtain the total mass of PM m_{PM} [g]:

$$m_{PM} = \bar{M}_{PM} \cdot \sum_{i=1}^{N} \left(\dot{n}_i \cdot \Delta t_i \right) \quad \text{(A.7-44)}$$

Where:

$\dot{n}_i$	=	instantaneous exhaust molar flow rate [mol/s]
$\bar{M}_{PM}$	=	mean PM concentration [g/mol]
Δt_i	=	sampling interval [s]

(b) Sampling from a constant flow rate

If a batch sample from a constant exhaust flow rate is collected, the mean molar flow rate from which the sample is extracted shall be determined. The mean PM concentration shall be multiplied by the total flow to obtain the total mass of PM m_{PM}[g]:

$$m_{PM} = \bar{M}_{PM} \cdot \dot{n} \cdot \Delta t \quad \text{(A.7-45)}$$

Where:

$\dot{n}$	=	exhaust molar flow rate [mol/s]

$\bar{M}_{PM}$ = mean PM concentration [g/mol]

Δt = time duration of test interval [s]

For sampling with a constant dilution ratio (DR), m_{PM} [g] shall be calculated using the following equation:

$$m_{PM} = m_{PMdil} \cdot DR \quad \text{(A.7-46)}$$

Where:

m_{PMdil} = PM mass in dilution air [g]

DR = dilution ratio [-] defined as the ratio between the mass of the emission m and the mass of diluted exhaust $m_{dil/exh}$ ($DR = m/m_{dil/exh}$).

The dilution ratio DR can be expressed as a function of $x_{dil/exh}$:

$$DR = \frac{1}{1 - x_{dil/exh}} \quad \text{(A.7-47)}$$

A.7.4.4.2. Background correction

The same approach as that of clause A.7.4.1. shall be applied to correct the mass of PM for the background. Multiplying $\overline{M}_{PMbkgnd}$ by the total flow of dilution air, the total background mass of PM ($m_{PMbkgnd}$ [g]) is obtained. Subtraction of total background mass from total mass gives background corrected mass of particulates m_{PMcor} [g]:

$$m_{PMcor} = m_{PMuncor} - \bar{M}_{PMbkgnd} \cdot n_{airdil} \quad \text{(A.7-48)}$$

Where:

$m_{PMuncor}$ = uncorrected PM mass [g]

$\overline{M}_{PMbkgnd}$ = mean PM concentration in dilution air [g/mol]

n_{airdil} = dilution air molar flow [mol]

A.7.5. CYCLE WORK AND SPECIFIC EMISSIONS

A.7.5.1. Gaseous emissions

A.7.5.1.1. Transient and ramped modal cycle

Reference is made to clauses A.7.3.1. and A.7.4.1. for raw and diluted exhaust respectively. The resulting values for power P_i [kW] shall be integrated over a test interval. The total work W_{act} [kWh] is calculated as follows:

$$W_{act} = \sum_{i=1}^{N} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^{N} (n_i \cdot T_i) \quad \text{(A.7-49)}$$

Where:

P_i = instantaneous engine power [kW]

n_i = instantaneous engine speed [min^{-1}]

T_i = instantaneous engine torque [N·m]

W_{act} = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

The specific emissions e_{gas} [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{gas} = \frac{m_{gas}}{W_{act}} \quad \text{(A.7-50)}$$

Where:

m_{gas} = total mass of emission [g/test]

W_{act} = cycle work [kWh]

In case of the transient cycle, the final test result e_{gas} [g/kWh] shall be a weighted average from cold start test and hot start test by using:

$$e_{gas} = \frac{(0.1 \cdot m_{cold}) + (0.9 \cdot m_{hot})}{(0.1 \cdot W_{actcold}) + (0.9 \cdot W_{acthot})} \quad \text{(A.7-51)}$$

In case of an infrequent (periodic) exhaust regeneration (clause 6.6.2.), the specific emissions shall be corrected with the multiplicative adjustment factor k_r (equation (6-4)) or with the two separate pairs of adjustment additive factors k_{Ur} (upward factor of equation (6-5)) and k_{Dr} (downward factor of equation (6-6)).

A.7.5.1.2. Steady-state discrete-mode cycle

The specific emissions e_{gas} [g/kWh] are calculated as follows:

$$e_{gas} = \frac{\sum_{i=1}^{N_{mode}} (\dot{m}_{gasi} \cdot WF_i)}{\sum_{i=1}^{N_{mode}} (P_i \cdot WF_i)} \quad \text{(A.7-52)}$$

Where:

$\dot{m}_{gas,i}$ = mean emission mass flow rate for the mode i [g/h]

P_i = engine power for the mode i [kW] with $P_i = P_{maxi} + P_{auxi}$ (see clause 6.3. and 7.7.1.2.)

WF_i = weighing factor for the mode i [-]

A.7.5.2. Particulate emissions

A.7.5.2.1. Transient and ramped modal cycles

The particulate specific emissions shall be calculated with equation (A.7-50) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{PM} = \frac{m_{PM}}{W_{act}} \quad \text{(A.7-53)}$$

Where:

m_{PM} = total mass of particulates emission, calculated according to clause A.8.3.4. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in clause A.7.5.1.

A.7.5.2.2. Steady state discrete-mode cycle

The particulate specific emission e_{PM}[g/kWh] shall be calculated in the following way:

A.7.5.2.2.1. For the single-filter method

$$e_{PM} = \frac{\dot{m}_{PM}}{\sum_{i=1}^{N}\left(P_i \cdot WF_i\right)} \quad \text{(A.7-54)}$$

Where:

P_i = engine power for the mode i [kW] with $P_i = P_{maxi} + P_{auxi}$ (see clauses 6.3. and 7.7.1.2.)

WF_i = weighing factor for the mode *i* [-]

$\dot{m}_{PM}$ = particulate mass flow rate [g/h]

A.7.5.2.2.2. For the multiple-filter method

$$e_{PM} = \frac{\sum_{i=1}^{N}\left(\dot{m}_{PMi} \cdot WF_i\right)}{\sum_{i=1}^{N}\left(P_i \cdot WF_i\right)} \quad \text{(A.7-55)}$$

Where:

P_i = engine power for the mode i [kW] with $P_i = P_{maxi} + P_{auxi}$ (see clauses 6.3. and 7.7.1.2.)

WF_i = weighing factor for the mode *i* [-]

$\dot{m}_{PMi}$ = particulate mass flow rate at mode *i* [g/h]

For the single-filter method, the effective weighing factor, WF_{effi}, for each mode shall be calculated in the following way:

$$WF_{effi} = \frac{m_{smpldexhi} \cdot \overline{\dot{m}_{eqdexhwet}}}{m_{smpldex} \cdot \dot{m}_{eqdexhweti}} \quad \text{(A.7-56)}$$

Where:

$m_{smpldexhi}$ = mass of the diluted exhaust sample passed through the particulate sampling filters at mode *i* [kg]

$m_{smpldexh}$ = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

$\dot{m}_{eqdexhweti}$ = equivalent diluted exhaust gas mass flow rate at mode *i* [kg/s]

$\overline{\dot{m}_{eqdexhwet}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

The value of the effective weighing factors shall be within ±0.005 (absolute value) of the weighing factors listed in Annex 5.

ANNEX 4 - APPENDIX A.7.1

DILUTED EXHAUST FLOW (CVS) CALIBRATION

This appendix describes the calculations for calibrating various flow-meters. Clause A.7.6.1. of this Appendix describes how to convert reference flow-meter outputs for use in the calibration equations, which are presented on a molar basis. The remaining paragraphs describe the calibration calculations that are specific to certain types of flow-meters.

A.7.6.1. REFERENCE METER CONVERSIONS

The calibration equations in this section use molar flow rate, $\dot{n}_{ref}$, as a reference quantity. If he adopted reference meter outputs a flow rate in a different quantity, such as standard volume rate, $\dot{V}_{stdref}$, actual volume rate, $\dot{V}_{actdref}$, or mass rate, $\dot{m}_{ref}$, the reference meter output shall be converted to a molar flow rate using the following equations, noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, they should be kept as constant as practical for each individual set point during a flow-meter calibration:

$$\dot{n}_{ref} = \frac{\dot{V}_{stdref} \cdot p_{std}}{T_{std} \cdot R} = \frac{\dot{V}_{actref} \cdot p_{act}}{T_{act} \cdot R} = \frac{\dot{m}_{ref}}{M_{mix}} \qquad \text{(A.7-57)}$$

Where:

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

$\dot{V}_{stdref}$ = reference volume flow rate, corrected to a standard pressure and a standard temperature [m^3/s]

$\dot{V}_{actref}$ = reference volume flow rate, at the actual pressure and temperature [m^3/s]

$\dot{m}_{ref}$ = reference mass flow [g/s]

p_{std} = standard pressure [Pa]

p_{act} = actual pressure of the gas [Pa]

T_{std} = standard temperature [K]

T_{act} = actual temperature of the gas [K]

R = molar gas constant $[J/(mol \cdot K)]$

M_{mix} = molar mass of the gas [g/mol]

A.7.6.2. PDP CALIBRATION CALCULATIONS

For each restrictor position, the following values shall be calculated from the mean values determined in clause 8.1.8.4. of this Annex, as follows:

(a) PDP volume pumped per revolution, V_{rev} (m^3/rev):

$$V_{rev} = \frac{\overline{\dot{n}}_{ref} \cdot R \cdot \overline{T}_{in}}{\overline{p}_{in} \cdot \overline{f}_{nPDP}} \quad \text{(A.7-58)}$$

Where:

$\overline{\dot{n}}_{ref}$ = mean value of reference molar flow rate [mol/s]

R = molar gas constant $[J/(mol \cdot K)]$

$\overline{T}_{in}$ = mean inlet temperature [K]

$\overline{p}_{in}$ = mean inlet pressure [Pa]

$\overline{f}_{nPDP}$ = mean rotational speed [rev/s]

(b) PDP slip correction factor, K_s [s/rev]:

$$K_s = \frac{1}{\overline{f}_{nPDP}} \cdot \sqrt{\frac{\overline{p}_{out} - \overline{p}_{in}}{\overline{p}_{out}}} \quad \text{(A.7-59)}$$

Where:

$\overline{\dot{n}}_{ref}$ = mean reference molar flow rate [mol/s]

$\overline{T}_{in}$ = mean inlet temperature [K]

$\overline{p}_{in}$ = mean inlet pressure [Pa]

$\overline{p}_{out}$ = mean outlet pressure [Pa]

$\overline{f}_{nPDP}$ = mean PDP revolution speed [rev/s]

R = molar gas constant $[J/(mol \cdot K)]$

(c) A least-squares regression of PDP volume pumped per revolution, V_{rev}, versus PDP slip correction factor,K_s, shall be performed by calculating slope, a_1, and intercept, a_0, as described in Annex 4, Appendix A.2;

(d) The procedure in sub- clauses (a) through (c) of this clause shall be repeated for every speed that PDP is operated;

(e) The following table illustrates these calculations for different values of $\overline{f}_{nPDP}$:

Table A.7.2

Example of PDP Calibration Data

f_{nPDP} [rev/min]	f_{nPDP} [rev/s]	a_1 [m^3/min]	a_1 [m^3/s]	a_0 [m^3/rev]
755.0	12.58	50.43	0.8405	0.056
987.6	16.46	49.86	0.831	-0.013
1254.5	20.9	48.54	0.809	0.028
1401.3	23.355	47.30	0.7883	-0.061

(f) For each speed at which the PDP is operated, the corresponding slope, a_1, and intercept, a_0, shall be used to calculate flow rate during emission testing as described in clause A.7.4.3.(b)

A.7.6.3. VENTURI GOVERNING EQUATIONS AND PERMISSIBLE ASSUMPTIONS

This section describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio, r (i.e.,r_{SSV} versus r_{CFV}). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In clause A.7.6.3.(d), other assumptions that may be made are described. If the assumption of an ideal gas for the measured flow is not allowed, the governing equations include a first-order correction for the behaviour of a real gas; namely, the compressibility factor, Z. If good engineering judgment dictates using a value other than Z = 1, an appropriate equation of state to determine values of Z as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed based on good engineering judgment. It shall be noted that the equation for the flow coefficient, C_f, is based on the ideal gas assumption that the isentropic exponent, γ, is equal to the ratio of specific heats, c_p/c_V. If good engineering judgment dictates using a real gas isentropic exponent, an appropriate equation of state to determine values of γ as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed. Molar flow rate, $\dot{n}$ [mol/s], shall be calculated as follows:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \qquad \text{(A.7-60)}$$

Where:

C_d = Discharge coefficient, as determined in clause A.7.6.3.(a) [-]

C_f = Flow coefficient, as determined in clause A.7.6.3.(b) [-]

A_t = Venturi throat cross-sectional area [m^2]

p_{in} = Venturi inlet absolute static pressure [Pa]

Z = Compressibility factor [-]

M_{mix} = Molar mass of gas mixture [kg/mol]

R = Molar gas constant $[J/(mol \cdot K)]$

T_{in} = Venturi inlet absolute temperature [K]

(a) Using the data collected in clause 8.1.8.4. of this Annex, C_d is calculated using the following equation:

$$C_d = \dot{n}_{ref} \cdot \frac{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}{C_f \cdot A_t \cdot p_{in}} \quad \text{(A.7-61)}$$

Where:

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

Other symbols as per equation (A.7-60).

(b) C_f shall be determined using one of the following methods:

(i) For CFV flow-meters only, CfCFV is derived from the following table based on values for β (ratio of venturi throat to inlet diameters) and γ (ratio of specific heats of the gas mixture), using linear interpolation to find intermediate values:

Table A.7.3
C_{fCFV} versus β and γ for CFV flow-meters

C_{fCFV}		
β	$\gamma_{exh} = 1.385$	$\gamma_{dexh} = \gamma_{air} = 1.399$
0.000	0.6822	0.6846
0.400	0.6857	0.6881
0.500	0.6910	0.6934
0.550	0.6953	0.6977
0.600	0.7011	0.7036
0.625	0.7047	0.7072
0.650	0.7089	0.7114
0.675	0.7137	0.7163

C_{fCFV}		
β	γ_{exh} =1.385	γ_{dexh} =γ_{air} =1.399
0.700	0.7193	0.7219
0.720	0.7245	0.7271
0.740	0.7303	0.7329
0.760	0.7368	0.7395
0.770	0.7404	0.7431
0.780	0.7442	0.7470
0.790	0.7483	0.7511
0.800	0.7527	0.7555
0.810	0.7573	0.7602
0.820	0.7624	0.7652
0.830	0.7677	0.7707
0.840	0.7735	0.7765
0.850	0.7798	0.7828

(ii) For any CFV or SSV flow-meter, the following equation may be used to calculate C_f:

$$C_f = \left[\frac{2 \cdot \gamma \cdot \left(r^{\frac{\gamma-1}{\gamma}} - 1 \right) \cdot}{(\gamma - 1) \cdot \left(\beta^4 - r^{\frac{-2}{\gamma}} \right)} \right]^{\frac{1}{2}} \qquad \text{(A.7-62)}$$

Where:

γ = isentropic exponent [-]. For an ideal gas, this is the ratio of specific heats of the gas mixture, c_p/c_V

r = pressure ratio, as determined in sub- clause (c)(3) of this section

β = ratio of venturi throat to inlet diameters

(c) The pressure ratio r shall be calculated as follows:

(i) For SSV systems only, r_{SSV} is calculated using the following equation:

$$r_{SSV} = 1 - \frac{\Delta p_{SSV}}{p_{in}} \quad \text{(A.7-63)}$$

Where:

Δp_{SSV} = differential static pressure; venturi inlet minus venturi throat [Pa]

(ii) For CFV systems only, r_{CFV} shall be calculated iteratively using the following equation:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma - 1}{2}\right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma + 1}{2} \quad \text{(A.7-64)}$$

(d) Any of the following simplifying assumptions of the governing equations may be made, or good engineering judgment may be used to develop more appropriate values for testing:

(i) For emission testing over the full ranges of raw exhaust, diluted exhaust and dilution air, the gas mixture may be assumed to behave as an ideal gas: Z = 1;

(ii) For the full range of raw exhaust a constant ratio of specific heats of γ = 1.385 may be assumed;

(iii) For the full range of diluted exhaust and air (e.g., calibration air or dilution air), a constant ratio of specific heats of □□=1.399 may be assumed;

(iv) For the full range of diluted exhaust and air, the molar mass of the mixture, M_{mix} [g/mol], may be considered as a function only of the amount of water in the dilution air or calibration air, x_{H2O}, determined as described in clause A.7.1.2., as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H2O}) + M_{H2O} \cdot (x_{H2O}) \quad \text{(A.7-65)}$$

Where:

M_{air} = 28.96559 g/mol

M_{H2O} = 18.01528 g/mol

x_{H2O} = amount of water in the dilution or calibration air [mol/mol]

(v) For the full range of diluted exhaust and air, a constant molar mass of the mixture, M_{mix}, may be assumed for all calibration and all testing as long as assumed molar mass differs no more than ±1 per cent from the estimated minimum and maximum molar mass during calibration and testing. This assumption may be made if sufficient control of the amount of water in calibration air and in dilution air is ensured, or if sufficient water is removed from both calibration air and dilution air. The following table gives examples of permissible ranges of dilution air dew point versus calibration air dew point.

Table A.7.4
Examples of Dilution Air and Calibration Air Dew Points at which a Constant M_{mix} may be Assumed

If calibration T_{dew} (^0C) is...	*the following constant M_{mix} (g/mol) is assumed*	*for the following ranges of T_{dew} (0C) during emission tests[a]*
dry	28.96559	dry to 18
0	28.89263	dry to 21
5	28.86148	dry to 22
10	28.81911	dry to 24
15	28.76224	dry to 26
20	28.68685	–8 to 28
25	28.58806	12 to 31
30	28.46005	23 to 34

[a] Range valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

A.7.6.4 SSV CALIBRATION

(a) Molar based approach. To calibrate an SSV flow-meter the following steps shall be performed:

(i) The Reynolds number, $Re^{\#}$, for each reference molar flow rate, shall be calculated using the throat diameter of the venturi, d_t. Because the dynamic viscosity, μ, is needed to compute $Re^{\#}$, a specific viscosity model may be used to determine μ for calibration gas (usually air), using good engineering judgment. Alternatively, the Sutherland three-coefficient viscosity model may be used to approximate μ:

$$Re^{\#} = \frac{4 \cdot M_{mix} \cdot \dot{n}_{ref}}{\pi \cdot d_t \cdot \mu} \qquad \text{(A.7-66)}$$

Where:

d_t = diameter of the SSV throat [m]

M_{mix} = mixture molar mass [kg/mol]

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

and, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \left(\frac{T_{in}}{T_0} \right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T_{in} + S} \right) \quad \text{(A.7-67)}$$

Where:

μ = Dynamic viscosity of calibration gas [kg/(m·s)]

μ_0 = Sutherland reference viscosity [kg/(m·s)]

S = Sutherland constant [K]

T_0 = Sutherland reference temperature [K]

T_{in} = Absolute temperature at the venturi inlet [K]

Table A.7.5
Sutherland Three-Coefficient Viscosity Model Parameters

	μ_0	T_0	S	*Temp range within ±2 per cent error*	*Pressure limit*
Gas[a]	*kg /(m·s)*	*K*	*K*	*K*	*kPa*
Air	1.716×10^{-5}	273	111	170 to 1900	≤ 1800
CO_2	1.370×10^{-5}	273	222	190 to 1700	≤ 3600
H_2O	1.12×10^{-5}	350	1,064	360 to 1500	≤ 10000
O_2	1.919×10^{-5}	273	139	190 to 2000	≤ 2500
N_2	1.663×10^{-5}	273	107	100 to 1500	≤ 1600

[a] Tabulated parameters only for the pure gases, as listed, shall be used. Parameters to calculate viscosities of gas mixtures shall not be combined.

(ii) An equation for C_d versus $Re^{\#}$ shall be created, using paired values of ($Re^{\#}$, C_d). C_d is calculated according to equation (A.7-61), with C_f obtained from equation (A.7-62), or any mathematical expression may be used, including a polynomial or a power series. The following equation is an example of a commonly used mathematical expression for relating C_d and $Re^{\#}$;

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}} \quad \text{(A.7-68)}$$

(iii) A least-squares regression analysis shall be performed to determine the best-fit coefficients to the equation and calculate the equation's regression statistics, the standard estimate error *SEE* and the coefficient of determination r^2, according to Annex 4, Appendix A.2;

(iv) If the equation meets the criteria of $SEE < 0.5\% \cdot \dot{n}_{\text{ref max}}$ (or $\dot{m}_{\text{refmax}}$) and $r^2 \geq 0.995$, the equation may be used to determine C_d for emission tests, as described in A.7.4.3.(b);

(v) If the *SEE* and r^2 criteria are not met, good engineering judgment may be used to omit calibration data points to meet the regression statistics. At least seven calibration data points shall be used to meet the criteria;

(vi) If omitting points does not resolve outliers, corrective action shall be taken. For example, another mathematical expression for the C_d versus $Re^{\#}$ equation shall be selected, leaks are to be checked, or the calibration process has to be repeated. If the process shall be repeated, tighter tolerances shall be applied to measurements and more time for flows to stabilize shall be allowed;

(vii) Once the equation meets the regression criteria, the equation may be used only to determine flow rates that are within the range of the reference flow rates used to meet the C_d versus $Re^{\#}$ equation's regression criteria.

A.7.6.5. CFV calibration

(a) Molar based approach. Some CFV flow-meters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flow-meters that consist of multiple venturis, either calibration of each venturi independently to determine a separate discharge coefficient, C_d, for each venturi, or calibration of each combination of venturis as one venture may be performed. In the case where a combination of venturis is calibrated, the sum of the active venturi throat areas is used as A_t, the square root of the sum of the squares of the active venturi throat diameters as d_t, and the ratio of the venturi throat to inlet diameters as the ratio of the venturi throat to inlet diameters as the ratio of the square root of the sum of the active venture throat diameters (d_t) to the diameter of the common entrance to all of the venturis (D). To determine the C_d for a single venturi or a single combination of venturis, the following steps shall be performed:

(i) With the data collected at each calibration set point to an individual C_d for each point shall be calculated using equation (A.7-60);

(ii) The mean and standard deviation of all the C_d values shall be calculated according to equations (A.2-1) and (A.2-2);

(iii) If the standard deviation of all the C_d values is less than or equal to 0.3 per cent of the mean C_d, then the mean C_d shall be used in equation (A.7-43), and the CFV shall be used only down to the lowest r measured during calibration;

$$r = 1 - \left(\Delta p / p_{in} \right) \quad \text{(A.7-69)}$$

(iv) If the standard deviation of all the C_d values exceeds 0.3 per cent of the mean C_d, the C_d values corresponding to the data point

collected at the lowest r measured during calibration shall be omitted;

(v) If the number of remaining data points is less than seven, corrective action shall be taken by checking calibration data or repeating the calibration process. If the calibration process is repeated, checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilize, is recommended;

(vi) If the number of remaining C_d values is seven or greater, the mean and standard deviation of the remaining C_d values shall be recalculated;

(vii) If the standard deviation of the remaining C_d values is less than or equal to 0.3 per cent of the mean of the remaining C_d, that meanC_d shall be used in equation (A.7-43) and the CFV values only down to the lowest*r* associated with the remaining C_d shall be used;

(viii) If the standard deviation of the remaining C_d still exceeds 0.3 per cent of the mean of the remaining C_d values, the steps in sub-clause (a) (4) through (8) of this section shall be repeated.

ANNEX 4 - APPENDIX A.7.2

DRIFT CORRECTION

A.7.7.1. SCOPE AND FREQUENCY

The calculations in this appendix are performed to determine if gas analyser drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, the test interval's gas analyser responses shall be corrected for drift according to this appendix. The drift-corrected gas analyser responses shall be used in all subsequent emission calculations. The acceptable threshold for gas analyser drift over a test interval is specified in clause 8.2.2.2. of this Annex 4.

A.7.7.2. CORRECTION PRINCIPLES

The calculations in this appendix utilize a gas analyser's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analyser's responses that were recorded during a test interval. The correction is based on an analyser's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validation and correction for drift shall be performed as follows:

A.7.7.3. DRIFT VALIDATION

After applying all the other corrections–except drift correction–to all the gas analyser signals, brake-specific emissions shall be calculated according to clause A.7.5. of Annex 4, Appendix A.7. Then all gas analyser signals shall be corrected for drift according to this appendix. Brake-specific emissions shall be recalculated using all of the drift-corrected gas analyser signals. The brake-specific emission results shall be validated and reported before and after drift correction according to clause 8.2.2.2. of this Annex 4.

A.7.7.4. DRIFT CORRECTION

All gas analyser signals shall be corrected as follows:

(a) Each recorded concentration, x_i, shall be corrected for continuous sampling or for batch sampling, $\overline{x}$;

(b) Correction for drift shall be done using the following equation:

$$x_{idriftcor} = x_{refzero} + \left(x_{refspan} - x_{refzero}\right)\frac{2x_i - \left(x_{prezero} + x_{postzero}\right)}{\left(x_{prespan} + x_{postspan}\right) - \left(x_{prezero} + x_{postzero}\right)} \quad \text{(A.7-70)}$$

Where:

$x_{idriftcor}$ = concentration corrected for drift [µmol/mol]

$x_{refzero}$ = reference concentration of the zero gas, which is usually zero unless known to be otherwise [µmol/mol]

$x_{refspan}$ = reference concentration of the span gas [µmol/mol]

$x_{prespan}$ = pre-test interval gas analyser response to the span gas concentration [µmol/mol]

$x_{postspan}$ = post-test interval gas analyser response to the span gas concentration [µmol/mol]

x_i or $\overline{x}$ = concentration recorded, i.e. measured, during test, before drift correction [µmol/mol]

$x_{prezero}$ = pre-test interval gas analyser response to the zero gas concentration [µmol/mol]

$x_{postzero}$ = post-test interval gas analyser response to the zero gas concentration [µmol/mol]

(c) For any pre-test interval concentrations, concentrations determined most recently before the test interval shall be used. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals;

(d) For any post-test interval concentrations, concentrations determined most recently after the test interval shall be used. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals;

(e) If any pre-test interval analyser response to the span gas concentration, $x_{prespan}$, is not recorded, $x_{prespan}$ shall be set equal to the reference concentration of the span gas: $x_{prespan} = x_{refspan}$;

(f) If any pre-test interval analyser response to the zero gas concentration, $x_{prezero}$, is not recorded, $x_{prezero}$ shall be set equal to the reference concentration of the zero gas: $x_{prezero} = x_{refzero}$;

(g) Usually the reference concentration of the zero gas, $x_{refzero}$, is zero: $x_{refzero} = 0$ µmol/mol. However, in some cases it might be known that $x_{refzero}$ has a non-zero concentration. For example, if a CO_2 analyser is zeroed using ambient air, the default ambient air concentration of CO_2, which is 375 µmol/mol, may be used. In this case, $x_{refzero} = 375$ µmol/mol. When an analyser is zeroed using a non-zero $x_{refzero}$, the analyser shall be set to output the actual $x_{refzero}$ concentration. For example, if $x_{refzero} = 375$ µmol/mol, the analyser shall be set to output a value of 375 µmol/mol when the zero gas is flowing to the analyser.

ANNEX 4 - APPENDIX A.8

MASS BASED EMISSION CALCULATIONS

A.8.0. SYMBOL CONVERSION

A.8.0.1. General symbols

Appendix A.8	Appendix A.7	Unit	Quantity
b, D_0	a_0	t.b.d.[3]	y intercept of the regression line
m	a_1	t.b.d.[3]	Slope of the regression line
A/F_{st}		-	Stoichiometric air to fuel ratio
C_d	C_d	-	Discharge coefficient
c	x	ppm, % vol	Concentration (µmol/mol = ppm)
c_d	[1]	ppm, % vol	Concentration on dry basis
c_w	[1]	ppm, % vol	Concentration on wet basis
c_b	[1]	ppm, % vol	Background concentration
D	x_{dil}	-	Dilution factor[2]
D_0		m^3/rev	PDP calibration intercept
d	d	m	Diameter
d_V		m	Throat diameter of venturi
e	e	g/kWh	Brake specific basis
e_{gas}	e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	e_{PM}	g/kWh	Specific emission of particulates
E	$1 - PF$	per cent	Conversion efficiency (PF = Penetration fraction)
F_s		-	Stoichiometric factor
f_c		-	Carbon factor
H		g/kg	Absolute humidity
K_V		$\left[\left(\sqrt{K} \cdot m^4 \cdot s\right)/kg\right]$	CFV calibration function
k_f		m^3/kg fuel	Fuel specific factor
k_h		-	Humidity correction factor for NO_x, diesel engines
k_{Dr}	k_{Dr}	-	Downward adjustment factor
k_r	k_r	-	Multiplicative regeneration factor

Appendix A.8	Appendix A.7	Unit	Quantity
k_{Ur}	k_{Ur}	-	Upward adjustment factor
$k_{w,a}$		-	Dry to wet correction factor for the intake air
$k_{w,d}$		-	Dry to wet correction factor for the dilution air
$k_{w,e}$		-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$		-	Dry to wet correction factor for the raw exhaust gas
μ	μ	kg/(m·s)	Dynamic viscosity
M	M	g/mol	Molar mass[3]
M_a	[1]	g/mol	Molar mass of the intake air
M_e	[1]	g/mol	Molar mass of the exhaust
M_{gas}	M_{gas}	g/mol	Molar mass of gaseous components
m	m	kg	Mass
q_m	$\dot{m}$	kg/s	Mass rate
m_d	[1]	kg	Mass of the dilution air sample passed through the particulate sampling filters
m_{ed}	[1]	kg	Total diluted exhaust mass over the cycle
m_{edf}	[1]	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_{ew}	[1]	kg	Total exhaust mass over the cycle
m_f	[1]	mg	Particulate sample mass collected
$m_{f,d}$	[1]	mg	Particulate sample mass of the dilution air collected
m_{gas}	m_{gas}	g	Mass of gaseous emissions over the test cycle
m_{PM}	m_{PM}	g	Mass of particulate emissions over the test cycle
m_{se}	[1]	kg	Exhaust sample mass over the test cycle
m_{sed}	[1]	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	[1]	kg	Mass of diluted exhaust gas passing the particulate collection filters
m_{ssd}		kg	Mass of secondary dilution air

Appendix A.8	Appendix A.7	Unit	Quantity
n	f_n	min^{-1}	Engine rotational speed
n_p		r/s	PDP pump speed
P	P	kW	Power
p	p	kPa	Pressure
p_a		kPa	Dry atmospheric pressure
p_b		kPa	Total atmospheric pressure
p_d		kPa	Saturation vapour pressure of the dilution air
p_p	p_{abs}	kPa	Absolute pressure
p_r	p_{H2O}	kPa	Water vapour pressure
p_s		kPa	Dry atmospheric pressure
1 – E	PF	per cent	Penetration fraction
q_{mad}	$\dot{m}$ [1]	kg/s	Intake air mass flow rate on dry basis
q_{maw}	[1]	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	[1]	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	[1]	kg/s	Carbon mass flow rate into the engine
q_{mCp}	[1]	kg/s	Carbon mass flow rate in the partial flow dilution system
q_{mdew}	[1]	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	[1]	kg/s	Dilution air mass flow rate on wet basis
q_{medf}	[1]	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	[1]	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	[1]	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	[1]	kg/s	Fuel mass flow rate
q_{mp}	[1]	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_V	$\dot{V}$	m^3/s	Volume flow rate
q_{VCVS}	[1]	m^3/s	CVS volume rate
q_{Vs}	[1]	dm^3/min	System flow rate of exhaust analyser system

Appendix A.8	Appendix A.7	Unit	Quantity
q_{Vt}	[1]	cm³/min	Tracer gas flow rate
ρ	ρ	kg/m³	Mass density
ρ_e		kg/m³	Exhaust gas density
r_d	*DR*	-	Dilution ratio[2]
RH		per cent	Relative humidity
r_D	β	m/m	Ratio of diameters (CVS systems)
r_p		-	Pressure ratio of SSV
Re	$Re^{\#}$	-	Reynolds number
σ	σ	-	Standard deviation
T	*T*	°C	Temperature
T_a		K	Absolute temperature
t	*t*	s	Time
Δt	Δt	s	Time interval
u		-	Ratio between densities of gas component and exhaust gas
V	*V*	m^3	Volume
q_V	$\dot{V}$	m^3/s	Volume rate
V_0		m^3/r	PDP gas volume pumped per revolution
W	*W*	kWh	Work
W_{act}	W_{act}	kWh	Actual cycle work of the test cycle
WF	*WF*	-	Weighing factor
w	*w*	g/g	Mass fraction
X_0	K_s	s/rev	PDP calibration function
$\overline{y}$	$\overline{y}$		Arithmetic mean

[1] See subscripts; e.g.: $\dot{m}_{air}$ for mass rate of dry air, $\dot{m}_{fuel}$ for fuel mass rate, etc.

[2] Dilution ratio r_d in Appendix A.8 and DR in Appendix A.7: different symbols but same meaning and same equations. Dilution factor D in Appendix A.8 and x_{dil} in Appendix A.7: different symbols but same physical meaning;
equation (A.7-47) shows the relationship between x_{dil} and DR.

[3] t.b.d. = to be defined

A.8.0.2. Subscripts

Appendix A.8[1]	*Appendix A.7*	*Quantity*
act	act	Actual quantity
i		Instantaneous measurement (e.g.: 1 Hz)
	i	An individual of a series

[1] In Appendix A.8 the meaning of subscript is determined by the associated quantity; for example, the subscript "d" can indicate a dry basis as in "c_d = concentration on dry basis", dilution air as in "p_d = saturation vapour pressure of the dilution air" or "$k_{w,d}$ = dry to wet correction factor for the dilution air", dilution ratio as in "r_d".

A.8.0.3. Symbols and abbreviations for the chemical components (used also as a subscript)

Appendix A.8	**Appendix A.7**	**Quantity**
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH_4	CH_4	Methane
C_2H_6	C_2H_6	Ethane
C_3H_8	C_3H_8	Propane
CO	CO	Carbon monoxide
CO_2	CO_2	Carbon dioxide
DOP	DOP	Di-octylphthalate
HC	HC	Hydrocarbon
H_2O	H_2O	Water
NMHC	NMHC	Non-methane hydrocarbon
NO_x	NO_x	Oxides of nitrogen
NO	NO	Nitric oxide
NO_2	NO_2	Nitrogen dioxide
PM	PM	Particulate matter
S	S	Sulphur

A.8.0.4. Symbols and abbreviations for the fuel composition

Appendix A.8[1]	Appendix A.7[2]	Quantity
w_C[4]	w_C[4]	Carbon content of fuel, mass fraction [g/g] or [per cent mass]
w_H	w_H	Hydrogen content of fuel, mass fraction [g/g] or [per cent mass]
w_N	w_N	Nitrogen content of fuel, mass fraction [g/g] or [per cent mass]
w_O	w_O	Oxygen content of fuel, mass fraction [g/g] or [per cent mass]
w_S	w_S	Sulphur content of fuel, mass fraction [g/g] or [per cent mass]
α	α	Atomic hydrogen-to-carbon ratio (H/C)
ε	β	Atomic oxygen-to-carbon ratio (O/C)[3]
γ	γ	Atomic sulphur-to-carbon ratio (S/C)
δ	δ	Atomic nitrogen-to-carbon ratio (N/C)

[1] Referred to a fuel with chemical formula $CH_\alpha O_\varepsilon N_\delta S_\gamma$

[2] Referred to a fuel with chemical formula $CH_\alpha O_\beta S_\gamma N_\delta$

[3] Attention should be paid to the different meaning of symbol β in the two emissions calculation Annexes: in Appendix A.8 it refers to a fuel having the chemical formula $CH_\alpha S_\gamma N_\delta O_\varepsilon$ (i.e. the formula $C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon$ whereβ = 1, assuming one carbon atom per molecule), while in Appendix A.7 it refers to the oxygen-to-carbon ratio with $CH_\alpha O_\beta S_\gamma N_\delta$. Then β of Appendix A.7 corresponds to ε of Appendix A.8.

[4] Mass fraction w accompanied by the symbol of the chemical component as a subscript.

A.8.1. BASIC PARAMETERS

A.8.1.1. Determination of methane and non-methane HC concentration

The calculation of NMHC and CH_4 depends on the calibration method used. The FID for the measurement without NMC, shall be calibrated with propane. For the calibration of the FID in series with NMC, the following methods are permitted:

(a) Calibration gas – propane; propane bypasses NMC,

(b) Calibration gas – methane; methane passes through NMC

The concentration of NMHC (c_{NMHC} [-]) and CH_4 (c_{CH4} [-]) shall be calculated as follows for sub- clause (a):

$$c_{NMHC} = \frac{c_{HC(w/oNMC)} \cdot \left(1 - E_{CH4}\right) - c_{HC(w/NMC)}}{E_{C2H6} - E_{CH4}} \quad \text{(A.8-1a)}$$

$$c_{CH4} = \frac{c_{HC(w/NMC)} - c_{HC(w/oNMC)} \cdot \left(1 - E_{C2H6}\right)}{RF_{CH4[THC\text{-}FID]} \cdot \left(E_{C2H6} - E_{CH4}\right)} \quad \text{(A.8-2a)}$$

The concentration of NMHC and CH_4 shall be calculated as follows for sub- clause (b):

$$c_{NMHC} = \frac{c_{HC(w/oNMC)} \cdot (1 - E_{CH4}) - c_{HC(w/NMC)} \cdot RF_{CH4[THC\text{-}FID]} \cdot (1 - E_{CH4})}{E_{C2H6} - E_{CH4}} \quad \text{(A.8-1b)}$$

$$c_{CH4} = \frac{c_{HC(w/NMC)} \cdot RF_{CH4[THC\text{-}FID]} \cdot (1 - E_{CH4}) - c_{HC(w/oNMC)} \cdot (1 - E_{C2H6})}{RF_{CH4[THC\text{-}FID]} \cdot (E_{C2H6} - E_{CH4})} \quad \text{(A.8-2b)}$$

Where:

$c_{HC(w/NMC)}$ = HC concentration with sample gas flowing through the NMC [ppm]

$c_{HC(w/oNMC)}$ = HC concentration with sample gas bypassing the NMC [ppm]

$RF_{CH4[THC\text{-}FID]}$ = methane response factor as determined in clause 8.1.10.1.4. [-]

E_{CH4} = methane efficiency, as determined in clause 8.1.10.3. [-]

E_{C2H6} = ethane efficiency, as determined in clause 8.1.10.3. [-]

If $RF_{CH4[THC\text{-}FID]} < 1.05$, it may be omitted in equations A.8-1a, A.8-1b and A.8-2b.

NMHC (non-methane hydrocarbon) emissions can be approximated as 98 percent of THC (total hydrocarbon).

A.8.2. RAW GASEOUS EMISSIONS

A.8.2.1. Gaseous emissions

A.8.2.1.1. Steady state tests

The emission rate of a gaseous emission $q_{mgas,i}$ for each mode *i* of the steady state test shall be calculated. The concentration of the gaseous emission shall be multiplied by its respective flow:

$$q_{mgas,i} = k_h \cdot k \cdot u_{gas} \cdot q_{mew,i} \cdot c_{gas,i} \cdot 3600 \quad \text{(A.8-3)}$$

$q_{mgas,I}$ = emission rate in mode i of the steady state test [g/h]

k = 1 for $c_{gasr,w,i}$ in [ppm] and k = 10,000 for $c_{gasr,w,i}$ in [per cent vol]

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation (see clause A.8.2.2.)

u_{gas} = component specific factor or ratio between densities of gas component and exhaust gas [-]; to be calculated with equations (A.8-12) or (A.8-13)

$q_{mew,I}$ = exhaust gas mass flow rate in mode i on a wet basis [kg/s]

$c_{gas,I}$ = emission concentration in the raw exhaust gas in mode i, on a wet basis [ppm] or [per cent vol]

A.8.2.1.2. Transient and ramped modal cycles tests

The total mass per test of a gaseous emission m_{gas} [g/test] shall be calculated by multiplication of the time aligned instantaneous concentrations and exhaust gas flows and integration over the test cycle according to the following equation:

$$m_{gas} = \frac{1}{f} \cdot k_h \cdot k \cdot u_{gas} \cdot \sum_{i=1}^{N} \left(q_{mew,i} \cdot c_{gas,i} \right) \quad \text{(A.8-4)}$$

Where:

f = data sampling rate [Hz]

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm] and k = 10,000 for $c_{gasr,w,i}$ in [per cent vol]

u_{gas} = component specific factor [-] (see clause A.8.2.4.)

N = number of measurements [-]

$q_{mew,i}$ = instantaneous exhaust gas mass flow rate on a wet basis [kg/s]

$c_{gas,i}$ = instantaneous emission concentration in the raw exhaust gas, on a wet basis [ppm] or [per cent vol]

The following clauses show how the needed quantities ($c_{gas,i}$, u_{gas} and $q_{mew,i}$) shall be calculated.

A.8.2.2. Dry-to wet concentration conversion

If the emissions are measured on a dry basis, the measured concentration c_d on dry basis shall be converted to the concentration c_w on a wet basis according to the following general equation:

$$c_w = k_w \cdot c_d \quad \text{(A.8-5)}$$

Where:

k_w = dry-to-wet conversion factor [-]

c_d = emission concentration on a dry basis [ppm] or [per cent vol]

For complete combustion, the dry-to-wet conversion factor for raw exhaust gas is written as $k_{w,a}$ [-] and shall be calculated as follows:

$$k_{w,a} = \frac{\left(1 - \frac{1.2442 \cdot H_a + 111.19 \cdot w_H \cdot \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \cdot H_a + \frac{q_{mf,i}}{q_{mad,i}} \cdot k_f \cdot 1000} \right)}{\left(1 - \frac{p_r}{p_b} \right)} \quad \text{(A.8-6)}$$

Where:

H_a = intake air humidity [g H_2O/kg dry air]

$q_{mf,I}$ = instantaneous fuel flow rate [kg/s]

$q_{mad,I}$ = instantaneous dry intake air flow rate [kg/s]

p_r = water pressure after cooler [kPa]

p_b = total barometric pressure [kPa]

w_H = hydrogen content of the fuel [per cent mass]

k_f = combustion additional volume [m^3/kg fuel]

With:

$$k_f = 0.055594 \cdot w_H + 0.0080021 \cdot w_N + 0.0070046 \cdot w_O \quad \text{(A.8-7)}$$

Where:

w_H = hydrogen content of fuel [per cent mass]

w_N = nitrogen content of fuel [per cent mass]

w_O = oxygen content of fuel [per cent mass]

In the equation (A.8-6), the ratio p_r / p_b may be assumed:

$$\frac{1}{\left(1 - \frac{p_r}{p_b}\right)} = 1.008 \quad \text{(A.8-8)}$$

For incomplete combustion (rich fuel air mixtures) and also for emission tests without direct air flow measurements, a second method of $k_{w,a}$ calculation is preferred:

$$k_{w,a} = \frac{\frac{1}{1 + \alpha \cdot 0.005 \cdot (c_{CO2} + c_{CO})} - k_{w1}}{1 - \frac{p_r}{p_b}} \quad \text{(A.8-9)}$$

Where:

c_{CO2} = concentration of CO_2 in the raw exhaust gas, on a dry basis [per cent vol]

c_{CO} = concentration of CO in the raw exhaust gas, on a dry basis [ppm]

p_r = water pressure after cooler [kPa] (see equation (A.8-9))

p_b = total barometric pressure [kPa] (see equation (A.8-9))

α = molar to carbon hydrogen ratio [-]

k_{w1} = intake air moisture [-]

$$k_{w1} = \frac{1.608 \cdot H_a}{1000 + 1.608 \cdot H_a} \quad \text{(A.8-10)}$$

A.8.2.3. NO_x correction for humidity and temperature

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for ambient air temperature and humidity with the factors k_h [-] given in the following equation. This factor is valid for a humidity range between 0 and 25 g H_2O/kg dry air.

$$k_h = \frac{15.698 \cdot H_a}{1\,000} + 0.832 \quad \text{(A.8-11)}$$

Where:

H_a = humidity of the intake air [g H_2O/kg dry air]

A.8.2.4. Component specific factor *u*

A.8.2.4.1. Tabulated values

Applying some simplifications (assumption on the□ value and on intake air conditions as shown in the following table) to the equations of clause A.8.2.4.2. figures for u_{gas}, can be calculated (see clause A.8.2.1.). The u_{gas} values are given in Table A.8.1.

Table A.8.1
Raw Exhaust Gas *u* and Component Densities
(the *u* figures are calculated for emission concentration expressed in ppm)

Gas		**NO_x**	**CO**	**HC**	**CO_2**	**O_2**	**CH_4**
ρ_{gas} [kg/m^3]		2.053	1.250	0.621	1.9636	1.4277	0.716
Fuel	ρ_e [kg/m^3]	Coefficient u_{gas} at λ = 2, dry air, 273 K, 101.3 kPa					
Diesel	1.2939	0.001587	0.000966	0.000479	0.001518	0.001103	0.000553

A.8.2.4.2. Calculated values

The component specific factor, $u_{gas,i}$, can be calculated by the density ratio of the component and the exhaust or alternatively by the corresponding ratio of molar masses:

$$u_{gas,i} = M_{gas} / \left(M_{e,i} \cdot 1000 \right) \quad \text{(A.8-12)}$$

or

$$u_{gas,i} = \rho_{gas} / \left(\rho_{e,i} \cdot 1000 \right) \quad \text{(A.8-13)}$$

Where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{e,i}$ = instantaneous molar mass of the wet raw exhaust gas [g/mol]

ρ_{gas} = density of the gas component [kg/m^3]

$\rho_{e,i}$ = instantaneous density of the wet raw exhaust gas [kg/m^3]

The molar mass of the exhaust, $M_{e,i}$ shall be derived for a general fuel composition $CH\alpha O_{\varepsilon}N_{\delta}S_{\gamma}$ under the assumption of complete combustion, as follows:

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \cdot \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.001 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.0065 \cdot \gamma} + \frac{\frac{H_a \cdot 10^{-3}}{2 \times 1.00794 + 15.9994} + \frac{1}{M_a}}{1 + H_a \cdot 10^{-3}}} \quad \text{(A.8-14)}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate on wet basis [kg/s]

$q_{maw,i}$ = instantaneous intake air mass flow rate on wet basis [kg/s]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

$\gamma\gamma$ = atomic sulphur-to-carbon ratio [-]

H_a = intake air humidity [g H_2O/kg dry air]

M_a = dry intake air molecular mass = 28.965 g/mol

The instantaneous raw exhaust density $\rho_{e,i}$ [kg/m^3] shall be derived as follows:

$$\rho_{e,i} = \frac{1000 + H_a + 1000 \cdot \left(q_{mf,i} / q_{mad,i}\right)}{773.4 + 1.2434 \cdot H_a + k_f \cdot 1000 \cdot \left(q_{mf,i} / q_{mad,i}\right)} \quad \text{(A.8-15)}$$

Where:

$q_{mf,I}$ = instantaneous fuel mass flow rate [kg/s]

$q_{mad,I}$ = instantaneous dry intake air mass flow rate [kg/s]

H_a = intake air humidity [g H_2O/kg dry air]

k_f = combustion additional volume [m^3/kg fuel] (see equation A.8-7)

A.8.2.5. Mass flow rate of the exhaust gas

A.8.2.5.1. Air and fuel measurement method

The method involves measurement of the air flow and the fuel flow with suitable flow-meters. The calculation of the instantaneous exhaust gas flow $q_{mew,i}$ [kg/s] shall be as follows:

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \quad \text{(A.8-16)}$$

Where:

$q_{maw,i}$ = instantaneous intake air mass flow rate [kg/s]

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

A.8.2.5.2. Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust. The calculation of the instantaneous exhaust gas flow $q_{mew,i}$ [kg/s] shall be as follows:

$$q_{mew,i} = \frac{q_{Vt} \cdot \rho_e}{10^{-6} \cdot \left(c_{mix,i} - c_b\right)} \quad \text{(A.8-17)}$$

Where:

q_{Vt} = tracer gas flow rate [m³/s]

$c_{mix,I}$ = instantaneous concentration of the tracer gas after mixing [ppm]

ρ_e = density of the raw exhaust gas [kg/m³]

c_b = background concentration of the tracer gas in the intake air [ppm]

The background concentration of the tracer gas c_b may be determined by averaging the background concentration measured immediately before the test run and after the test run. When the background concentration is less than 1 per cent of the concentration of the tracer gas after mixing $c_{mix,i}$ at maximum exhaust flow, the background concentration may be neglected.

A.8.2.5.3. Air flow and air to fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air to fuel ratio. The calculation of the instantaneous exhaust gas mass flow $q_{mew,i}$[kg/s] is as follows:

$$q_{mew,i} = q_{maw,i} \cdot \left(1 + \frac{1}{A/F_{st} \cdot \lambda_i}\right) \quad \text{(A.8-18)}$$

With:

$$A/F_{st} = \frac{138.0 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} \quad \text{(A.8-19)}$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \cdot 10^{-4}}{2} - c_{HCw} \cdot 10^{-4}\right) + \left(\frac{\alpha}{4} \cdot \frac{1 - \frac{2 \cdot c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}}{1 + \frac{c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \cdot \left(c_{CO2d} + c_{COd} \cdot 10^{-4}\right)}{4.764 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \cdot \left(c_{CO2d} + c_{COd} \cdot 10^{-4} + c_{HCw} \cdot 10^{-4}\right)} \quad \text{(A.8-20)}$$

Where:

$q_{maw,I}$ = wet intake air mass flow rate [kg/s]

A/F_{st} = stoichiometric air-to-fuel ratio [-]

λ_I = instantaneous excess air ratio [-]

c_{Cod} = concentration of CO in the raw exhaust gas on a dry basis [ppm]

c_{CO2d} = concentration of CO_2 in the raw exhaust gas on a dry basis [per cent]

c_{HCw} = concentration of HC in the raw exhaust gas on a wet basis [ppm C1]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

γ = atomic sulphur-to-carbon ratio [-]

A.8.2.5.4. Carbon balance method, 1 step-procedure

The following 1-step formula can be used for the calculation of the wet exhaust mass flow rate $q_{mew,i}$ [kg/s]:

$$q_{mew,i} = q_{mf,i} \cdot \left[\frac{1.4 \cdot w_C^2}{\left(1.0828 \cdot w_C + k_{fd} \cdot f_c\right) f_c} \left(1 + \frac{H_a}{1000}\right) + 1 \right] \quad \text{(A.8-21)}$$

With the carbon factor f_c [-] given by:

$$f_c = 0.5441 \cdot \left(c_{CO2d} - c_{CO2d,a}\right) + \frac{c_{COd}}{18522} + \frac{c_{HCw}}{17355} \quad \text{(A.8-22)}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

w_C = carbon content of fuel [per cent mass]

H_a = intake air humidity [g H_2O/kg dry air]

k_{fd} = combustion additional volume on a dry basis [m^3/kg fuel]

c_{CO2d} = dry CO_2 concentration in the raw exhaust [per cent]

$c_{CO2d,a}$ = dry CO_2 concentration in the ambient air [per cent]

c_{Cod} = dry CO concentration in the raw exhaust [ppm]

c_{HCw} = wet HC concentration in the raw exhaust [ppm]

and factor k_{fd} [m^3/kg fuel] that is calculated on a dry basis by subtracting the water formed by combustion from k_f:

$$k_{fd} = k_f - 0.11118 \cdot w_H \quad \text{(A.8-23)}$$

Where:

k_f = fuel specific factor of equation (A.8-7) [m^3/kg fuel]

w_H = hydrogen content of fuel [per cent mass]

A.8.3. DILUTED GASEOUS EMISSIONS

A.8.3.1. Mass of the gaseous emissions

A.8.3.1.1. Full flow dilution measurement (CVS)

The exhaust mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a positive displacement pump (PDP), a critical flow venturi (CFV) or a subsonic venturi (SSV).

For systems with constant mass flow (i.e. with heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined from the following equation:

$$m_{gas} = k_h \cdot k \cdot u_{gas} \cdot c_{gas} \cdot m_{ed} \quad \text{(A.8-24)}$$

Where:

u_{gas} = ratio between density of exhaust component and density of air, as given in Table A.8.2 or calculated with equation (A.8-35) [-]

c_{gas} = mean background corrected concentration of the component on a wet basis [ppm] or [per cent vol] respectively

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm], k = 10,000 for $c_{gasr,w,i}$ in [per cent vol]

m_{ed} = total diluted exhaust gas mass over the cycle [kg/test]

For systems with flow compensation (without heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined by calculation of the instantaneous mass emissions, by integration and by background correction according to the following equation:

$$m_{gas} = k_h \cdot k \cdot \left\{ \sum_{i=1}^{N} \left[\left(m_{ed,i} \cdot c_e \cdot u_{gas} \right) \right] - \left[\left(m_{ed} \cdot c_d \cdot \left(1 - \frac{1}{D} \right) \cdot u_{gas} \right) \right] \right\} \quad \text{(A.8-25)}$$

Where:

c_e = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [per cent vol]

c_d = emission concentration in the dilution air, on a wet basis [ppm] or [per cent vol]

$m_{ed,i}$ = mass of the diluted exhaust gas during time interval i [kg]

m_{ed} = total mass of diluted exhaust gas over the cycle [kg]

u_{gas} = tabulated value from Table A.8.2 [-]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

k_h = NO_x correction factor [-], only to be applied for the NO_x emission calculation

k = 1 for c in [ppm], k = 10,000 for c in [per cent vol]

The concentrations c_{gas}, c_e and c_d can be either values measured in a batch sample (bag, but not allowed for NO_x and HC) or be averaged by integration from continuous measurements. Also $m_{ed,i}$ has to be averaged by integration over the test cycle.

The following equations show how the needed quantities (c_e, u_{gas} and m_{ed}) shall be calculated.

A.8.3.2. Dry-to wet concentration conversion

All concentrations in clause A.8.3.2. shall be converted using equation (A.8-5) ($c_w = k_w \cdot c_d$).

A.8.3.2.1. Diluted exhaust gas

All concentrations measured dry shall be converted to wet concentrations by one of the following two equations applied to equation:

$$k_{w,e} = \left[\left(1 - \frac{\alpha \cdot c_{CO2w}}{200} \right) - k_{w2} \right] \cdot 1.008 \quad \text{(A.8-26)}$$

or

$$k_{w,e} = \left(\frac{\left(1 - k_{w2} \right)}{1 + \frac{\alpha \cdot c_{CO2d}}{200}} \right) \cdot 1.008 \quad \text{(A.8-27)}$$

Where:

$k_{w,e}$ = dry-to-wet conversion factor for the diluted exhaust gas [-]

α = molar hydrogen to carbon ratio of the fuel [-]

c_{CO2w} = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

c_{CO2d} = concentration of CO_2 in the diluted exhaust gas on a dry basis [per cent vol]

The dry to wet correction factor k_{w2} takes into consideration the water content of both intake air and dilution air:

$$k_{w2} = \frac{1.608 \cdot \left[H_d \cdot \left(1 - \frac{1}{D} \right) + H_a \cdot \left(\frac{1}{D} \right) \right]}{1000 + \left\{ 1.608 \cdot \left[H_d \cdot \left(1 - \frac{1}{D} \right) + H_a \cdot \left(\frac{1}{D} \right) \right] \right\}} \quad \text{(A.8-28)}$$

Where:

H_a = intake air humidity [g H_2O/kg dry air]

H_d = dilution air humidity [g H_2O/kg dry air]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

A.8.3.2.2. Dilution factor

The dilution factor D [-] (which is necessary for the background correction and the k_{w2} calculation) shall be calculated as follows:

$$D = \frac{F_S}{c_{CO2,e} + \left(c_{HC,e} + c_{CO,e}\right) \cdot 10^{-4}} \quad \text{(A.8-29)}$$

Where:

F_S = stoichiometric factor [-]

$c_{CO2,e}$ = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

$c_{HC,e}$ = concentration of HC in the diluted exhaust gas on a wet basis [ppm C1]

$c_{CO,e}$ = concentration of CO in the diluted exhaust gas on a wet basis [ppm]

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 \cdot \frac{1}{1 + \frac{\alpha}{2} + 3.76 \cdot \left(1 + \frac{\alpha}{4}\right)} \quad \text{(A.8-30)}$$

Where:

α = molar hydrogen to carbon ratio in the fuel [-]

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used: F_S (diesel) = 13.4

If a direct measurement is made of the exhaust gas flow, the dilution factor D [-] may be calculated as follows:

$$D = \frac{q_{VCVS}}{q_{Vew}} \quad \text{(A.8-31)}$$

Where:

q_{VCVS} = volumetric flow rate of diluted exhaust gas [m^3/s]

q_{Vew} = volumetric flow rate of raw exhaust gas [m^3/s]

A.8.3.2.3. Dilution air

$$k_{w,d} = \left(1 - k_{w3}\right) \cdot 1.008 \quad \text{(A.8-32)}$$

With

$$k_{w3} = \frac{1.608 \cdot H_d}{1000 + 1.608 \cdot H_d} \quad \text{(A.8-33)}$$

Where:

H_d = dilution air humidity [g H_2O/kg dry air]

A.8.3.2.4. Determination of the background corrected concentration

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be

determined by the sample bag method or by continuous measurement with integration. The following equation shall be used:

$$c_{gas} = c_{gas,e} - c_d \cdot \left(1 - \frac{1}{D}\right) \quad \text{(A.8-34)}$$

Where:

c_{gas} = net concentration of the gaseous pollutant [ppm] or [per cent vol]

$c_{gas,e}$ = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [per cent vol]

c_d = emission concentration in the dilution air, on a wet basis [ppm] or [per cent vol]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

A.8.3.3. Component specific factor u

The component specific factor u_{gas} of diluted gas can either be calculated by the following equation or be taken from Table A.8.2; in Table A.8.2 the density of the diluted exhaust gas has been assumed equal to air density.

$$u = \frac{M_{gas}}{M_{d,w} \cdot 1000} = \frac{M_{gas}}{\left[M_{da,w} \cdot \left(1 - \frac{1}{D}\right) + M_{r,w} \cdot \left(\frac{1}{D}\right)\right] \cdot 1000} \quad \text{(A.8-35)}$$

Where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{d,w}$ = molar mass of diluted exhaust gas [g/mol]

$M_{da,w}$ = molar mass of dilution air [g/mol]

$M_{r,w}$ = molar mass of raw exhaust gas [g/mol]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

Table A.8.2
Diluted Exhaust Gas *u* Values and Component Densities
(the *u* figures are calculated for emission concentration expressed in ppm)

Gas		*NO_x*	*CO*	*HC*	*CO_2*	*O_2*	*CH_4*
ρ_{gas} [kg/m^3]		2.053	1.250	0.621	1.9636	1.4277	0.716
Fuel	ρ_e [kg/m^3]	Coefficient u_{gas} at λ = 2, dry air, 273 K, 101.3 kPa					
Diesel	1.293	0.001588	0.000967	0.000480	0.001519	0.00110	0.000553

A.8.3.4. Exhaust gas mass flow calculation

A.8.3.4.1. PDP-CVS system

The calculation of the mass of the diluted exhaust [kg/test] over the cycle is as follows, if the temperature of the diluted exhaust m_{ed} is kept within ±6 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \cdot V_0 \cdot n_P \cdot \frac{p_p}{101.325} \cdot \frac{273.15}{\bar{T}} \quad \text{(A.8-36)}$$

Where:

V_0 = volume of gas pumped per revolution under test conditions [m³/rev]

n_P = total revolutions of pump per test [rev/test]

p_p = absolute pressure at pump inlet [kPa]

$\bar{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1.293 kg/m³ = air density at 273.15 K and 101.325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated as follows:

$$m_{ed,i} = 1.293 \cdot V_0 \cdot n_{P,i} \cdot \frac{p_p}{101.325} \cdot \frac{273.15}{\bar{T}} \quad \text{(A.8-37)}$$

Where:

V_0 = volume of gas pumped per revolution under test conditions [m³/rev]

p_p = absolute pressure at pump inlet [kPa]

$n_{P,i}$ = total revolutions of pump per time interval i [rev/Δt]

$\bar{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1.293 kg/m³ = air density at 273.15 K and 101.325 kPa

A.8.3.4.2. CFV-CVS system

The calculation of the mass flow over the cycle m_{ed} [g/test] is as follows, if the temperature of the diluted exhaust is kept within ±11 K over the cycle by using a heat exchanger:

$$m_{ed} = \frac{1.293 \cdot t \cdot K_V \cdot p_p}{T^{0.5}} \quad \text{(A.8-38)}$$

Where:

t = cycle time [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\text{K}} \cdot \text{m}^4 \cdot \text{s}\right)/\text{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1.293 kg/m^3 = air density [ ] at 273.15 K and 101.325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated as follows:

$$m_{ed,i} = \frac{1.293 \cdot \Delta t_i \cdot K_V \cdot p_p}{T^{0.5}} \quad \text{(A.8-39)}$$

Where:

Δt_i = time interval of the test [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\text{K}} \cdot \text{m}^4 \cdot \text{s}\right)/\text{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

A.8.3.4.3. SSV-CVS system

The calculation of the diluted exhaust gas mass over the cycle m_{ed} [kg/test] shall be as follows, if the temperature of the diluted exhaust is kept within ±11K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \cdot q_{VSSV} \cdot \Delta t \quad \text{(A.8-40)}$$

Where:

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

Δt = cycle time [s]

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

With

$$q_{VSSV} = \frac{A_0}{60} d_V{}^2 C_d p_p \sqrt{\left[\frac{1}{T_{in}}\left(r_p{}^{1.4286} - r_p{}^{1.7143}\right) \cdot \left(\frac{1}{1 - r_D{}^4 r_p{}^{1.4286}}\right)\right]} \quad \text{(A.8-41)}$$

Where:

A_0 = collection of constants and units conversions = 0.0056940 $\left[\frac{\text{m}^3}{\text{min}} \cdot \frac{\text{K}^{\frac{1}{2}}}{\text{kPa}} \cdot \frac{1}{\text{mm}^2}\right]$

d_V = diameter of the SSV throat [mm]

C_d = discharge coefficient of the SSV [-]

p_p = absolute pressure at venturi inlet [kPa]

T_{in} = temperature at the venturi inlet [K]

r_p = ratio of the SSV throat to inlet absolute static pressure, $\left(1-\frac{\Delta p}{p_a}\right)$ [-]

r_D = ratio of the SSV throat diameter to the inlet pipe inner diameter $\frac{d}{D}$ [-]

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated as follows:

$$m_{ed,i} = 1.293 \cdot q_{VSSV} \cdot \Delta t_i \quad \text{(A.8-42)}$$

Where:

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

Δt_i = time interval [s]

q_{VSSV} = volumetric flow rate of the SSV [m^3/s]

A.8.3.5. Calculation of particulates emission

A.8.3.5.1. Transient and ramped modal cycles

The particulate mass shall be calculated after buoyancy correction of the particulate sample mass according to clause 8.1.12.2.5. of this Annex 4.

A.8.3.5.1.1. Partial flow dilution system

The calculation for double dilution system is shown in clause A.8.3.5.1.2.

A.8.3.5.1.1.1. Calculation based on sample ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated with the following equation:

$$m_{PM} = \frac{m_f}{r_s \cdot 1000} \quad \text{(A.8-43)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

r_s = average sample ratio over the test cycle [-]

With:

$$r_s = \frac{m_{se}}{m_{ew}} \cdot \frac{m_{sep}}{m_{sed}} \quad \text{(A.8-44)}$$

Where:

m_{se} = sample mass of raw exhaust over the cycle [kg]

m_{ew} = total mass of raw exhaust over the cycle [kg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sed} = mass of diluted exhaust gas passing the dilution tunnel [kg]

In case of the total sampling type system, m_{sep} and m_{sed} are identical.

A.8.3.5.1.1.2. Calculation based on dilution ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated with the following equation:

$$m_{PM} = \frac{m_f}{m_{sep}} \cdot \frac{m_{edf}}{1000} \quad \text{(A.8-45)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{edf} = mass of equivalent diluted exhaust gas over the cycle [kg]

The total mass of equivalent diluted exhaust gas mass over the cycle m_{edf} [kg] shall be determined as follows:

$$m_{edf} = \frac{1}{f} \cdot \sum_{i=1}^{N} q_{medf,i} \quad \text{(A.8-46)}$$

$$q_{medf,i} = q_{mew,i} \cdot r_{d,i} \quad \text{(A.8-47)}$$

$$r_{d,i} = \frac{q_{mdew,i}}{q_{mdew,i} - q_{mdw,i}} \quad \text{(A.8-48)}$$

Where:

$q_{medf,i}$ = instantaneous equivalent diluted exhaust mass flow rate [kg/s]

$q_{mew,i}$ = instantaneous exhaust mass flow rate on a wet basis [kg/s]

$r_{d,I}$ = instantaneous dilution ratio [-]

$q_{mdew,i}$ = instantaneous diluted exhaust mass flow rate on a wet basis [kg/s]

$q_{mdw,i}$ = instantaneous dilution air mass flow rate [kg/s]

f = data sampling rate [Hz]

N = number of measurements [-]

A.8.3.5.1.2. Full flow dilution system

The mass emission shall be calculated as follows:

$$m_{PM} = \frac{m_f}{m_{sep}} \cdot \frac{m_{ed}}{1000} \quad \text{(A.8-49)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{ed} = mass of diluted exhaust gas over the cycle [kg]

with

$$m_{sep} = m_{set} - m_{ssd} \quad \text{(A.8-50)}$$

Where:

m_{set} = mass of double diluted exhaust gas through particulate filter [kg]

m_{ssd} = mass of secondary dilution air [kg]

A.8.3.5.1.3. Background correction

The particulate mass $m_{PM,c}$ [g] may be background corrected as follows:

$$m_{PM,c} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_b}{m_{sd}} \cdot \left(1 - \frac{1}{D} \right) \right] \right\} \cdot \frac{m_{ed}}{1000} \quad \text{(A.8-51)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sd} = mass of dilution air sampled by background particulate sampler [kg]

m_b = mass of collected background particulates of dilution air [mg]

m_{ed} = mass of diluted exhaust gas over the cycle [kg]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

A.8.3.5.2. Calculation for steady-state discrete-mode cycles

A.8.3.5.2.1. Dilution system

All calculations shall be based upon the average values of the individual modes i during the sampling period.

(a) For partial-flow dilution, the equivalent mass flow of diluted exhaust gas shall be determined by means of the system with flow measurement shown in Figure 9.2:

$$q_{medf} = q_{mew} \cdot r_d \quad \text{(A.8-52)}$$

$$r_d = \frac{q_{mdew}}{q_{mdew} - q_{mdw}} \quad \text{(A.8-53)}$$

Where:

q_{medf} = equivalent diluted exhaust mass flow rate [kg/s]

q_{mew} = exhaust mass flow rate on a wet basis [kg/s]

r_d = dilution ratio [-]

q_{mdew} = diluted exhaust mass flow rate on a wet basis [kg/s]

q_{mdw} = dilution air mass flow rate [kg/s]

(b) For full-flow dilution systems q_{mdew} is used as q_{medf}.

A.8.3.5.2.2. Calculation of the particulate mass flow rate

The particulate emission flow rate over the cycle q_{mPM} [g/h] shall be calculated as follows:

(a) For the single-filter method

$$q_{mPM} = \frac{m_f}{m_{sep}} \cdot \overline{q_{medf}} \cdot \frac{3600}{1000} \quad \text{(A.8-54)}$$

$$\overline{q_{medf}} = \sum_{i=1}^{N} q_{medfi} \cdot WF_i \quad \text{(A.8-55)}$$

$$m_{sep} = \sum_{i=1}^{N} m_{sepi} \quad \text{(A.8-56)}$$

Where:

q_{mPM} = particulate mass flow rate [g/h]

m_f = particulate mass sampled over the cycle [mg]

$\overline{q_{medf}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

q_{medfi} = equivalent diluted exhaust gas mass flow rate on wet basis at mode *i* [kg/s]

WF_i = weighing factor for the mode *i* [-]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sepi} = mass of diluted exhaust sample passed through the particulate sampling filter at mode *i* [kg]

N = number of measurements [-]

(b) For the multiple-filter method

$$q_{mPMi} = \frac{m_{fi}}{m_{sepi}} \cdot q_{medfi} \cdot \frac{3600}{1000} \quad \text{(A.8-57)}$$

Where:

q_{mPMi} = particulate mass flow rate for the mode *i* [g/h]

m_{fi} = particulate sample mass collected at mode *i* [mg]

q_{medfi} = equivalent diluted exhaust gas mass flow rate on wet basis at mode *i* [kg/s]

m_{sepi} = mass of diluted exhaust sample passed through the particulate sampling filter at mode *i* [kg]

The PM mass is determined over the test cycle by summation of the average values of the individual modes *i* during the sampling period.

The particulate mass flow rate q_{mPM} [g/h] or q_{mPMi}[g/h] may be background corrected as follows:

(a) For the single-filter method

$$q_{mPM} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_{f,d}}{m_d} \cdot \sum_{i=1}^{N} \left(1 - \frac{1}{D_i} \right) \cdot WF_i \right] \right\} \cdot \overline{q_{medf}} \frac{3600}{1000} \quad \text{(A.8-58)}$$

Where:

q_{mPM} = particulate mass flow rate [g/h]

m_f = particulate sample mass collected [mg]

m_{sep} = mass of diluted exhaust sample passed through the particulate sampling filter [kg]

$m_{f,d}$ = particulate sample mass of the dilution air collected [mg]

m_d = mass of the dilution air sample passed through the particulate sampling filters [kg]

D_i = dilution factor at mode *i* (see equation (A.8-29) of clause A.8.3.2.2.) [-]

WF_i = weighing factor for the mode *i* [-]

$\overline{q_{medf}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

(b) For the multiple-filter method

$$q_{mPMi} = \left\{ \frac{m_{fi}}{m_{sepi}} - \left[\frac{m_{f,d}}{m_d} \cdot \left(1 - \frac{1}{D} \right) \right] \right\} \cdot q_{medfi} \frac{3600}{1000} \quad \text{(A.8-59)}$$

Where:

q_{mPM} = particulate mass flow rate [g/h]

m_{fi} = particulate sample mass collected at mode *i* [mg]

$m_{f,d}$ = particulate sample mass of the dilution air collected [mg]

q_{medfi} = equivalent diluted exhaust gas mass flow rate on wet basis at mode i [kg/h]

m_{sepi} = mass of diluted exhaust sample passed through the particulate sampling filter at mode *i* [kg]

m_d = mass of the dilution air sample passed through the particulate sampling filters [kg]

D = dilution factor (see equation (A.8-29) of clause A.8.3.2.2.) [-]

$\overline{q_{medf}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

If more than one measurement is made, $m_{f,d}/m_d$ shall be replaced with $\overline{m_{f,d}/m_d}$.

A.8.4. CYCLE WORK AND SPECIFIC EMISSIONS

A.8.4.1. Gaseous emissions

A.8.4.1.1. Transient and ramped modal cycles

Reference is made to clauses A.8.2.1. and A.8.3.1. for raw and diluted exhaust respectively. The resulting values for power P [kW] shall be integrated over a test interval. The total work W_{act} [kWh] is calculated as follows:

$$W_{act} = \sum_{i=1}^{N} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^{N} \left(n_i \cdot T_i \right) \quad \text{(A.8-60)}$$

Where:

P_i = instantaneous engine power [kW]

n_i = instantaneous engine speed [min^{-1}]

T_i = instantaneous engine torque [Nm]

W_{act} = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

The specific emissions e_{gas} [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{gas} = \frac{m_{gas}}{W_{act}} \quad \text{(A.8-61)}$$

Where:

m_{gas} = total mass of emission [g/test]

W_{act} = cycle work [kWh]

In case of the transient cycle, the final test result e_{gas} [g/kWh] shall be a weighted average from cold start test and hot start test by using:

$$e_{gas} = \frac{(0.1 \cdot m_{cold}) + (0.9 \cdot m_{hot})}{(0.1 \cdot W_{act,cold}) + (0.9 \cdot W_{act,hot})} \quad \text{(A.8-62)}$$

In case of an infrequent (periodic) exhaust regeneration (clause 6.6.2. of this Annex **4**), the specific emissions shall be corrected with the multiplicative adjustment factor k_r (equation (6-4)) or with the two separate pairs of adjustment additive factors k_{Ur} (upward factor of equation (6-5)) and k_{Dr} (downward factor of equation (6-6)).

A.8.4.1.2. Steady-state discrete-mode cycle

The specific emissions e_{gas} [g/kWh] are calculated as follows:

$$e_{gas} = \frac{\sum_{i=1}^{N_{mode}} (q_{mgasi} \cdot WF_i)}{\sum_{i=1}^{N_{mode}} (P_i \cdot WF_i)} \quad \text{(A.8-63)}$$

Where:

$q_{mgas,i}$ = mean emission mass flow rate for the mode *i* [g/h]

P_i = engine power for the mode *i* [kW] with $P_i = P_{maxi} + P_{auxi}$ (see clauses 6.3 and 7.7.1.2.)

WF_i = weighing factor for the mode *i* [-]

A.8.4.2. Particulate emissions

A.8.4.2.1. Transient and ramped modal cycles

The particulate specific emissions shall be calculated with equation (A.8-61) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{PM} = \frac{m_{PM}}{W_{act}} \quad \text{(A.8-64)}$$

Where:

m_{PM} = total mass of particulates emission, calculated according to clause A.8.3.5. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in clause A.8.4.1.

A.8.4.2.2. Steady state discrete-mode cycle

The particulate specific emission e_{PM} [g/kWh] shall be calculated in the following way:

(a) For the single-filter method

$$e_{PM} = \frac{q_{mPM}}{\sum_{i=1}^{N} (P_i \cdot WF_i)} \quad \text{(A.8-65)}$$

Where:

P_i = engine power for the mode *i* [kW] with $P_i = P_{\text{max}i} + P_{\text{aux}i}$ (see clauses 6.3. and 7.7.1.2. of this Annex)

WF_i = weighing factor for the mode *i* [-]

q_{mPM} = particulate mass flow rate [g/h]

(b) For the multiple-filter method

$$e_{\text{PM}} = \frac{\sum_{i=1}^{\text{N}} \left(q_{m\text{PM}i} \cdot WF_i \right)}{\sum_{i=1}^{\text{N}} \left(P_i \cdot WF_i \right)} \qquad \text{(A.8-66)}$$

Where:

P_i = engine power for the mode *i* [kW] with $P_i = P_{\text{max}i} + P_{\text{aux}i}$ (see clauses 6.3. and 7.7.1.2 of this Annex)

WF_i = weighing factor for the mode *i* [-]

q_{mPMi} = particulate mass flow rate at mode *i* [g/h]

For the single-filter method, the effective weighing factor, WF_{ei}, for each mode shall be calculated in the following way:

$$WF_{\text{e}i} = \frac{m_{\text{sep}i} \cdot \overline{q_{m\text{edf}}}}{m_{\text{sep}} \cdot q_{m\text{edf}i}} \qquad \text{(A.8-67)}$$

Where:

m_{sepi} = mass of the diluted exhaust sample passed through the particulate sampling filters at mode *i* [kg]

$\overline{q_{m\text{edf}}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

q_{medfi} = equivalent diluted exhaust gas mass flow rate at mode *i* [kg/s]

m_{sep} = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

The value of the effective weighing factors shall be within ± 0.005 (absolute value) of the weighing factors listed in Annex 5.

ANNEX 4 - APPENDIX A.8.1

DILUTED EXHAUST FLOW (CVS) CALIBRATION

A.8.5. CALIBRATION OF CVS SYSTEM

The CVS system shall be calibrated by using an accurate flow-meter and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various types of flow-meters may be used, e.g. calibrated venturi, calibrated laminar flow-meter, calibrated turbine meter.

A.8.5.1. Positive displacement pump (PDP)

All the parameters related to the pump shall be simultaneously measured along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m^3/s at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used.

Temperature stability shall be maintained during calibration.

Leaks in all the connections and ducting between the calibration venturi and the CVS pump shall be maintained lower than 0.3 per cent of the lowest flow point (highest restriction and lowest PDP speed point).

The airflow rate (q_{VCVS}) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/s from the flow-meter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{VCVS}}{n} \cdot \frac{T}{273.15} \cdot \frac{101.325}{p_p} \qquad \text{(A.8-68)}$$

Where:

q_{VCVS} = airflow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

T = temperature at pump inlet [K]

p_p = absolute pressure at pump inlet [kPa]

n = pump speed [rev/s]

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) [s/rev] between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$X_0 = \frac{1}{n} \cdot \sqrt{\frac{\Delta p_p}{p_p}} \qquad \text{(A.8-69)}$$

Where:

Δp_p = pressure differential from pump inlet to pump outlet [kPa]

p_p = absolute outlet pressure at pump outlet [kPa]

n = pump speed [rev/s]

A linear least-square fit shall be performed to generate the calibration equation as follows:

$$V_0 = D_0 - m \cdot X_0 \quad \text{(A.8-70)}$$

With D_0 [m^3/rev] and m [m^3/s], intercept and slope respectively, describing the regression line.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D_0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ±0.5 per cent of the measured value of V_0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for *m*. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

A.8.5.2. Critical flow venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of venturi inlet pressure and temperature.

To determine the range of critical flow, K_V shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, K_V will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_V decreases, which indicates that the CFV is operated outside the permissible range.

The airflow rate (q_{VCVS}) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/s from the flow-meter data using the manufacturer's prescribed method. The calibration coefficient $K_V \left[\left(\sqrt{\mathrm{K}} \cdot \mathrm{m}^4 \cdot \mathrm{s} \right) / \mathrm{kg} \right]$ shall be calculated from the calibration data for each setting as follows:

$$K_V = \frac{q_{VCVS} \cdot \sqrt{T}}{p_p} \quad \text{(A.8-71)}$$

Where:

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

T = temperature at the venturi inlet [K]

p_p = absolute pressure at venturi inlet [kPa]

The average K_V and the standard deviation shall be calculated. The standard deviation shall not exceed ±0.3 per cent of the average K_V.

A.8.5.3. Subsonic venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown in equation (A.8-41).

The airflow rate (q_{VSSV}) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/s from the flow-meter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting as follows:

$$C_d = \frac{q_{VSSV}}{\frac{A_0}{60} \cdot {d_V}^2 \cdot p_p \cdot \sqrt{\left[\frac{1}{T_{in,V}}\left({r_p}^{1.4286} - {r_p}^{1.7143}\right)\left(\frac{1}{1-{r_D}^4 \cdot {r_p}^{1.4286}}\right)\right]}}$$

(A.8-72)

Where:

A_0 = collection of constants and units conversions = 0.0056940 $\left[\frac{\mathbf{m^3}}{\mathbf{min}} \cdot \frac{\mathbf{K^{\frac{1}{2}}}}{\mathbf{kPa}} \cdot \frac{\mathbf{1}}{\mathbf{mm^2}}\right]$

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

$T_{in,V}$ = temperature at the venturi inlet [K]

d_V = diameter of the SSV throat [mm]

r_p = ratio of the SSV throat to inlet absolute static pressure = $1 - \Delta p / p_p$ [-]

r_D = ratio of the SSV throat diameter, d_V, to the inlet pipe inner diameter D [-]

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number *Re*, at the SSV throat. The *Re* at the SSV throat shall be calculated with the following equation:

$$Re = A_1 \cdot 60 \cdot \frac{q_{VSSV}}{d_V \cdot \mu} \quad \text{(A.8-73)}$$

With

$$\mu = \frac{b \times T^{1.5}}{S + T} \quad \text{(A.8-74)}$$

Where:

A_1 = collection of constants and units conversions = 27.43831 $\left[\frac{kg}{m^3} \cdot \frac{min}{s} \cdot \frac{mm}{m}\right]$

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

d_V = diameter of the SSV throat [mm]

μ = absolute or dynamic viscosity of the gas [kg/(m·s)]

b = 1.458 x 10^6 (empirical constant) [kg/(m·s·$K^{0.5}$)]

S = 110.4 (empirical constant) [K]

Because q_{VSSV} is an input to the *Re* equation, the calculations shall be started with an initial guess for q_{VSSV} or C_d of the calibration venturi, and repeated until q_{VSSV} converges. The convergence method shall be accurate to 0.1 per cent of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ±0.5 per cent of the measured C_d for each calibration point.

ANNEX 4 - APPENDIX A.8.2

DRIFT CORRECTION

A.8.6. CALCULATIONS IN THIS APPENDIX ARE PERFORMED AS DESCRIBED IN APPENDIX A.7.2 TO APPENDIX A.7 TO ANNEX 4.

$$c_{idriftcor} = c_{refzero} + \left(c_{refspan} - c_{refzero}\right)\frac{2c_i - \left(c_{prezero} + c_{postzero}\right)}{\left(c_{prespan} + c_{postspan}\right) - \left(c_{prezero} + c_{postzero}\right)} \quad \text{(A.8-75)}$$

Where:

$c_{idriftcor}$ = concentration corrected for drift [ppm]

$c_{refzero}$ = reference concentration of the zero gas, which is usually zero unless known to be otherwise [ppm]

$c_{refspan}$ = reference concentration of the span gas [ppm]

$c_{prespan}$ = pre-test interval gas analyser response to the span gas concentration [ppm]

$c_{postspan}$ = post-test interval gas analyser response to the span gas concentration [ppm]

c_i or $\overline{c}$ = concentration recorded, i.e. measured, during test, before drift correction [ppm]

$c_{prezero}$ = pre-test interval gas analyser response to the zero gas concentration [ppm]

$c_{postzero}$ = post-test interval gas analyser response to the zero gas concentration [ppm]

ANNEX 5
TEST CYCLES

1. TEST CYCLE

1.1. Steady-state discrete-mode testing

(a) For variable-speed engines, the following 8-mode cycle[1] shall be followed in dynamometer operation on the test engine:

Mode Number	Engine Speed	Torque [per cent]	Weighing Factor
1	Rated (*)	100	0.15
2	Rated (*)	75	0.15
3	Rated (*)	50	0.15
4	Rated (*)	10	0.10
5	Intermediate	100	0.10
6	Intermediate	75	0.10
7	Intermediate	50	0.10
8	Idle	---	0.15

(*) Denormalization speed (ndenorm) shall be used in place of rated speed for engines tested according to Annex 4 and is defined in clause 7.7.1.1. of Annex 4. In this case (ndenorm) shall also be used in place of rated speed when determining the intermediate speed.

(b) For constant-speed engines, the following 5-mode cycle[2] shall be followed in dynamometer operation on the test engine:

Mode Number	Engine Speed	Torque [per cent]	Weighing Factor
1	Rated	100	0.05
2	Rated	75	0.25
3	Rated	50	0.30
4	Rated	25	0.30
5	Rated	10	0.10

The load figures are percentage values of the torque corresponding to the prime power[3] rating defined as the maximum power available during a variable power sequence, which may be run for an unlimited number of hours per year, between stated maintenance intervals and under the stated ambient conditions, the maintenance being carried out as prescribed by the manufacturer.

1.2. Steady-state ramped-modal testing

[1] Identical to C1 cycle as described in clause 8.3. of ISO 8178-4: 2007 (corr. 2008).
[2] Identical to D2 cycle as described in clause 8.4. of ISO 8178-4: 2007 (corr. 2008).
[3] For a better illustration of the prime power definition, see Figure 2 of ISO 8528-1: 2005.

(a) For variable-speed engines, the following 9-mode duty cycle applies in case of ramped-modal testing:

RMC mode	Time in mode [s]	Engine speed[a,c]	Torque (per cent)[b,c]
1a Steady-state	126	Warm idle	0
1b Transition	20	Linear transition	Linear transition
2a Steady-state	159	Intermediate	100
2b Transition	20	Intermediate	Linear transition
3a Steady-state	160	Intermediate	50
3b Transition	20	Intermediate	Linear transition
4a Steady-state	162	Intermediate	75
4b Transition	20	Linear transition	Linear transition
5a Steady-state	246	Rated	100
5b Transition	20	Rated	Linear transition
6a Steady-state	164	Rated	10
6b Transition	20	Rated	Linear transition
7a Steady-state	248	Rated	75
7b Transition	20	Rated	Linear transition
8a Steady-state	247	Rated	50
8b Transition	20	Linear transition	Linear transition
9 Steady-state	128	Warm idle	0

[a] Speed terms as per footnote of the steady-state discrete mode test.

[b] The percent torque is relative to the maximum torque at the commanded engine speed.

[c] Advance from one mode to the next within a 20 s transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode, and simultaneously command a similar linear progression for engine speed if there is a change in speed setting

(b) For constant-speed engines, the following 5-mode duty cycle applies in case of ramped-modal testing:

RMC mode	Time in mode [s]	Engine speed	Torque (per cent)[a,b]
1a Steady-state	53	Engine governed	100
1b Transition	20	Engine governed	Linear transition
2a Steady-state	101	Engine governed	10
2b Transition	20	Engine governed	Linear transition
3a Steady-state	277	Engine governed	75
3b Transition	20	Engine governed	Linear transition
4a Steady-state	339	Engine governed	25
4b Transition	20	Engine governed	Linear transition
5 Steady-state	350	Engine governed	50

[a] The percent torque is relative to maximum test torque.

[b] Advance from one mode to the next within a 20 s transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode.

1.3. Transient cycle

(a) For variable-speed engines, the following full transient (variable speed and variable load) engine dynamometer schedule applies:

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	%	%	s	%	%	s	%	%
1	0	0	51	102	50	101	75	24
2	0	0	52	102	46	102	73	30
3	0	0	53	102	41	103	74	24
4	0	0	54	102	31	104	77	6
5	0	0	55	89	2	105	76	12
6	0	0	56	82	0	106	74	39
7	0	0	57	47	1	107	72	30
8	0	0	58	23	1	108	75	22
9	0	0	59	1	3	109	78	64
10	0	0	60	1	8	110	102	34
11	0	0	61	1	3	111	103	28
12	0	0	62	1	5	112	103	28
13	0	0	63	1	6	113	103	19
14	0	0	64	1	4	114	103	32
15	0	0	65	1	4	115	104	25
16	0	0	66	0	6	116	103	38
17	0	0	67	1	4	117	103	39
18	0	0	68	9	21	118	103	34
19	0	0	69	25	56	119	102	44
20	0	0	70	64	26	120	103	38
21	0	0	71	60	31	121	102	43
22	0	0	72	63	20	122	103	34
23	0	0	73	62	24	123	102	41
24	1	3	74	64	8	124	103	44
25	1	3	75	58	44	125	103	37
26	1	3	76	65	10	126	103	27
27	1	3	77	65	12	127	104	13
28	1	3	78	68	23	128	104	30
29	1	3	79	69	30	129	104	19
30	1	6	80	71	30	130	103	28
31	1	6	81	74	15	131	104	40
32	2	1	82	71	23	132	104	32
33	4	13	83	73	20	133	101	63
34	7	18	84	73	21	134	102	54
35	9	21	85	73	19	135	102	52
36	17	20	86	70	33	136	102	51
37	33	42	87	70	34	137	103	40
38	57	46	88	65	47	138	104	34
39	44	33	89	66	47	139	102	36
40	31	0	90	64	53	140	104	44
41	22	27	91	65	45	141	103	44
42	33	43	92	66	38	142	104	33
43	80	49	93	67	49	143	102	27
44	105	47	94	69	39	144	103	26
45	98	70	95	69	39	145	79	53
46	104	36	96	66	42	146	51	37
47	104	65	97	71	29	147	24	23
48	96	71	98	75	29	148	13	33
49	101	62	99	72	23	149	19	55
50	102	51	100	74	22	150	45	30

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
151	34	7	200	3	8	249	54	39
152	14	4	201	3	22	250	60	42
153	8	16	202	12	20	251	48	18
154	15	6	203	14	20	252	54	51
155	39	47	204	16	17	253	88	90
156	39	4	205	20	18	254	103	84
157	35	26	206	27	34	255	103	85
158	27	38	207	32	33	256	102	84
159	43	40	208	41	31	257	58	66
160	14	23	209	43	31	258	64	97
161	10	10	210	37	33	259	56	80
162	15	33	211	26	18	260	51	67
163	35	72	212	18	29	261	52	96
164	60	39	213	14	51	262	63	62
165	55	31	214	13	11	263	71	6
166	47	30	215	12	9	264	33	16
167	16	7	216	15	33	265	47	45
168	0	6	217	20	25	266	43	56
169	0	8	218	25	17	267	42	27
170	0	8	219	31	29	268	42	64
171	0	2	220	36	66	269	75	74
172	2	17	221	66	40	270	68	96
173	10	28	222	50	13	271	86	61
174	28	31	223	16	24	272	66	0
175	33	30	224	26	50	273	37	0
176	36	0	225	64	23	274	45	37
177	19	10	226	81	20	275	68	96
178	1	18	227	83	11	276	80	97
179	0	16	228	79	23	277	92	96
180	1	3	229	76	31	278	90	97
181	1	4	230	68	24	279	82	96
182	1	5	231	59	33	280	94	81
183	1	6	232	59	3	281	90	85
184	1	5	233	25	7	282	96	65
185	1	3	234	21	10	283	70	96
186	1	4	235	20	19	284	55	95
187	1	4	236	4	10	285	70	96
188	1	6	237	5	7	286	79	96
189	8	18	238	4	5	287	81	71
190	20	51	239	4	6	288	71	60
191	49	19	240	4	6	289	92	65
192	41	13	241	4	5	290	82	63
193	31	16	242	7	5	291	61	47
194	28	21	243	16	28	292	52	37
195	21	17	244	28	25	293	24	0
196	31	21	245	52	53	294	20	7
197	21	8	246	50	8	295	39	48
198	0	14	247	26	40	296	39	54
199	0	12	248	48	29	297	63	58

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
298	53	31	347	57	79	396	60	90
299	51	24	348	76	97	397	53	66
300	48	40	349	84	97	398	70	48
301	39	0	350	86	97	399	77	93
302	35	18	351	81	98	400	79	67
303	36	16	352	83	83	401	46	65
304	29	17	353	65	96	402	69	98
305	28	21	354	93	72	403	80	97
306	31	15	355	63	60	404	74	97
307	31	10	356	72	49	405	75	98
308	43	19	357	56	27	406	56	61
309	49	63	358	29	0	407	42	0
310	78	61	359	18	13	408	36	32
311	78	46	360	25	11	409	34	43
312	66	65	361	28	24	410	68	83
313	78	97	362	34	53	411	102	48
314	84	63	363	65	83	412	62	0
315	57	26	364	80	44	413	41	39
316	36	22	365	77	46	414	71	86
317	20	34	366	76	50	415	91	52
318	19	8	367	45	52	416	89	55
319	9	10	368	61	98	417	89	56
320	5	5	369	61	69	418	88	58
321	7	11	370	63	49	419	78	69
322	15	15	371	32	0	420	98	39
323	12	9	372	10	8	421	64	61
324	13	27	373	17	7	422	90	34
325	15	28	374	16	13	423	88	38
326	16	28	375	11	6	424	97	62
327	16	31	376	9	5	425	100	53
328	15	20	377	9	12	426	81	58
329	17	0	378	12	46	427	74	51
330	20	34	379	15	30	428	76	57
331	21	25	380	26	28	429	76	72
332	20	0	381	13	9	430	85	72
333	23	25	382	16	21	431	84	60
334	30	58	383	24	4	432	83	72
335	63	96	384	36	43	433	83	72
336	83	60	385	65	85	434	86	72
337	61	0	386	78	66	435	89	72
338	26	0	387	63	39	436	86	72
339	29	44	388	32	34	437	87	72
340	68	97	389	46	55	438	88	72
341	80	97	390	47	42	439	88	71
342	88	97	391	42	39	440	87	72
343	99	88	392	27	0	441	85	71
344	102	86	393	14	5	442	88	72
345	100	82	394	14	14	443	88	72
346	74	79	395	24	54	444	84	72

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
445	83	73	495	51	61	545	24	72
446	77	73	496	68	47	546	64	70
447	74	73	497	29	42	547	77	62
448	76	72	498	24	73	548	80	68
449	46	77	499	64	71	549	83	53
450	78	62	500	90	71	550	83	50
451	79	35	501	100	61	551	83	50
452	82	38	502	94	73	552	85	43
453	81	41	503	84	73	553	86	45
454	79	37	504	79	73	554	89	35
455	78	35	505	75	72	555	82	61
456	78	38	506	78	73	556	87	50
457	78	46	507	80	73	557	85	55
458	75	49	508	81	73	558	89	49
459	73	50	509	81	73	559	87	70
460	79	58	510	83	73	560	91	39
461	79	71	511	85	73	561	72	3
462	83	44	512	84	73	562	43	25
463	53	48	513	85	73	563	30	60
464	40	48	514	86	73	564	40	45
465	51	75	515	85	73	565	37	32
466	75	72	516	85	73	566	37	32
467	89	67	517	85	72	567	43	70
468	93	60	518	85	73	568	70	54
469	89	73	519	83	73	569	77	47
470	86	73	520	79	73	570	79	66
471	81	73	521	78	73	571	85	53
472	78	73	522	81	73	572	83	57
473	78	73	523	82	72	573	86	52
474	76	73	524	94	56	574	85	51
475	79	73	525	66	48	575	70	39
476	82	73	526	35	71	576	50	5
477	86	73	527	51	44	577	38	36
478	88	72	528	60	23	578	30	71
479	92	71	529	64	10	579	75	53
480	97	54	530	63	14	580	84	40
481	73	43	531	70	37	581	85	42
482	36	64	532	76	45	582	86	49
483	63	31	533	78	18	583	86	57
484	78	1	534	76	51	584	89	68
485	69	27	535	75	33	585	99	61
486	67	28	536	81	17	586	77	29
487	72	9	537	76	45	587	81	72
488	71	9	538	76	30	588	89	69
489	78	36	539	80	14	589	49	56
490	81	56	540	71	18	590	79	70
491	75	53	541	71	14	591	104	59
492	60	45	542	71	11	592	103	54
493	50	37	543	65	2	593	102	56
494	66	41	544	31	26	594	102	56

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
595	103	61	644	79	72	693	100	69
596	102	64	645	78	70	694	102	72
597	103	60	646	80	70	695	101	69
598	93	72	647	82	71	696	100	69
599	86	73	648	84	71	697	102	71
600	76	73	649	83	71	698	102	71
601	59	49	650	83	73	699	102	69
602	46	22	651	81	70	700	102	71
603	40	65	652	80	71	701	102	68
604	72	31	653	78	71	702	100	69
605	72	27	654	76	70	703	102	70
606	67	44	655	76	70	704	102	68
607	68	37	656	76	71	705	102	70
608	67	42	657	79	71	706	102	72
609	68	50	658	78	71	707	102	68
610	77	43	659	81	70	708	102	69
611	58	4	660	83	72	709	100	68
612	22	37	661	84	71	710	102	71
613	57	69	662	86	71	711	101	64
614	68	38	663	87	71	712	102	69
615	73	2	664	92	72	713	102	69
616	40	14	665	91	72	714	101	69
617	42	38	666	90	71	715	102	64
618	64	69	667	90	71	716	102	69
619	64	74	668	91	71	717	102	68
620	67	73	669	90	70	718	102	70
621	65	73	670	90	72	719	102	69
622	68	73	671	91	71	720	102	70
623	65	49	672	90	71	721	102	70
624	81	0	673	90	71	722	102	62
625	37	25	674	92	72	723	104	38
626	24	69	675	93	69	724	104	15
627	68	71	676	90	70	725	102	24
628	70	71	677	93	72	726	102	45
629	76	70	678	91	70	727	102	47
630	71	72	679	89	71	728	104	40
631	73	69	680	91	71	729	101	52
632	76	70	681	90	71	730	103	32
633	77	72	682	90	71	731	102	50
634	77	72	683	92	71	732	103	30
635	77	72	684	91	71	733	103	44
636	77	70	685	93	71	734	102	40
637	76	71	686	93	68	735	103	43
638	76	71	687	98	68	736	103	41
639	77	71	688	98	67	737	102	46
640	77	71	689	100	69	738	103	39
641	78	70	690	99	68	739	102	41
642	77	70	691	100	71	740	103	41
643	77	71	692	99	68	741	102	38

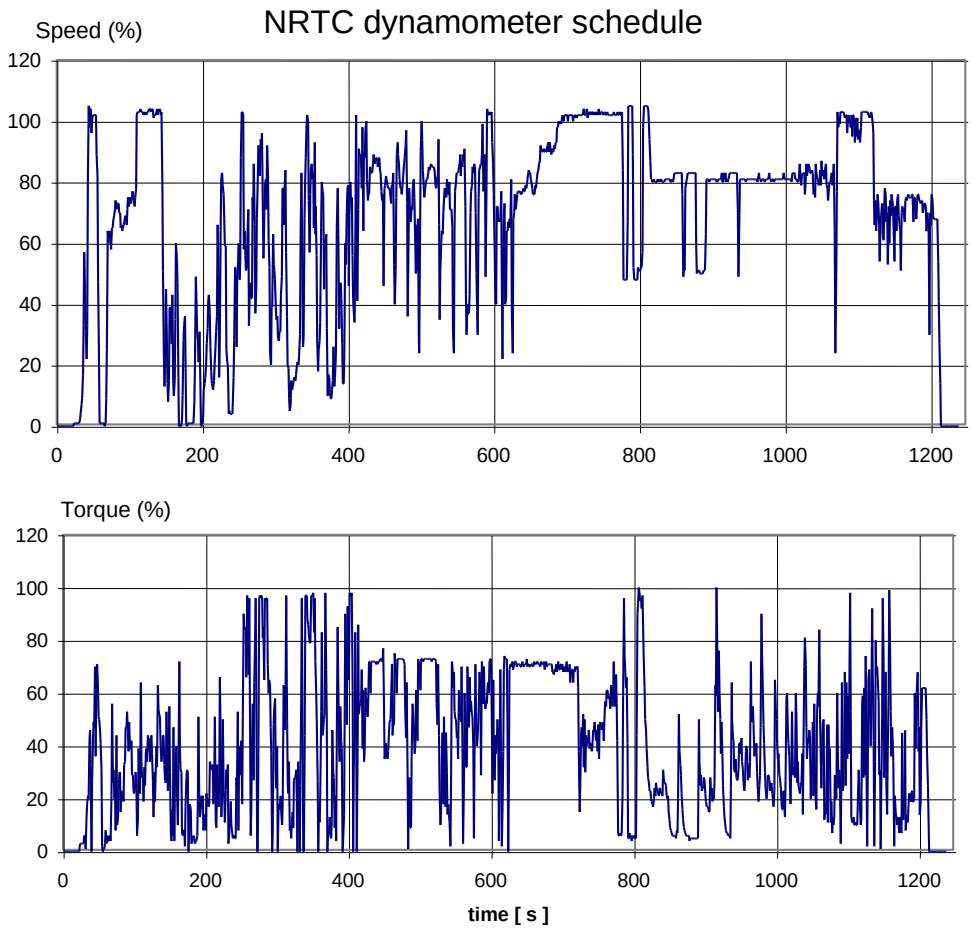
Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
742	103	39	792	52	5	842	81	27
743	102	46	793	48	5	843	80	26
744	104	46	794	48	7	844	80	26
745	103	49	795	48	5	845	81	25
746	102	45	796	48	6	846	80	21
747	103	42	797	48	4	847	81	20
748	103	46	798	52	6	848	83	21
749	103	38	799	51	5	849	83	15
750	102	48	800	51	6	850	83	12
751	103	35	801	51	6	851	83	9
752	102	48	802	52	5	852	83	8
753	103	49	803	52	5	853	83	7
754	102	48	804	57	44	854	83	6
755	102	46	805	98	90	855	83	6
756	103	47	806	105	94	856	83	6
757	102	49	807	105	100	857	83	6
758	102	42	808	105	98	858	83	6
759	102	52	809	105	95	859	76	5
760	102	57	810	105	96	860	49	8
761	102	55	811	105	92	861	51	7
762	102	61	812	104	97	862	51	20
763	102	61	813	100	85	863	78	52
764	102	58	814	94	74	864	80	38
765	103	58	815	87	62	865	81	33
766	102	59	816	81	50	866	83	29
767	102	54	817	81	46	867	83	22
768	102	63	818	80	39	868	83	16
769	102	61	819	80	32	869	83	12
770	103	55	820	81	28	870	83	9
771	102	60	821	80	26	871	83	8
772	102	72	822	80	23	872	83	7
773	103	56	823	80	23	873	83	6
774	102	55	824	80	20	874	83	6
775	102	67	825	81	19	875	83	6
776	103	56	826	80	18	876	83	6
777	84	42	827	81	17	877	83	6
778	48	7	828	80	20	878	59	4
779	48	6	829	81	24	879	50	5
780	48	6	830	81	21	880	51	5
781	48	7	831	80	26	881	51	5
782	48	6	832	80	24	882	51	5
783	48	7	833	80	23	883	50	5
784	67	21	834	80	22	884	50	5
785	105	59	835	81	21	885	50	5
786	105	96	836	81	24	886	50	5
787	105	74	837	81	24	887	50	5
788	105	66	838	81	22	888	51	5
789	105	62	839	81	22	889	51	5
790	105	66	840	81	21	890	51	5
791	89	41	841	81	31	891	63	50

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
892	81	34	941	81	31	990	81	27
893	81	25	942	81	30	991	81	23
894	81	29	943	81	35	992	81	25
895	81	23	944	81	28	993	81	26
896	80	24	945	81	27	994	81	22
897	81	24	946	80	27	995	81	20
898	81	28	947	81	31	996	81	17
899	81	27	948	81	41	997	81	23
900	81	22	949	81	41	998	83	65
901	81	19	950	81	37	999	81	54
902	81	17	951	81	43	1000	81	50
903	81	17	952	81	34	1001	81	41
904	81	17	953	81	31	1002	81	35
905	81	15	954	81	26	1003	81	37
906	80	15	955	81	23	1004	81	29
907	80	28	956	81	27	1005	81	28
908	81	22	957	81	38	1006	81	24
909	81	24	958	81	40	1007	81	19
910	81	19	959	81	39	1008	81	16
911	81	21	960	81	27	1009	80	16
912	81	20	961	81	33	1010	83	23
913	83	26	962	80	28	1011	83	17
914	80	63	963	81	34	1012	83	13
915	80	59	964	83	72	1013	83	27
916	83	100	965	81	49	1014	81	58
917	81	73	966	81	51	1015	81	60
918	83	53	967	80	55	1016	81	46
919	80	76	968	81	48	1017	80	41
920	81	61	969	81	36	1018	80	36
921	80	50	970	81	39	1019	81	26
922	81	37	971	81	38	1020	86	18
923	82	49	972	80	41	1021	82	35
924	83	37	973	81	30	1022	79	53
925	83	25	974	81	23	1023	82	30
926	83	17	975	81	19	1024	83	29
927	83	13	976	81	25	1025	83	32
928	83	10	977	81	29	1026	83	28
929	83	8	978	83	47	1027	76	60
930	83	7	979	81	90	1028	79	51
931	83	7	980	81	75	1029	86	26
932	83	6	981	80	60	1030	82	34
933	83	6	982	81	48	1031	84	25
934	83	6	983	81	41	1032	86	23
935	71	5	984	81	30	1033	85	22
936	49	24	985	80	24	1034	83	26
937	69	64	986	81	20	1035	83	25
938	81	50	987	81	21	1036	83	37
939	81	43	988	81	29	1037	84	14
940	81	42	989	81	29	1038	83	39

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
1039	76	70	1088	100	31	1137	78	2
1040	78	81	1089	100	28	1138	76	34
1041	75	71	1090	98	3	1139	67	80
1042	86	47	1091	102	26	1140	70	67
1043	83	35	1092	95	64	1141	53	70
1044	81	43	1093	102	23	1142	72	65
1045	81	41	1094	102	25	1143	60	57
1046	79	46	1095	98	42	1144	74	29
1047	80	44	1096	93	68	1145	69	31
1048	84	20	1097	101	25	1146	76	1
1049	79	31	1098	95	64	1147	74	22
1050	87	29	1099	101	35	1148	72	52
1051	82	49	1100	94	59	1149	62	96
1052	84	21	1101	97	37	1150	54	72
1053	82	56	1102	97	60	1151	72	28
1054	81	30	1103	93	98	1152	72	35
1055	85	21	1104	98	53	1153	64	68
1056	86	16	1105	103	13	1154	74	27
1057	79	52	1106	103	11	1155	76	14
1058	78	60	1107	103	11	1156	69	38
1059	74	55	1108	103	13	1157	66	59
1060	78	84	1109	103	10	1158	64	99
1061	80	54	1110	103	10	1159	51	86
1062	80	35	1111	103	11	1160	70	53
1063	82	24	1112	103	10	1161	72	36
1064	83	43	1113	103	10	1162	71	47
1065	79	49	1114	102	18	1163	70	42
1066	83	50	1115	102	31	1164	67	34
1067	86	12	1116	101	24	1165	74	2
1068	64	14	1117	102	19	1166	75	21
1069	24	14	1118	103	10	1167	74	15
1070	49	21	1119	102	12	1168	75	13
1071	77	48	1120	99	56	1169	76	10
1072	103	11	1121	96	59	1170	75	13
1073	98	48	1122	74	28	1171	75	10
1074	101	34	1123	66	62	1172	75	7
1075	99	39	1124	74	29	1173	75	13
1076	103	11	1125	64	74	1174	76	8
1077	103	19	1126	69	40	1175	76	7
1078	103	7	1127	76	2	1176	67	45
1079	103	13	1128	72	29	1177	75	13
1080	103	10	1129	66	65	1178	75	12
1081	102	13	1130	54	69	1179	73	21
1082	101	29	1131	69	56	1180	68	46
1083	102	25	1132	69	40	1181	74	8
1084	102	20	1133	73	54	1182	76	11
1085	96	60	1134	63	92	1183	76	14
1086	99	38	1135	61	67	1184	74	11
1087	102	24	1136	72	42	1185	74	18

Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %	Time s	Norm. Speed %	Norm. Torque %
1186	73	22	1236	0	0			
1187	74	20	1237	0	0			
1188	74	19	1238	0	0			
1189	70	22						
1190	71	23						
1191	73	19						
1192	73	19						
1193	72	20						
1194	64	60						
1195	70	39						
1196	66	56						
1197	68	64						
1198	30	68						
1199	70	38						
1200	66	47						
1201	76	14						
1202	74	18						
1203	69	46						
1204	68	62						
1205	68	62						
1206	68	62						
1207	68	62						
1208	68	62						
1209	68	62						
1210	54	50						
1211	41	37						
1212	27	25						
1213	14	12						
1214	0	0						
1215	0	0						
1216	0	0						
1217	0	0						
1218	0	0						
1219	0	0						
1220	0	0						
1221	0	0						
1222	0	0						
1223	0	0						
1224	0	0						
1225	0	0						
1226	0	0						
1227	0	0						
1228	0	0						
1229	0	0						
1230	0	0						
1231	0	0						
1232	0	0						
1233	0	0						
1234	0	0						
1235	0	0						

A graphical display of the NRTC dynamometer schedule is shown below



ANNEX 6

TECHNICAL CHARACTERISTICS OF DIESEL FUEL

For Type Approval and Conformity of Production (COP) test, fuel shall be reference fuel or commercial fuel as recommended by manufacturer.

ANNEX 6 - APPENDIX 1
REFERENCE DIESEL FUEL CHARACTERISTICS

REFERENCE DIESEL FUEL SPECIFICATION FOR BHARAT STAGE (AGRICULTURAL TRACTOR, CONSTRUCTION EQUIPMENT VEHICLE AND COMBINE HARVESTER) BS IV

Parameter	Unit	Limits [1]		Test method
		Minimum	Maximum	
Cetane Index		46.0		EN ISO 4264
Cetane number [2]		52.0	56.0	EN ISO 5165
Density at 15 °C	kg/m^3	833.0	837.0	EN ISO 12185
Distillation:				
- 50% point	°C	245.0	—	EN ISO 3405
- 95% point	°C	345.0	360.0	EN ISO 3405
- final boiling point	°C	—	370.0	EN ISO 3405
Flash point	°C	55	—	EN ISO 2719
Cloud point	°C	-	-10	EN 23015
Viscosity at 40 °C	mm^2/s	2.30	3.30	EN ISO 3104
Polycyclic aromatic hydrocarbons	% m/m	2.0	4.0	EN 12916
Sulphur content	mg/kg	—	10.0	EN ISO 20846 EN ISO 20884
Copper corrosion 3hrs, 50 °C		—	Class 1	EN ISO 2160
Conradson carbon residue (10 % DR)	% m/m	—	0.20	EN ISO 10370
Ash content	% m/m	—	0.010	EN ISO 6245
Total contamination	mg/kg	-	24	EN 12662
Water content	mg/kg	—	200	EN ISO 12937
Acid number	mg KOH/g	—	0.10	EN ISO 6618
Lubricity (HFRR wear scan diameter at 60 °C)	µm	—	400	EN ISO 12156
Oxidation stability @ 110 °C [3]	h	20.0		EN 15751
FAME [4]	% v/v	6.0	7.0	EN 14078

1 The values quoted in the specifications are 'true values'. In establishment of their limit values the terms of ISO 4259 Petroleum products – Determination and application of precision data in relation to methods of test have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

2 The range for cetane number is not in accordance with the requirements of a minimum range of 4R. However, in the case of a dispute between fuel supplier and fuel user, the terms of ISO 4259 may be used to resolve such disputes provided replicate measurements, of sufficient number to archive the necessary precision, are made in preference to single determinations.

3 Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice shall be sought from the supplier as to storage conditions and life.

4 FAME content to meet the specification of EN 14214.

ANNEX 6 - APPENDIX 2

COMMERCIAL DIESEL FUEL CHARACTERISTICS

COMMERCIAL DIESEL FUEL SPECIFICATION FOR BHARAT STAGE (AGRICULTURAL TRACTOR, CONSTRUCTION EQUIPMENT VEHICLE AND COMBINE HARVESTER) BS IV

Characteristics	Unit	Requirements
Ash, max	% mass	0.01
Carbon Residue (Ramsbottom) on 10 % residue, max	% mass	0.3 without additives
Cetane number (CN), min		51
Cetane Index (CI), min		46
Distillation :		
95% vol. recovery at ^{0}C, max	^{0}C	360
Flash point :		
a) Abel, min	^{0}C	35
Kinematic Viscosity @ 40 ^{0}C	cst	2.0-4.5
Density @15 ^{0}C	kg/m^3	845
Total Sulphur, max.	mg/kg	10
Water content, max	mg/kg	200
Cold filter Plugging point (CFPP)		
a) Summer, max	^{0}C	18
b) Winter, max	^{0}C	6
Total contaminations, max	mg/kg	24
Oxidation stability, max	g/m^3	25
Polycyclic Aromatic Hydrocarbon (PAH), max	% mass	8
Lubricity, corrected wear scar diameter @ 60 ^{0}C, max	µm (microns)	460
Copper strip corrosion for 3 hrs @ 50^{0}C	rating	Class – 1
FAME content max.	% v/v	7.0

Note :

- Test methods and other provisions / details along with the requirements as given above shall be issued by Bureau of Indian Standards.
- The Cetane number (CN),(min) shall be permitted up to 48 in North Eastern States till 01.04.2023

ANNEX 7

INSTALLATION REQUIREMENTS FOR EQUIPMENT AND AUXILIARIES

Number	Equipment and auxiliaries	Fitted foremissiontest
1	Inlet system	
	Inlet manifold	Yes
	Crank case emission control system	Yes
	Airflow-meter	Yes
	Air filter	Yes[a]
	Inlet silencer	Yes[a]
	Induction-heating device of inlet manifold	Yes, standard production equipment. If possible to be set in the most favourable condition
2	Exhaust system	
	Exhaust after treatment	Yes
	Exhaust manifold	Yes
	Connecting pipes	Yes[b]
	Silencer	Yes[b]
	Tail pipe	Yes[b]
	Exhaust brake	No[c]
	Pressure charging device	Yes
3	Fuel supply pump	Yes[d]
4	Fuel injection equipment	
	Prefilter	Yes
	Filter	Yes
	Pump	Yes
	High-pressurepipe	Yes
	Injector	Yes
	Electronic control unit, sensors,etc.	Yes
	Governor/controlsystem	Yes

Number	Equipment andauxiliaries	Fitted foremissiontest
	Automaticfull-load stop for the control rack depending on atmospheric conditions	Yes
5	Liquid-cooling equipment	
	Radiator	No
	Fan	No
	Fancowl	No
	Water pump	Yes[e]
	Thermostat	Yes[f]
6	Aircooling	
	Cowl	No[g]
	FanorBlower	No[g]
	Temperature-regulating device	No
7	Electrical equipment Generator	Yes[h]
8	Pressure charging equipment	
	Compressor driven either directly by the engine and/or by the exhaust gases	Yes
	Charge air cooler	Yes[g,i]
	Coolant pump or fan (engine-driven)	No[g]
	Coolant flow control device	Yes
9	Auxiliary test-bed fan	Yes,ifnecessary
10	Anti-pollution device	Yes
11	Starting equipment	Yes or test bed equipment[j]
12	Lubricating oil pump	Yes

13	Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test. The following non-exhaustive list is given as an example: (i) Air compressor for brakes (ii) Power steering compressor (iii) Suspension compressor (iv) air-conditioning system.	No

[a] The complete inlet system shall be fitted as provided for the intended application:

(i) where there is a risk of an appreciable effect on the engine power;

(ii) when the manufacturer requests that this should be done.

In other cases, an equivalent system may be used and a check should be made to ascertain that the intake pressure does not differ by more than 100 Pa from the upper limit specified by the manufacturer for a clean air filter.

[b] The complete exhaust system shall be fitted as provided for the intended application:

(i) where there is a risk of an appreciable effect on the engine power;

(ii) when the manufacturer requests that this should be done.

In other cases, an equivalent system may be installed provided the pressure measured does not differ by more than 1,000 Pa from the upper limit specified by the manufacturer.

[c] If an exhaust brake is incorporated in the engine, the throttle valve shall be fixed in the fully open position.

[d] The fuel feed pressure may be adjusted, if necessary, to reproduce the pressure existing in the particular engine application (particularly when a "fuel return" system is used).

[e] The cooling-liquid circulation shall be operated by the engine water pump only. Cooling of the liquid may be produced by an external circuit, such that the pressure loss of this circuit and the pressure at the pump inlet remain substantially the same as those of the engine cooling system.

[f] The thermostat may be fixed in the fully open position.

[g] When the cooling fan or blower is fitted for the test, the power absorbed shall be added to the results, except for cooling fans of air cooled engines directly fitted on the crankshaft. The fan or blower power shall be determined at the speeds used for the test either by calculation from standard characteristics or by practical tests.

[h] Minimum power of the generator: the electrical power of the generator shall be limited to that necessary for operation of accessories which are indispensable for engine operation. If the connection of a battery is necessary, a fully charged battery in good condition shall be used.

[i] Charge air-cooled engines shall be tested with charge air cooling, whether liquid - or air-cooled, but if the manufacturer prefers, a test bench system may replace the air cooler. In either case, the measurement of power at each speed shall be made with the maximum pressure drop and the minimum temperature drop of the engine air across the charge air cooler on the test bench system as those specified by the manufacturer.

[j] The power for electrical or other starting systems shall be provided from the test bed.

ANNEX 8

DURABILITY REQUIREMENTS

1. VERIFYING THE DURABILITY OF CI ENGINES OF POWER BANDS 37 KW ≤ P < 56 KW

This annex shall apply to CI engines for power bands 37 kW ≤ P < 56 kW only.

1.1. Manufacturers shall determine a Deterioration Factor (DF) value for each regulated pollutant for all engine families of power bands 37 kW ≤ P < 56 kW. Such DFs shall be used for type approval and production line testing.

1.1.1. Test to establish DFs shall be conducted as follows:

1.1.1.1. The manufacturer shall conduct durability tests to accumulate engine operating hours according to a test schedule that is selected on the basis of good engineering judgement to be representative of in-use engine operation in respect to characterising emission performance deterioration. The durability test period should typically represent the equivalent of at least one quarter of the emission durability period (EDP).

Service accumulation operating hours may be acquired through running engines on a dynamometer test bed or from actual in-field machine operation. Accelerated durability tests can be applied whereby the service accumulation schedule is performed at a higher load factor than typically experienced in the field. The acceleration factor relating the number of engine durability test hours to the equivalent number of EDP hours shall be determined by the engine manufacturer based on good engineering judgement.

During the period of the durability test, no emission sensitive components can be serviced or replaced other than to the routine service schedule recommended by the manufacturer.

The test engine, subsystems, or components to be used to determine exhaust emission DFs for an engine family, or for engine families of equivalent emission control system technology, shall be selected by the engine manufacturer on the basis of good engineering judgement. The criterion is that the test engine should represent the emission deterioration characteristics of the engine families that will apply the resulting DF values for type approval. Engines of different bore and stroke, different configuration, different air management systems, different fuel systems can be considered as equivalent in respect to emissions deterioration characteristics if there is a reasonable technical basis for such determination.

DF values from another manufacturer can be applied if there is a reasonable basis for considering technology equivalence with respect to emissions deterioration, and evidence that the tests have been carried according to the specified requirements.

Emissions testing shall be performed according to the procedures defined in this Part for the test engine after initial run-in but before any service accumulation test, and at the completion of the durability test. Emission tests can also be performed at intervals during the service accumulation test period, and applied in determining the deterioration trend.

1.1.1.2. The service accumulation tests or the emissions tests performed to determine deterioration need not be witnessed by the Test Agency.

1.1.1.3. Determination of DF values from durability tests

An additive DF is defined as the value obtained by subtraction of the emission value determine at the beginning of the EDP, from the emissions value determined to represent the emission performance at the end of the EDP.

A multiplicative DF is defined as the emission level determined for the end of the EDP divided by the emission value recorded at the beginning of the EDP.

Separate DF values shall be established for each of the pollutants covered by the legislation. In the case of establishing a DF value relative to the NO_x + HC standard, for an additive DF, this is determined based on the sum of the pollutants notwithstanding that a negative deterioration for one pollutant may not offset deterioration for the other. For a multiplicative NO_x + HC DF, separate HC and NO_x DFs shall be determined and applied separately when calculating the deteriorated emission levels from an emissions test result before combining the resultant deteriorated NO_x and HC values to establish compliance with the standard.

In cases where the testing is not conducted for the full EDP, the emission values at the end of the EDP is determined by extrapolation of the emission deterioration trend established for the test period, to the full EDP.

When emissions test results have been recorded periodically during the service accumulation durability testing, standard statistical processing techniques based on good practice shall be applied to determine the emission levels at the end of the EDP; statistical significance testing can be applied in the determination of the final emissions values.

If the calculation results in a value of less than 1.00 for a multiplicative DF, or less than 0.00 for an additive DF, then the DF shall be 1.0 or 0.00, respectively.

1.1.1.4. A manufacturer may, with the approval of the Test Agency, use DF values established from results of durability tests conducted to obtain DF values for certification of on-road HD CI engines. This will be allowed if there is technological equivalency between the test on-road engine and the non-road engine families applying the DF values for certification. The DF values derived from on-road engine emission durability test results shall be calculated on the basis of EDP values defined in clause 3.

1.1.1.5. In the case where an engine family uses established technology, an analysis based on good engineering practices may be used in lieu of testing to determine a deterioration factor for that engine family subject to approval of the Test Agency.

1.2. DF information in approval applications

1.2.1. Additive DFs shall be specified for each pollutant in an engine family approval application for CI engines not using any after-treatment device.

1.2.2. Multiplicative DFs shall be specified for each pollutant in an engine family approval application for CI engines using an after-treatment device.

1.2.3. The manufacturer shall furnish the Test Agency on request with information to support the DF values. This would typically include emission test results, service accumulation schedule, maintenance procedures together with information to support engineering judgements of technological equivalency, if applicable.

2. VERIFYING THE DURABILITY OF CI ENGINES

2.1 General

2.1.1. This clause shall apply to CI engines.

2.1.2. This clause 2. details the procedures for selecting engines to be tested over a service accumulation schedule for the purpose of determining deterioration factors for stage IV engine type approval and conformity of production assessments. The deterioration factors shall be applied in accordance with clause 2.4.7. to the emissions measured according to Annex 4 to this Part.

2.1.3. The service accumulation tests or the emissions tests performed to determine deterioration need not be witnessed by the Test Agency.

2.1.4. This clause 2. also details the emission-related and non-emission-related maintenance that should be or may be carried out on engines undergoing a service accumulation schedule. Such maintenance shall conform to the maintenance performed on in-service engines and communicated to owners of new engines.

2.1.5. At the request of the manufacturer, the Test Agency may allow the use of deterioration factors that have been established using alternative procedures to those specified in clauses 2.4.1. to 2.4.5. In this case, the manufacturer shall demonstrate to the satisfaction of the Test Agency that the alternative procedures that have been used are no less rigorous than those contained in clauses 2.4.1 to 2.4.5.

2.2. Reserved

2.3. Selection of engines for establishing emission durability period deterioration factors

2.3.1. Engines shall be selected from the engine family defined in Annex 1B of this Part for emission testing to establish emission durability period deterioration factors.

2.3.2. Engines from different engine families may be further combined into families based on the type of exhaust after-treatment system utilised. In order to place engines with different cylinder configuration but having similar technical specifications and installation for the exhaust after-treatment systems into the same engine after-treatment system family, the manufacturer shall provide data to the Test Agency that demonstrates that the emissions reduction performance of such engine systems is similar.

2.3.3. One engine representing the engine-after-treatment system family, as determined in accordance with clause 2.3.2., shall be selected by the engine manufacturer for testing over the service accumulation schedule defined in clause 2.4.2., and shall be reported to the Test Agency before any testing commences.

2.3.3.1. If the Test Agency decides that the worst case emissions of the engine-after-treatment system family can be characterised better by another engine then the test engine shall be selected jointly by the Test Agency and the engine manufacturer.

2.4. Establishing emission durability period deterioration factors

2.4.1. General

Deterioration factors applicable to an engine-after-treatment system family are developed from the selected engines based on a service accumulation schedule that includes periodic testing for gaseous and particulate emissions over the NRSC and NRTC tests.

2.4.2. Service accumulation schedule

Service accumulation schedules may be carried out at the choice of the manufacturer by running a machine equipped with the selected engine over an "in-service" accumulation schedule or by running the selected engine over a "dynamometer service" accumulation schedule.

2.4.2.1. In-service and dynamometer service accumulation

2.4.2.1.1. The manufacturer shall determine the form and duration of the service accumulation and the ageing cycle for engines in a manner consistent with good engineering practice.

2.4.2.1.2. The manufacturer shall determine the test points where gaseous and particulate emissions will be measured over the hot NRTC and NRSC cycles. The minimum number of test points shall be three, one at the beginning, one approximately in the middle and one at the end of the service accumulation schedule.

2.4.2.1.3. The emission values at the start point and at the emission durability period endpoint calculated in accordance with clause 2.4.5.2. shall be within the limit values applicable to the engine family, but individual emission results from the test points may exceed those limit values.

2.4.2.1.4. At the request of the manufacturer and with the agreement of the Test Agency, only one test cycle (either the hot NRTC or NRSC cycle) needs to be run at each test point, with the other test cycle run only at the beginning and at the end of the service accumulation schedule.

2.4.2.1.5. In the case of constant speed engines only the NRSC cycle shall be run at each test point.

2.4.2.1.6. Service accumulation schedules may be different for different engine-after-treatment system families.

2.4.2.1.7. Service accumulation schedules may be shorter than the emission durability period, but shall not be shorter than the equivalent of at least one quarter of the relevant emission durability period specified in clause 3 of this Annex.

2.4.2.1.8. Accelerated ageing by adjusting the service accumulation schedule on a fuel consumption basis is permitted. The adjustment shall be based on the ratio between the typical in-use fuel consumption and the fuel consumption on the ageing cycle, but fuel consumption on the ageing cycle shall not exceed typical in-use fuel consumption by more than 30 per cent.

2.4.2.1.9. At the request of the manufacturer and with the agreement of the Test Agency, alternative methods of accelerated ageing may be permitted.

2.4.2.1.10. The service accumulation schedule shall be fully described in the application for type-approval and reported to the Test Agency before the start of any testing.

2.4.2.2. If the Test Agency decides that additional measurements need to be performed between the points selected by the manufacturer it shall notify the manufacturer. The revised service accumulation schedule shall be prepared by the manufacturer and agreed by the Test Agency.

2.4.3. Engine testing

2.4.3.1. Engine system stabilisation

2.4.3.1.1. For each engine-after-treatment system family, the manufacturer shall determine the number of hours of machine or engine running after which the operation of the engine-after-treatment system has stabilised. If requested by the Test Agency the manufacturer shall make available the data and analysis used to make this determination. As an alternative, the manufacturer may select to run the engine or machine between 60 and 125 hours or the equivalent time on the ageing cycle to stabilise the engine-after-treatment system.

2.4.3.1.2. The end of the stabilisation period determined in clause 2.4.3.1.1. shall be deemed to be the start of the service accumulation schedule.

2.4.3.2. Service accumulation testing

2.4.3.2.1. After stabilisation, the engine shall be run over the service accumulation schedule selected by the manufacturer, as described in clause 2.3.2. At the periodic intervals in the service accumulation schedule determined by the manufacturer, and, where appropriate, also stipulated by the Test Agency in accordance with clause 2.4.2.2., the engine shall be tested for gaseous and particulate emissions over the hot NRTC and NRSC cycles.

The manufacturer may select to measure the pollutant emissions before any exhaust after-treatment system separately from the pollutant emissions after any exhaust after-treatment system.

In accordance with clause 2.4.2.1.4., if it has been agreed that only one test cycle (hot NRTC or NRSC) be run at each test point, the other test cycle (hot NRTC or NRSC) shall be run at the beginning and end of the service accumulation schedule.

In accordance with clause 2.4.2.1.5., in the case of constant speed engines only the NRSC cycle shall be run at each test point.

2.4.3.2.2. During the service accumulation schedule, maintenance shall be carried out on the engine according to clause 2.5.

2.4.3.2.3. During the service accumulation schedule, unscheduled maintenance on the engine or machine may be performed, for example if the manufacturer's normal diagnostic system has detected a problem that would have indicated to the machine operator that a fault had arisen.

2.4.4. Reporting

2.4.4.1. The results of all emission tests (hot NRTC and NRSC) conducted during the service accumulation schedule shall be made available to the Test Agency. If any

emission test is declared to be void, the manufacturer shall provide an explanation of why the test has been declared void. In such a case, another series of emission tests shall be carried out within the following 100 hours of service accumulation.

2.4.4.2. The manufacturer shall retain records of all information concerning all the emission tests and maintenance carried out on the engine during the service accumulation schedule. This information shall be submitted to the Test Agency along with the results of the emission tests conducted over the service accumulation schedule.

2.4.5. Determination of deterioration factors

2.4.5.1. For each pollutant measured over the hot NRTC and NRSC cycles at each test point during the service accumulation schedule, a "best fit" linear regression analysis shall be made on the basis of all test results. The results of each test for each pollutant shall be expressed to the same number of decimal places as the limit value for that pollutant, as applicable to the engine family, plus one additional decimal place.

In accordance with clause 2.4.2.1.4. or clause 2.4.2.1.5., if only one test cycle (hot NRTC or NRSC) has been run at each test point, the regression analysis shall be made only on the basis of the test results from the test cycle run at each test point.

At the request of the manufacturer and with the prior approval of the Test Agency, non linear regression is permitted.

2.4.5.2. The emission values for each pollutant at the start of the service accumulation schedule and at the emission durability period end point that is applicable for the engine under test shall be calculated from the regression equation. If the service accumulation schedule is shorter than the emission durability period, the emission values at the emission durability period end point shall be determined by extrapolation of the regression equation as determined in clause 2.4.5.1.

In the case that emission values are used for engine families in the same engine-after-treatment family but with different emission durability periods, then the emission values at the emission durability period end point shall be recalculated for each emission durability period by extrapolation or interpolation of the regression equation as determined in clause 2.4.5.1.

2.4.5.3. The deterioration factor (DF) for each pollutant is defined as the ratio of the applied emission values at the emission durability period end point and at the start of the service accumulation schedule (multiplicative deterioration factor).

At the request of the manufacturer and with the prior approval of the Test Agency, an additive DF for each pollutant may be applied. The additive DF is defined as the difference between the calculated emission values at the emission durability period end point and at the start of the service accumulation schedule.

An example for determination of DF*s* by using linear regression is shown in figure 1 for NO_x emission.

Mixing of multiplicative and additive DF*s* within one set of pollutants is not permitted.

If the calculation results in a value of less than 1.00 for a multiplicative DF, or less than 0.00 for an additive DF, then the deterioration factor shall be 1.0 or 0.00, respectively.

In accordance with clause 2.4.2.1.4., if it has been agreed that only one test cycle (hot NRTC or NRSC) be run at each test point and the other test cycle (hot NRTC or NRSC) run only at the beginning and end of the service accumulation schedule, the deterioration factor calculated for the test cycle that has been run at each test point shall be applicable also for the other test cycle.

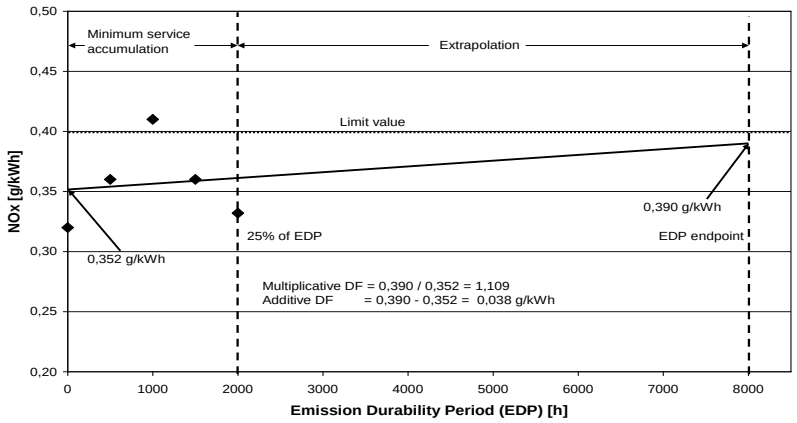


Figure 1
Example of DF Determination

2.4.6. Assigned deterioration factors

2.4.6.1. As an alternative to using a service accumulation schedule to determine DFs, engine manufacturers may select to use the following assigned multiplicative DFs:

Test cycle	CO	HC	NO_x	PM
NRTC	1.3	1.3	1.15	1.05
NRSC	1.3	1.3	1.15	1.05

Assigned additive DFs are not given. It is not permitted to transform the assigned multiplicative DFs into additive DFs.

Where assigned DFs are used, the manufacturer shall present to the Test Agency robust evidence that the emission control components can reasonably be expected to have the emission durability associated with those assigned factors. This evidence may be based upon design analysis, or tests, or a combination of both.

2.4.7. Application of deterioration factors

2.4.7.1. The engines shall meet the respective emission limits for each pollutant, as applicable to the engine family, after application of the deterioration factors to

the test result as measured in accordance with Annex 4 to this Part (cycle-weighted specific emission for particulate and each individual gas). Depending on the type of DF, the following provisions apply:

(a) Multiplicative: (cycle weighted specific emission) * DF ≤ emission limit

(b) Additive: (cycle weighted specific emission) + DF ≤ emission limit

2.4.7.2. For a multiplicative NO_x+HC DF, separate HC and NO_x DFs shall be determined and applied separately when calculating the deteriorated emission levels from an emissions test result before combining the resultant deteriorated NO_x and HC values to establish compliance with the emission limit.

2.4.7.3. The manufacturer may select to carry across the DFs determined for an engine-after-treatment system family to an engine system that does not fall into the same engine-after-treatment system family. In such cases, the manufacturer shall demonstrate to the Test Agency that the engine system for which the engine-after-treatment system family was originally tested and the engine system for which the DFs are being carried across have similar technical specifications and installation requirements on the machine and that the emissions of such engine or engine system are similar.

In the case that DFs are carried across to an engine system with a different emission durability period, then the DFs shall be recalculated for the applicable emission durability period by extrapolation or interpolation of the regression equation as determined in clause 2.4.5.1.

2.4.7.4. The DF for each pollutant for each applicable test cycle shall be recorded in the test result document set out in Annex 2 to this Part.

2.4.8. Checking of conformity of production

2.4.8.1. Conformity of production for emissions compliance is checked on the basis of clause 7. of this Part.

2.4.8.2. The manufacturer may select to measure the pollutant emissions before any exhaust after-treatment system at the same time as the type-approval test is being performed. In so doing, the manufacturer may develop informal DFs separately for the engine and for the after-treatment system that may be used by the manufacturer as an aid to end of production line auditing.

2.4.8.3. For the purposes of type-approval, only the DFs determined in accordance with clause 2.4.5. or 2.4.6. shall be recorded in the test result document set out in Annex 2 to this Part.

2.5. Maintenance

For the purpose of the service accumulation schedule, maintenance shall be performed in accordance with the manufacturer's manual for service and maintenance.

2.5.1. Emission-related scheduled maintenance

2.5.1.1. Emission-related scheduled maintenance during engine running, undertaken for the purpose of conducting a service accumulation schedule, shall occur at equivalent intervals to those that shall be specified in the manufacturer's maintenance instructions to the owner of the machine or engine. This maintenance schedule may be updated as necessary throughout the service accumulation schedule provided that no maintenance operation is deleted from

the maintenance schedule after the operation has been performed on the test engine.

2.5.1.2. The engine manufacturer shall specify for the service accumulation schedules any adjustment, cleaning, maintenance (where necessary) and scheduled exchange of the following items:

(a) Filters and coolers in the exhaust gas re-circulation system

(b) Positive crankcase ventilation valve, if applicable

(c) Fuel injector tips (only cleaning is permitted)

(d) Fuel injectors

(e) Turbocharger

(f) Electronic engine control unit and its associated sensors and actuators

(g) Particulate after-treatment system (including related components)

(h) NO_x after-treatment system (including related components)

(i) Exhaust gas re-circulation system, including all related control valves and tubing

(j) Any other exhaust after-treatment system.

2.5.1.3. Critical emission-related scheduled maintenance shall only be performed if intended to be performed in-use and the requirement to perform such maintenance is to be communicated to the owner of the machine.

2.5.2. Changes to scheduled maintenance

2.5.2.1. The manufacturer shall submit a request to the Test Agency for approval of any new scheduled maintenance that it wishes to perform during the service accumulation schedule and subsequently to recommend to owners of machines and engines. The request shall be accompanied by data supporting the need for the new scheduled maintenance and the maintenance interval.

2.5.3. Non-emission-related scheduled maintenance

2.5.3.1. Non-emission-related scheduled maintenance which is reasonable and technically necessary (for example oil change, oil filter change, fuel filter change, air filter change, cooling system maintenance, idle speed adjustment, governor, engine bolt torque, valve lash, injector lash, adjustment of the tension of any drive-belt, etc.) may be performed on engines or machines selected for the service accumulation schedule at the least frequent intervals recommended by the manufacturer to the owner (for example not at the intervals recommended for severe service).

2.5.4. Repair

2.5.4.1. Repairs to the components of an engine system selected for testing over a service accumulation schedule shall be performed only as a result of component failure or engine system malfunction. Repair of the engine itself, the emission control system or the fuel system is not permitted except to the extent defined in clause 2.5.4.2.

2.5.4.2. If the engine itself, the emission control system or the fuel system fail during the service accumulation schedule, the service accumulation shall be considered

void, and a new service accumulation shall be started with a new engine system, unless the failed components are replaced with equivalent components that have been subject to a similar number of hours of service accumulation.

3. EMISSION DURABILITY PERIOD FOR ENGINES.

3.1. Manufacturers shall use the emission durability period in Table 1 of this clause.

Table 1
Emission Durability Period for CI Engines (Hours)

Category (power band)	Emission durability period (hours)
> 37 kW	8000

ANNEX 9

REQUIREMENTS TO ENSURE THE CORRECT OPERATION OF NO_X CONTROL MEASURES

1. INTRODUCTION

This annex sets out the requirements to ensure the correct operation of NO_x control measures. It includes requirements for engines that rely on the use of a reagent in order to reduce emissions.

2. GENERAL REQUIREMENTS

The engine system shall be equipped with a NO_x Control Diagnostic system (NCD) able to identify the NO_x control malfunctions (NCMs) considered by this annex. Any engine system covered by this clause shall be designed, constructed and installed so as to be capable of meeting these requirements throughout the normal life of the engine under normal conditions of use. In achieving this objective, it is acceptable that engines which have been used in excess of the useful life period as specified in clause 3.1. of Annex 8 to this Part show some deterioration in the performance and the sensitivity of the NO_x Control Diagnostic system (NCD), such that the thresholds specified in this annex may be exceeded before the warning and/or inducement systems are activated.

2.1. Required information

2.1.1. If the emission control system requires a reagent, the characteristics of that reagent, including the type of reagent, information on concentration when the reagent is in solution, operational temperature conditions and reference to international standards for composition and quality shall be specified by the manufacturer, in clause 2.2.1.13. of Appendix 1 and in clause 2.2.1.13. of Appendix 3 to Annex 1A to this Part.

2.1.2. Detailed written information fully describing the functional operation characteristics of the operator warning system in clause 4. and of the operator inducement system in clause 5. shall be provided to the Test Agency at the time of type-approval.

2.1.3. The manufacturer shall provide installation documents that, when used by the OEM, will ensure that the engine, inclusive of the emission control system that is part of the approved engine type, when installed in the machine, will operate, in conjunction with the necessary machinery parts, in a manner that will comply with the requirements of this annex. This documentation shall include the detailed technical requirements and the provisions of the engine system (software, hardware, and communication) needed for the correct installation of the engine system in the machine.

2.2. Operating conditions

2.2.1. The NOx control diagnostic system shall be operational at the following conditions:

(a) Ambient temperatures between 273 K and 315 K (0°C and 42 °C);

(b) All altitudes below 1,600 m;

(c) Engine coolant temperatures above 343 K (70°C).

This clause shall not apply in the case of monitoring for reagent level in the storage tank where monitoring shall be conducted under all conditions where measurement is technically feasible (for instance, under all conditions when a liquid reagent is not frozen).

2.3. Reagent freeze protection

2.3.1. It is permitted to use a heated or a non-heated reagent tank and dosing system. A heated system shall meet the requirements of clause 2.3.2. A non-heated system shall meet the requirements of clause 2.3.3.

2.3.1.1. The use of a non-heated reagent tank and dosing system shall be indicated in the written instructions to the owner of the machine.

2.3.2. Reagent tank and dosing system

2.3.2.1. If the reagent has frozen, the reagent shall be available for use within a maximum of 70 minutes after the start of the engine at 266 K (- 7 °C) ambient temperature.

2.3.2.2. Design criteria for a heated system

A heated system shall be so designed that it meets the performance requirements set out in this clause when tested using the procedure defined.

Demonstration: Demonstration test at the time of type approval is not mandatory.

2.3.2.2.1. The reagent tank and dosing system shall be soaked at 255 K (- 18°C) for 72 hours or until the reagent becomes solid, whichever occurs first.

2.3.2.2.2. After the soak period in clause 2.3.2.2.1., the machine/engine shall be started and operated at 266 K (-7 °C) ambient temperature or lower as follows:

(a) 10 to 20 minutes idling;

(b) Followed by up to 50 minutes at no more than 40 per cent of rated load.

2.3.2.2.3. At the conclusion of the test procedure in clause 2.3.2.2.2., the reagent dosing system shall be fully functional.

2.3.2.3. Evaluation of the design criteria may be performed in a cold chamber test cell using an entire machine or parts representative of those to be installed on a machine or based on field tests.

2.3.3. Activation of the operator warning and inducement system for a non-heated system

2.3.3.1. The operator warning system described in clause 4. shall be activated if no reagent dosing occurs at an ambient temperature ≥ 273 K (0°C).

2.3.3.2. The driver inducement system described in clause 8.0 shall be activated if no reagent dosing occurs within a maximum of 70 minutes after engine start at an ambient temperature ≥ 273 K (0°C).

2.4. Diagnostic requirements

2.4.1 The NO_x Control Diagnostic system (NCD) shall be able to identify the NO_x control malfunctions (NCMs) considered by this annex by means of Diagnostic Trouble Codes (DTCs) stored in the computer memory and to communicate that information off-board upon request.

2.4.2 Requirements for recording Diagnostic Trouble Codes (DTCs)

2.4.2.1 The NCD system shall record a DTC for each distinct NO_x Control Malfunction (NCM).

2.4.2.2 The NCD system shall conclude within 60 minutes of engine operation whether a detectable malfunction is present. At this time, a "confirmed and active" DTC shall be stored and the warning system be activated according to clause 4.

2.4.2.3 In cases where more than 60 minutes running time is required for the monitors to accurately detect and confirm a NCM (e.g. monitors using statistical models or with respect to fluid consumption on the machine), the Test Agency may permit a longer period for monitoring provided the manufacturer justifies the need for the longer period (for example by technical rationale, experimental results, in house experience, etc.).

2.4.3. Requirements for erasing Diagnostic trouble codes (DTCs)

(a) DTCs shall not be erased by the NCD system itself from the computer memory until the failure related to that DTC has been remedied.

(b) The NCD system may erase all the DTCs upon request of a proprietary scan or maintenance tool that is provided by the engine manufacturer upon request, or using a pass code provided by the engine manufacturer.

2.4.4. An NCD system shall not be programmed or otherwise designed to partially or totally deactivate based on age of the machine during the actual life of the engine, nor shall the system contain any algorithm or strategy designed to reduce the effectiveness of the NCD system over time.

2.4.5. Any reprogrammable computer codes or operating parameters of the NCD system shall be resistant to tampering.

2.4.6. NCD engine family

The manufacturer is responsible for determining the composition of an NCD engine family. Grouping engine systems within an NCD engine family shall be based on good engineering judgment and be subject to approval by the Test Agency.

Engines that do not belong to the same engine family may still belong to the same NCD engine family.

2.4.6.1. Parameters defining an NCD engine family

An NCD engine family is characterized by basic design parameters that shall be common to engine systems within the family.

In order that engine systems are considered to belong to the same NCD engine family, the following list of basic parameters shall be similar:

(a) Emission control systems;

(b) Methods of NCD monitoring;

(c) Criteria for NCD monitoring;

(d) Monitoring parameters (e.g. frequency).

These similarities shall be demonstrated by the manufacturer by means of relevant engineering demonstration or other appropriate procedures and subject to the approval of the Test Agency.

The manufacturer may request approval by the Test Agency of minor differences in the methods of monitoring/diagnosing the NCD system due to engine system configuration variation, when these methods are considered similar by the manufacturer and they differ only in order to match specific characteristics of the components under consideration (e.g. size, exhaust flow, etc.); or their similarities are based on good engineering judgment.

3. MAINTENANCE REQUIREMENTS

3.1. The manufacturer shall furnish or cause to be furnished to all owners of new engines or machines written instructions about the emission control system and its correct operation.

These instructions shall state that if the emission control system is not functioning correctly, the operator will be informed of a problem by the operator warning system and that activation of the operator inducement system as a consequence of ignoring this warning will result in the machine being unable to conduct its mission.

3.2. The instructions shall indicate requirements for the proper use and maintenance of engines in order to maintain their emissions performance, including, where relevant, the proper use of consumable reagents.

3.3. The instructions shall be written in a clear and non-technical manner using the same language as is used in the operator's manual on the agricultural tractor, construction equipment vehicle and combine harvester or engine.

3.4. The instructions shall specify whether consumable reagents have to be refilled by the operator between normal maintenance intervals. The instructions shall also specify the required reagent quality. They shall indicate how the operator should refill the reagent tank. The information shall also indicate a likely rate of reagent consumption for the engine type and how often it should be replenished.

3.5. The instructions shall state that use of, and refilling of, a required reagent of the correct specifications is essential in order for the engine to comply with the requirements for the issuing of the type approval for that engine type.

3.6. The instructions shall explain how the operator warning and inducement systems work. In addition, the consequences, in terms of performance and fault logging, of ignoring the warning system and not replenishing the reagent or rectifying the problem shall be explained.

4. OPERATOR WARNING SYSTEM

4.1. The machine shall include an operator warning system using visual alarms that informs the operator when a low reagent level, incorrect reagent quality, interruption of dosing or a malfunction of the type specified in clause 9. has been detected that will lead to activation of the operator inducement system if not rectified in a timely manner. The warning system shall remain active when the operator inducement system described in clause 5. has been activated.

4.2. The warning shall not be the same as the warning used for the purposes of signalling a malfunction or other engine maintenance, though it may use the same warning system.

4.3. The operator warning system may consist of one or more lamps, or display short messages, which may include, for example, messages indicating clearly:

(a) The remaining time before activation of the low-level and/or severe inducements;

(b) The amount of low-level and/or severe inducement, for example the amount of torque reduction;

(c) The conditions under which machine disablement can be cleared.

Where messages are displayed, the system used for displaying these messages may be the same as the one used for other maintenance purposes.

4.4. At the choice of the manufacturer, the warning system may include an audible component to alert the operator. The cancelling of audible warnings by the operator is permitted.

4.5. The operator warning system shall be activated as specified in clauses 2.3.3.1., 6.2., 7.2., 8.4., and 9.3. respectively.

4.6. The operator warning system shall be deactivated when the conditions for its activation have ceased to exist. The operator warning system shall not be automatically deactivated without the reason for its activation having been remedied.

4.7. The warning system may be temporarily interrupted by other warning signals providing important safety related messages.

4.8. Details of the operator warning system activation and deactivation procedures are described in Appendix 2 to this annex.

4.9. As part of the application for type-approval under this Part, the manufacturer shall demonstrate the operation of the operator warning system, as specified in Appendix 2 to this annex.

5. OPERATOR INDUCEMENT SYSTEM

5.1. The machine shall incorporate an operator inducement system based on one of the following principles:

5.1.1. A two-stage inducement system starting with a low-level inducement (performance restriction) followed by a severe inducement (effective disablement of machine operation);

5.1.2. A one-stage severe inducement system (effective disablement of machine operation) activated under the conditions of a low-level inducement system as specified in clauses 6.3.1., 7.3.1., 8.4.1., and 9.4.1.

5.2. Upon prior approval of the Test Agency, the engine may be fitted with a means to disable the operator inducement during an emergency declared by a national or regional government, their emergency services or their armed services.

5.3. Low-level inducement system

5.3.1. The low-level inducement system shall be activated after any of the conditions specified in clauses 6.3.1., 7.3.1., 8.4.1., and 9.4.1. has occurred.

5.3.2. The low-level inducement system shall gradually reduce the maximum available engine torque across the engine speed range by at least 25 per cent between the peak torque speed and the governor breakpoint as shown in Figure 1. The rate of torque reduction shall be a minimum of 1 per cent per minute.

5.3.3. Other inducement measures that are demonstrated to the Test Agency as having the same or greater level of severity may be used.

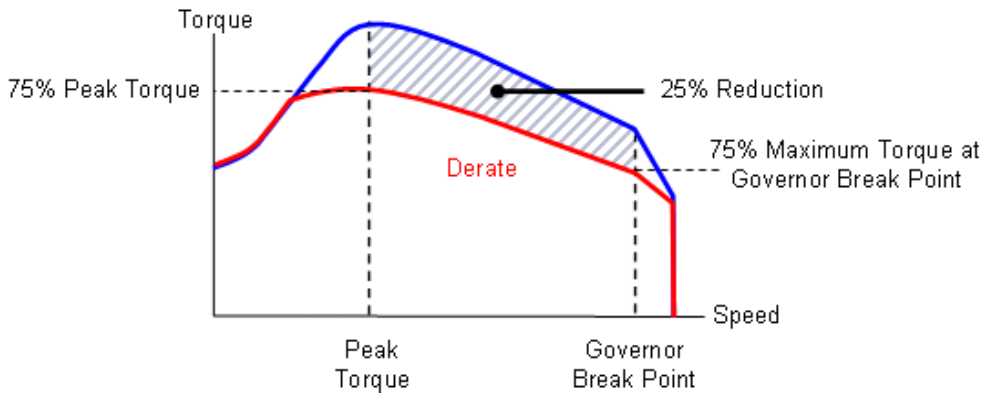


Figure 1

Low-Level Inducement Torque Reduction Scheme

5.4. Severe inducement system

5.4.1. The severe inducement system shall be activated after any of the conditions specified in clauses 2.3.3.2., 6.3.2., 7.3.2., 8.4.2., and 9.4.2. has occurred.

5.4.2. The severe inducement system shall reduce the machine's utility to a level that is sufficiently onerous as to cause the operator to remedy any problems related to clauses 6. to 9. The following strategies are acceptable:

5.4.2.1. Engine torque between the peak torque speed and the governor breakpoint shall be gradually reduced from the low-level inducement torque in Figure 1 by a minimum of 1 per cent per minute to 50 per cent of maximum torque or lower and engine speed shall be gradually reduced to 60 per cent of rated speed or lower within the same time period as the torque reduction, as shown in Figure 2.

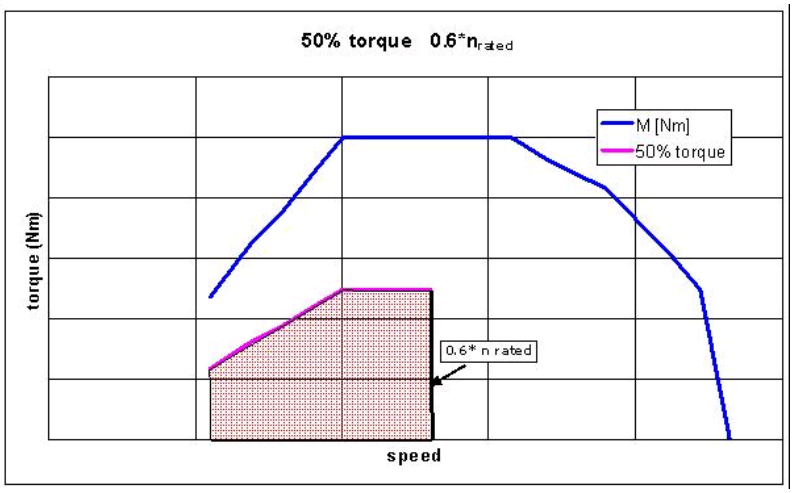


Figure 2

Severe Inducement Torque Reduction Scheme

5.4.2.2. Other inducement measures that are demonstrated to the Test Agency as having the same or greater level of severity may be used.

5.5. In order to account for safety concerns and to allow for self-healing diagnostics, use of an inducement override function for releasing full engine power is permitted, provided it

(a) Is active for no longer than 30 minutes, and

(b) Is limited to 3 activations during each period that the operator inducement system is active.

5.6. The operator inducement system shall be deactivated when the conditions for its activation have ceased to exist. The operator inducement system shall not be automatically deactivated without the reason for its activation having been remedied.

5.7. Details of the operator inducement system activation and deactivation procedures are described in Appendix 2 to this annex.

5.8. As part of the application for type-approval under this Part, the manufacturer shall demonstrate the operation of the operator inducement system, as specified in Appendix 2 to this annex.

6. REAGENT AVAILABILITY

6.1. Reagent level indicator

The machine shall include an indicator that clearly informs the operator of the level of reagent in the reagent storage tank. The minimum acceptable performance level for the reagent indicator is that it shall continuously indicate the reagent level whilst the operator warning system referred to in clause 4. is activated. The reagent indicator may be in the form of an analogue

or digital display, and may show the level as a proportion of the full tank capacity, the amount of remaining reagent, or the estimated operating hours remaining.

6.2. Activation of the operator warning system

6.2.1. The operator warning system specified in clause 4. shall be activated when the level of reagent goes below 10 per cent of the capacity of the reagent tank or a higher percentage at the choice of the manufacturer.

6.2.2. The warning provided shall be sufficiently clear, in conjunction with the reagent indicator, for the operator to understand that the reagent level is low. When the warning system includes a message display system, the visual warning shall display a message indicating a low level of reagent (for example "urea level low", "AdBlue level low", or "reagent low").

6.2.3. The operator warning system does not initially need to be continuously activated (for example a message does not need to be continuously displayed), however activation shall escalate in intensity so that it becomes continuous as the level of the reagent approaches empty and the point where the operator inducement system will come into effect is approached (for example frequency at which a lamp flashes). It shall culminate in an operator notification at a level that is at the choice of the manufacturer, but sufficiently more noticeable at the point where the operator inducement system in clause 6.3 comes into effect than when it was first activated.

6.2.4. The continuous warning shall not be easily disabled or ignored. When the warning system includes a message display system, an explicit message shall be displayed (for example "fill up urea", "fill up AdBlue", or "fill up reagent"). The continuous warning may be temporarily interrupted by other warning signals providing important safety related messages.

6.2.5. It shall not be possible to turn off the operating warning system until the reagent has been replenished to a level not requiring its activation.

6.3. Activation of the operator inducement system

6.3.1 The low-level inducement system described in clause 5.3. shall be activated if the reagent tank level goes below 2.5 per cent of its nominally full capacity or a higher percentage at the choice of the manufacturer.

6.3.2. The severe inducement system described in clause 5.4. shall be activated if the reagent tank is empty (that is, when the dosing system is unable to draw further reagent from the tank) or at any level below 2.5 per cent of its nominally full capacity at the discretion of the manufacturer.

6.3.3. Except to the extent permitted by clause 5.5., it shall not be possible to turn off the low-level or severe inducement system until the reagent has been replenished to a level not requiring their respective activation.

7. REAGENT QUALITY MONITORING

7.1. The engine or machine shall include a means of determining the presence of an incorrect reagent on board a machine.

7.1.1. The manufacturer shall specify a minimum acceptable reagent concentration CD_{min}, which results in tailpipe NO_x emissions not exceeding a threshold of 0.9 g/kWh.

7.1.1.1. The correct value of CD_{min} shall be demonstrated during type approval by the procedure defined in Appendix 3 to this annex and recorded in the extended documentation package as specified in 5.3. of this Part.

7.1.2. Any reagent concentration lower than CD_{min} shall be detected and be regarded, for the purpose of clause 7.1., as being incorrect reagent.

7.1.3. A specific counter ("the reagent quality counter") shall be attributed to the reagent quality. The reagent quality counter shall count the number of engine operating hours with an incorrect reagent.

7.1.3.1. Optionally, the manufacturer may group the reagent quality failure together with one or more of the failures listed in clauses 8. and 9. into a single counter.

7.1.4. Details of the reagent quality counter activation and deactivation criteria and mechanisms are described in Appendix 2 to this Annex.

7.2. Activation of the operator warning system

When the monitoring system confirms that the reagent quality is incorrect, the operator warning system described in clause 4. shall be activated. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (for example "incorrect urea detected", "incorrect AdBlue detected", or "incorrect reagent detected").

7.3 Activation of the operator inducement system

7.3.1. The low-level inducement system described in clause 5.3. shall be activated if the reagent quality is not rectified within a maximum of 10 engine operating hours after the activation of the operator warning system described in clause 7.2.

7.3.2. The severe inducement system described in clause 5.4. shall be activated if the reagent quality is not rectified within a maximum of 20 engine operating hours after the activation of the operator warning system in described clause 7.2.

7.3.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in Appendix 2 of this annex.

8. REAGENT DOSING ACTIVITY

8.1 The engine shall include a means of determining interruption of dosing.

8.2. Reagent dosing activity counter

8.2.1. A specific counter shall be attributed to the dosing activity (the "dosing activity counter"). The counter shall count the number of engine operating hours which occur with an interruption of the reagent dosing activity. This is not required where such interruption is demanded by the engine ECU because the machine operating conditions are such that the machine's emission performance does not require reagent dosing.

8.2.1.1. Optionally, the manufacturer may group the reagent dosing failure together with one or more of the failures listed in clauses 7. and 9. into a single counter.

8.2.2. Details of the reagent dosing activity counter activation and deactivation criteria and mechanisms are described in Appendix 2 to this Annex.

8.3. Activation of the operator warning system

The operator warning system described in clause 4. shall be activated in the case of interruption of dosing which sets the dosing activity counter in accordance with clause 8.2.1. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (e.g. "urea dosing malfunction", "AdBlue dosing malfunction", or "reagent dosing malfunction").

8.4. Activation of the operator inducement system

8.4.1. The low-level inducement system described in clause 5.3. shall be activated if an interruption in reagent dosing is not rectified within a maximum of 10 engine operating hours after the activation of the operator warning system in clause 8.3.

8.4.2. The severe inducement system described in clause 5.4. shall be activated if an interruption in reagent dosing is not rectified within a maximum of 20 engine operating hours after the activation of the operator warning system in clause 8.3.

8.4.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in Appendix 2 of this Annex.

9. MONITORING FAILURES THAT MAY BE ATTRIBUTED TO TAMPERING

9.1. In addition to the level of reagent in the reagent tank, the reagent quality, and the interruption of dosing, the following failures shall be monitored because they may be attributed to tampering:

(a) Impeded EGR valve;

(b) Failures of the NO_x Control Diagnostic (NCD) system, as described in clause 9.2.1.

9.2. Monitoring requirements

9.2.1. The NO_x Control Diagnostic (NCD) system shall be monitored for electrical failures and for removal or deactivation of any sensor that prevents it from diagnosing any other failures mentioned in clauses 6. to 8. (component monitoring).

A non-exhaustive list of sensors that affect the diagnostic capability are those directly measuring NO_x concentration, urea quality sensors, ambient sensors and sensors used for monitoring reagent dosing activity, reagent level, or reagent consumption.

9.2.2. EGR valve counter

9.2.2.1. A specific counter shall be attributed to an impeded EGR valve. The EGR valve counter shall count the number of engine operating hours when the DTC associated to an impeded EGR valve is confirmed to be active.

9.2.2.1.1. Optionally, the manufacturer may group the impeded EGR valve failure together with one or more of the failures listed in clauses 7., 8. and 9.2.3. into a single counter.

9.2.2.2. Details of the EGR valve counter activation and deactivation criteria and mechanisms are described in Appendix 2 of this Annex.

9.2.3. NCD system counter(s)

9.2.3.1. A specific counter shall be attributed to each of the monitoring failures considered in clause 9.1. The NCD system counters shall count the number of engine operating hours when the DTC associated to a malfunction of the NCD system is confirmed to be active. Grouping of several faults into a single counter is permitted.

9.2.3.1.1. Optionally, the manufacturer may group the NCD system failure together with one or more of the failures listed in clauses 7., 8. and 9.2.2. into a single counter.

9.2.3.2. Details of the NCD system counter(s) activation and deactivation criteria and mechanisms are described in Appendix 2 to this annex.

9.3. Activation of the operator warning system

The operator warning system described in clause 4. shall be activated in case any of the failures specified in clause 9.1. occur, and shall indicate that an urgent repair is required. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (for example "reagent dosing valve disconnected", or "critical emission failure").

9.4. Activation of the operator inducement system

9.4.1. The low-level inducement system described in clause 5.3. shall be activated if a failure specified in clause 9.1. is not rectified within a maximum of 36 engine operating hours after the activation of the operator warning system in clause 9.3.

9.4.2. The severe inducement system described in clause 5.4. shall be activated if a failure specified in clause 9.1. is not rectified within a maximum of 100 engine operating hours after the activation of the operator warning system in clause 9.3.

9.4.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in Appendix 2 to this annex.

9.5. As an alternative to the requirements in clause 9.2., the manufacturer may use a NO_x sensor located in the exhaust gas. In this case,

(a) The NO_x value shall not exceed a threshold of 0.9 g/kWh;
(b) Use of a single failure "high NO_x - root cause unknown" may be used;
(c) Clause 9.4.1. shall read "within 10 engine hours";
(d) Clause 9.4.2. shall read "within 20 engine hours".

ANNEX 9 - APPENDIX 1

DEMONSTRATION REQUIREMENTS

1. GENERAL

The compliance to the requirements of this annex shall be demonstrated during type-approval by performing, as illustrated in Table 1 and specified in this clause:

(a) A demonstration of the warning system activation;

(b) A demonstration of the low level inducement system activation, if applicable;

(c) A demonstration of the severe inducement system activation.

Table 1

Illustration of the Content of the Demonstration Process according to the Provisions in Clauses 3. and 4.

Mechanism	Demonstration Elements
Warning system activation specified in clause 3. of this Appendix.	• 2 activation tests (incl. lack of reagent) • Supplementary demonstration elements, as appropriate
Low-level inducement activation specified in clause 4. of this Appendix.	• 2 activation tests (incl. lack of reagent) • Supplementary demonstration elements, as appropriate • 1 torque reduction test
Severe inducement activation specified in clause 4.6. of this clause.	• 2 activation tests (incl. lack of reagent) • Supplementary demonstration elements, as appropriate

2. ENGINE FAMILIES AND NCD ENGINE FAMILIES

The compliance of an engine family or an NCD engine family with the requirements of this appendix may be demonstrated by testing one of the members of the considered family, provided the manufacturer demonstrates to the Test Agency that the monitoring systems necessary for complying with the requirements of this annex are similar within the family.

2.1. The demonstration that the monitoring systems for other members of the NCD family are similar may be performed by presenting to the approval authorities such elements as algorithms, functional analyses, etc.

2.2. The test engine is selected by the manufacturer in agreement with the Test Agency. It may or may not be the parent engine of the considered family.

2.3. In the case where engines of an engine family belong to an NCD engine family that has already been type-approved according to clause 2.1. (Figure 3), the compliance of that engine family is deemed to be demonstrated without further testing, provided the manufacturer demonstrates to the Test Agency that the monitoring systems necessary for **complying with the requirements of this annex are similar within the considered engine and NCD engine families.**

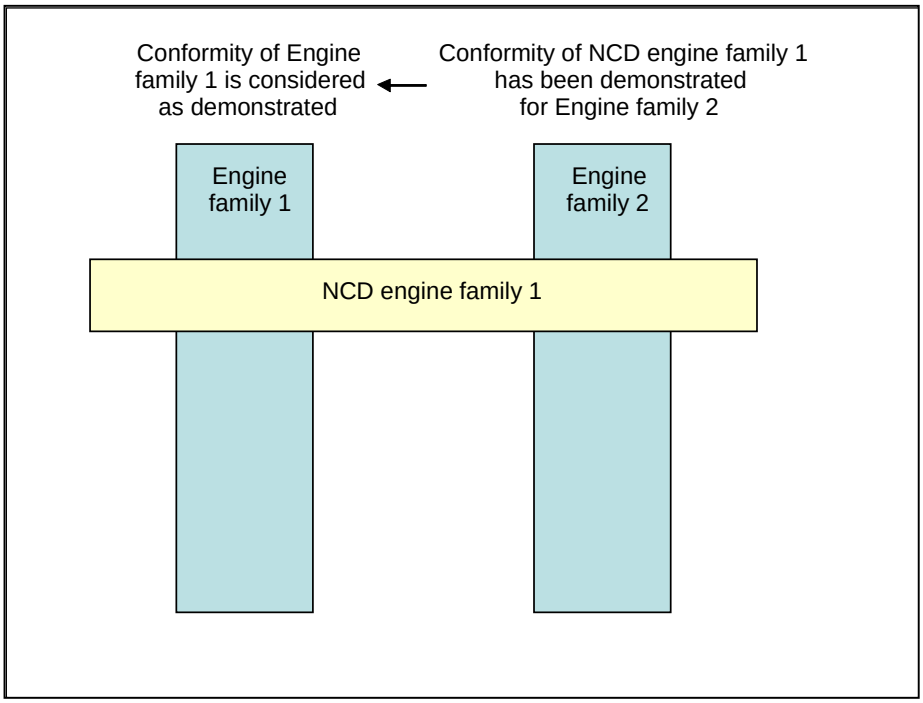


Figure 3

Previously Demonstrated Conformity of an NCD Engine Family

3. DEMONSTRATION OF THE WARNING SYSTEM ACTIVATION

3.1. The compliance of the warning system activation shall be demonstrated by performing two tests: lack of reagent, and one failure category considered in clauses 7. to 9. of this Annex.

3.2. Selection of the failures to be tested

3.2.1. For the purpose of demonstrating the activation of the warning system in case of a wrong reagent quality, a reagent shall be selected with a dilution of the active ingredient at least as dilute as that communicated by the manufacturer according to the requirements of clause 7. of this Annex

3.2.2. For the purpose of demonstrating the activation of the warning system in case of failures that may be attributed to tampering, and are defined in clause 9. of this Annex, the selection shall be performed according to the following requirements:

3.2.2.1. The manufacturer shall provide the Test Agency with a list of such potential failures.

3.2.2.2. The failure to be considered in the test shall be selected by the Test Agency from this list referred to in clause 3.2.2.1.

3.3. Demonstration

3.3.1. For the purpose of this demonstration, a separate test shall be performed for each of the failures considered in clause 3.1.

3.3.2. During a test, no failure shall be present other than the one addressed by the test.

3.3.3. Prior to starting a test, all DTC shall have been erased.

3.3.4. At the request of the manufacturer, and with the agreement of the Test Agency, the failures subject to testing may be simulated.

3.3.5. Detection of failures other than lack of reagent

For failures other than lack of reagent, once the failure installed or simulated, the detection of that failure shall be performed as follows:

3.3.5.1. The NCD system shall respond to the introduction of a failure selected as appropriate by the Test Agency in accordance to the provisions of this appendix. This is considered to be demonstrated if activation occurs within two consecutive NCD test-cycles according to clause 3.3.7.

When it has been specified in the monitoring description and agreed by the Test Agency that a specific monitor needs more than two NCD test-cycles to complete its monitoring, the number of NCD test-cycles may be increased to 3 NCD test-cycles.

Each individual NCD test-cycle in the demonstration test may be separated by an engine shut-off. The time until the next start-up shall take into consideration any monitoring that may occur after engine shut-off and any necessary condition that shall exist for monitoring to occur at the next start up.

3.3.5.2. The demonstration of the warning system activation is deemed to be accomplished if, at the end of each demonstration test performed according to clause 3.2.1, the warning system has been properly activated and the DTC for the selected failure has got the "confirmed and active" status.

3.3.6. Detection in case of lack of reagent availability

For the purpose of demonstrating the activation of the warning system in case of lack of reagent availability, the engine system shall be operated over one or more NCD test cycles at the discretion of the manufacturer.

3.3.6.1. The demonstration shall start with a level of reagent in the tank to be agreed between the manufacturer and the Test Agency, but representing not less than 10 per cent of the nominal capacity of the tank.

3.3.6.2. The warning system is deemed to have performed in the correct manner if the following conditions are met simultaneously:

(a) The warning system has been activated with a reagent availability greater or equal to 10 per cent of the capacity of the reagent tank, and

(b) The "continuous" warning system has been activated with a reagent availability greater or equal to the value declared by the manufacturer according to the provisions of clause 6. of this Annex.

3.3.7. NCD test cycle

3.3.7.1 The NCD test cycle considered in this clause for demonstrating the correct performance of the NCD system is the hot NRTC cycle.

3.3.7.2 On request of the manufacturer and with approval of the Test Agency, an alternative NCD test-cycle can be used (e.g. the NRSC) for a specific monitor. The request shall contain elements (technical considerations, simulation, test results, etc.) demonstrating:

(a) The requested test-cycle results in a monitor that will run in real world driving, and

(b) The applicable NCD test-cycle specified in clause 3.3.7.1. is shown to be less appropriate for the considered monitoring.

3.4. The demonstration of the warning system activation is deemed to be accomplished if, at the end of each demonstration test performed according to clause 3.3., the warning system has been properly activated.

4. DEMONSTRATION OF THE INDUCEMENT SYSTEM ACTIVATION

4.1. The demonstration of the inducement system activation shall be done by tests performed on an engine test bench.

4.1.1. Any components or sub-systems not physically mounted on the engine system, such as, but not limited to, ambient temperature sensors, level sensors, and operator warning and information systems, that are required in order to perform the demonstrations shall be connected to the engine system for that purpose, or shall be simulated, to the satisfaction of the Test Agency.

4.1.2. If the manufacturer chooses, and subject to the agreement of the Test Agency, the demonstration tests may be performed on a complete machine or machinery either by mounting the machine on a suitable test bed or by running it on a test track under controlled conditions.

4.2. The test sequence shall demonstrate the activation of the inducement system in case of lack of reagent and in case of one of the failures defined in clauses 7., 8., or 9. of this Annex.

4.3. For the purpose of this demonstration,

(a) The Test Agency shall select, in addition to the lack of reagent, one of the failures defined in clauses 7., 8. or 9. of this annex that has been previously used in the demonstration of the warning system activation;

(b) The manufacturer shall, in agreement with the Test Agency, be permitted to accelerate the test by simulating the achievement of a certain number of operating hours;

(c) The achievement of the torque reduction required for low-level inducement may be demonstrated at the same time as the general engine performance approval process performed in accordance with this Part. Separate torque measurement during the inducement system demonstration is not required in this case;

(d) The severe inducement shall be demonstrated according to the requirements of clause 4.6 of this Appendix.

4.4. The manufacturer shall, in addition, demonstrate the operation of the inducement system under those failure conditions defined in clauses 8. or 9. of this Annex which have not been chosen for use in demonstration tests described in clauses 4.1. to 4.3.

These additional demonstrations may be performed by presentation to the Test Agency of a technical case using evidence such as algorithms, functional analyses, and the result of previous tests.

4.4.1. These additional demonstrations shall in particular demonstrate to the satisfaction of the Test Agency the inclusion of the correct torque reduction mechanism in the engine ECU.

4.5. Demonstration test of the low level inducement system

4.5.1. This demonstration starts when the warning system or when appropriate "continuous" warning system has been activated as a result of the detection of a failure selected by the Test Agency.

4.5.2. When the system is being checked for its reaction to the case of lack of reagent in the tank, the engine system shall be run until the reagent availability has reached a value of 2.5 per cent of the nominal full capacity of the tank or the value declared by the manufacturer in accordance with clause 6.3.1. of this Annex at which the low-level inducement system is intended to operate.

4.5.2.1. The manufacturer may, with the agreement of the Test Agency, simulate continuous running by extracting reagent from the tank, either while the engine is running or is stopped.

4.5.3. When the system is checked for its reaction in the case of a failure other than a lack of reagent in the tank, the engine system shall be run for the relevant number of operating hours indicated in Table 4 of Appendix 2 of this Annex or, at the choice of the manufacturer, until the relevant counter has reached the value at which the low-level inducement system is activated.

4.5.4. The demonstration of the low-level inducement system shall be deemed to be accomplished if, at the end of each demonstration test performed according to clauses 4.5.2. and 4.5.3., the manufacturer has demonstrated to the Test Agency that the engine ECU has activated the torque reduction mechanism.

4.6. Demonstration test of the severe inducement system

4.6.1. This demonstration shall start from a condition where the low-level inducement system has been previously activated and may be performed as a continuation of the tests undertaken to demonstrate the low-level inducement system.

4.6.2. When the system is checked for its reaction in the case of lack of reagent in the tank, the engine system shall be run until the reagent tank is empty, or has reached the level below 2.5 per cent of the nominal full capacity of the tank at which the manufacturer has declared to activate the severe inducement system.

4.6.2.1. The manufacturer may, with the agreement of the Test Agency, simulate continuous running by extracting reagent from the tank, either while the engine is running or is stopped.

4.6.3. When the system is checked for its reaction in the case of a failure that is not a lack of reagent in the tank, the engine system shall then be run for the relevant number of operating hours indicated in Table 4 of Appendix 2 of this Annex or, at the choice of the manufacturer, until the relevant counter has reached the value at which the severe inducement system is activated.

4.6.4. The demonstration of the severe inducement system shall be deemed to be accomplished if, at the end of each demonstration test performed according to clauses 4.6.2. and 4.6.3., the manufacturer has demonstrated to the Test Agency that the severe inducement mechanism considered in this annex has been activated.

4.7. Alternatively, if the manufacturer chooses, and subject to the agreement of the Test Agency, the demonstration of the inducement mechanisms may be performed on a complete machine in accordance with the requirements of clause 5.4., either by mounting the machine on a suitable test bed or by running it on a test track under controlled conditions.

4.7.1. The machine shall be operated until the counter associated with the selected failure has reached the relevant number of operating hours indicated in Table 4 of Appendix 2 of this Annex or, as appropriate, until either the reagent tank is empty or, has reached the level below 2.5 per cent of the nominal full capacity of the tank at which the manufacturer has chosen to activate the severe inducement system.

ANNEX 9 - APPENDIX 2

DESCRIPTION OF THE OPERATOR WARNING AND INDUCEMENT ACTIVATION AND DEACTIVATION MECHANISMS

1. To complement the requirements specified in this annex concerning the warning and inducement activation and deactivation mechanisms, this appendix specifies the technical requirements for an implementation of those activation and deactivation mechanisms.

2. ACTIVATION AND DEACTIVATION MECHANISMS OF THE WARNING SYSTEM

2.1. The operator warning system shall be activated when the diagnostic trouble code (DTC) associated with a NCM justifying its activation has the status defined in Table 2 of this appendix.

Table 2
Activation of the Operator Warning System

Failure type	DTC status for activation of the warning system
poor reagent quality	confirmed and active
interruption of dosing	confirmed and active
impeded EGR valve	confirmed and active
malfunction of the monitoring system	confirmed and active
NO_x threshold, if applicable	confirmed and active

2.2. The operator warning system shall be deactivated when the diagnostic system concludes that the malfunction relevant to that warning is no longer present or when the information including DTCs relative to the failures justifying its activation is erased by a scan tool.

2.2.1 Requirements for erasing "NO_x control information"

2.2.1.1. Erasing / resetting "NO_x control information" by a scan-tool

On request of the scan tool, the following data shall be erased or reset to the value specified in this appendix from the computer memory (see Table 3).

Table 3
Erasing / Resetting "NO_x Control Information" by a Scan-Tool

NO_x control information	Erasable	Resetable
all DTCs	X	
the value of the counter with the highest number of engine operating hours		X
the number of engine operating hours from the NCD counter(s)		X

2.2.1.2. NO_x control information shall not be erased by disconnection of the machine's battery(s).

2.2.1.3. The erasing of "NO_x control information" shall only be possible under "engine-off" conditions.

2.2.1.4. When "NO_x control information" including DTCs are erased, any counter reading associated with these failures and which is specified in this annex shall not be erased, but reset to the value specified in the appropriate clause of this Annex.

3. ACTIVATION AND DEACTIVATION MECHANISM OF THE OPERATOR INDUCEMENT SYSTEM

3.1. The operator inducement system shall be activated when the warning system is active and the counter relevant to the type of NCM justifying its activation has reached the value specified in Table 4 of this appendix.

3.2. The operator inducement system shall be deactivated when the system no longer detects a malfunction justifying its activation, or if the information including the DTCs relative to the NCMs justifying its activation has been erased by a scan tool or maintenance tool.

3.3. The operator warning and inducement systems shall be immediately activated or deactivated as appropriate according to the provisions of clause 6 of this Annex after assessment of the reagent quantity in the reagent tank. In that case, the activation or deactivation mechanisms shall not depend upon the status of any associated DTC.

4. COUNTER MECHANISM

4.1. General

4.1.1. To comply with the requirements of this annex, the system shall contain at least 4 counters to record the number of hours during which the engine has been operated while the system has detected any of the following:

(a) An incorrect reagent quality;

(b) An interruption of reagent dosing activity;

(c) An impeded EGR valve;

(d) A failure of the NCD system according to clause 9.1. (b) of this Annex.

4.1.1.1. Optionally, the manufacturer may use one or more counters for grouping the failures indicated in clause 4.1.1.

4.1.2. Each of the counters shall count up to the maximum value provided in a 2 byte counter with 1 hour resolution and hold that value unless the conditions allowing the counter to be reset to zero are met.

4.1.3. A manufacturer may use a single or multiple NCD system counters. A single counter may accumulate the number of hours of 2 or more different malfunctions relevant to that type of counter, none of them having reached the time the single counter indicates.

4.1.3.1. When the manufacturer decides to use multiple NCD system counters, the system shall be capable of assigning a specific monitoring system counter to each malfunction relevant according to this annex to that type of counters.

4.2. Principle of counters mechanism

4.2.1. Each of the counters shall operate as follows:

4.2.1.1. If starting from zero, the counter shall begin counting as soon as a malfunction relevant to that counter is detected and the corresponding diagnostic trouble code (DTC) has the status defined in Table 2.

4.2.1.2. In case of repeated failures, one of the following provisions shall apply at the choice of the manufacturer:

(a) If a single monitoring event occurs and the malfunction that originally activated the counter is no longer detected or if the failure has been erased by a scan tool or a maintenance tool, the counter shall halt and hold its current value. If the counter stops counting when the severe inducement system is active, the counter shall be kept frozen at the value defined in Table 4 of this appendix or a value of greater than or equal to the counter value for severe inducement minus 30 minutes.

(b) The counter shall be kept frozen at the value defined in Table 4 of this appendix or a value greater than or equal to the counter value for severe inducement minus 30 minutes.

4.2.1.3. In the case of a single monitoring system counter, that counter shall continue counting if a NCM relevant to that counter has been detected and its corresponding Diagnostic trouble code (DTC) has the status "confirmed and active". It shall halt and hold one of the values specified in clause 4.2.1.2, if no NCM that would justify the counter activation is detected or if all the failures relevant to that counter have been erased by a scan tool or a maintenance tool.

Table 4

Counters and Inducement

	DTC status for first activation of the counter	**counter value for low-level inducement**	**counter value for severe inducement**	**Frozen value held by the counter**
reagent quality counter	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90% of counter value for severe inducement
dosing counter	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90% of counter value for severe inducement
EGR valve counter	confirmed and active	≤ 36 hours	≤ 100 hours	≥ 95% of counter value for severe inducement
monitoring system counter	confirmed and active	≤ 36 hours	≤ 100 hours	≥ 95% of counter value for severe inducement
NO_x threshold, if applicable	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90% of counter value for severe inducement

4.2.1.4. Once frozen, the counter shall be reset to zero when the monitors relevant to that counter have run at least once to completion of their monitoring cycle without having detected a malfunction and no malfunction relevant to that counter has been detected during 40 engine operating hours since the counter was last held (see Figure 4).

4.2.1.5. The counter shall continue counting from the point at which it had been held if a malfunction relevant to that counter is detected during a period when the counter is frozen (see Figure 4).

5. ILLUSTRATION OF THE ACTIVATION AND DEACTIVATION AND COUNTER MECHANISMS

5.1. This clause illustrates the activation and deactivation and counter mechanisms for some typical cases. The figures and descriptions given in clauses 5.2., 5.3. and 5.4. are provided solely for the purposes of illustration in this annex and should not be referenced as examples of either the requirements of this Part or as definitive statements of the processes involved. The counter hours in Figures 6 and 7 refer to the maximum severe inducement values in Table 4. For simplification purposes, for example, the fact that the warning system will also be active when the inducement system is active has not been mentioned in the illustrations given.

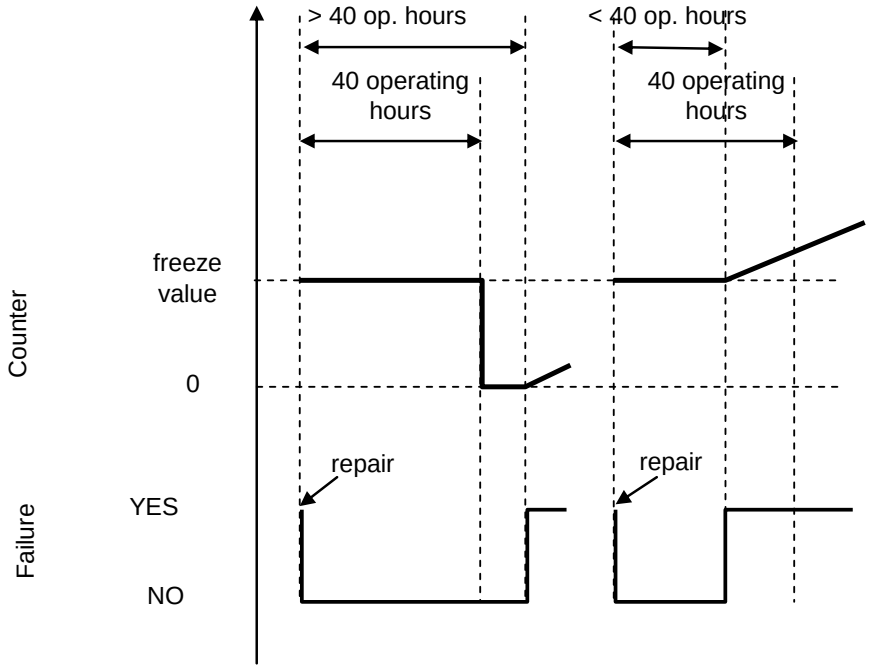


Figure 4

Reactivation and Resetting to Zero of a Counter after a Period when its Value has been Frozen

5.2. Figure 5 illustrates the operation of the activation and deactivation mechanisms when monitoring the reagent availability for five cases:

Use case 1: the operator continues operating the machine in spite of the warning until machine operation is disabled.

Refilling case 1 ("adequate" refilling): the operator refills the reagent tank so that a level above the 10 per cent threshold is reached. Warning and inducement are de-activated.

Refilling cases 2 and 3 ("inadequate" refilling): The warning system is activated. The level of warning depends on the amount of available reagent.

Refilling case 4 ("very inadequate" refilling): The low level inducement is activated immediately.

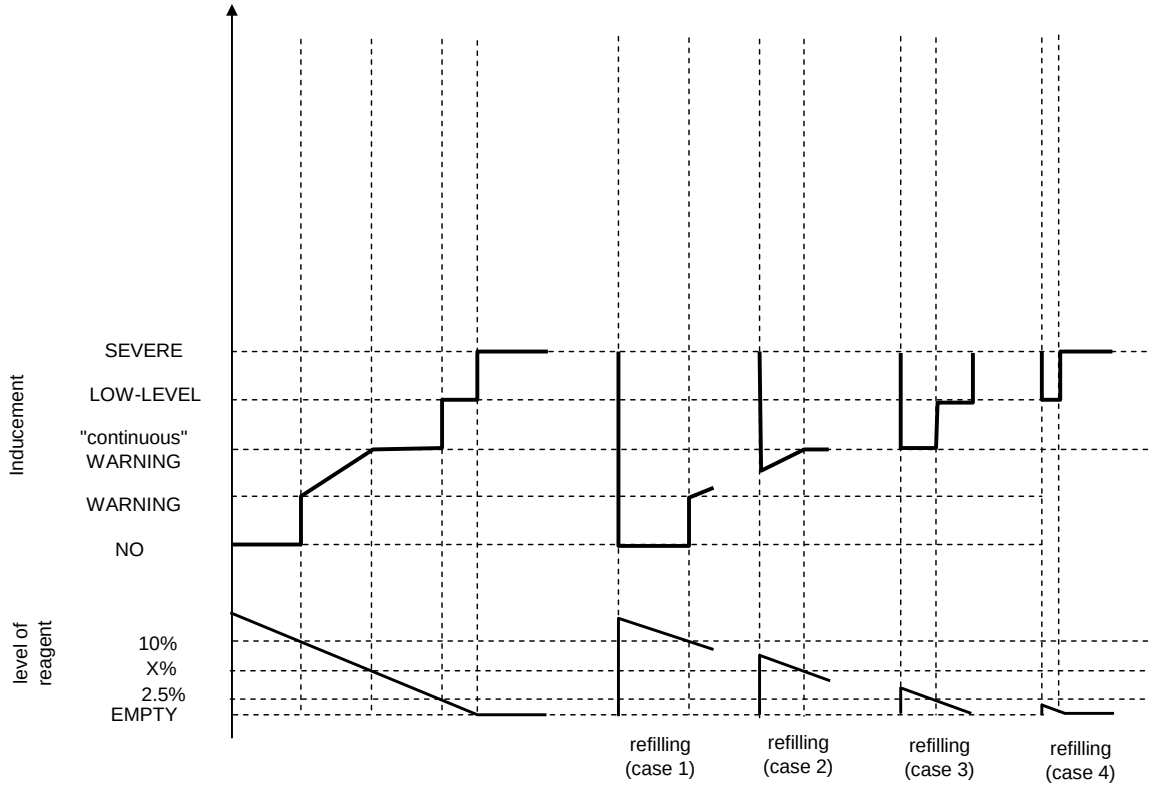


Figure 5

Reagent Availability

5.3. Figure 6 illustrates three cases of wrong reagent quality:

Use case 1: the operator continues operating the machine in spite of the warning until machine operation is disabled.

Repair case 1 ("bad" or "dishonest" repair): after disablement of the machine, the operator changes the quality of the reagent, but soon after, changes it again for a poor quality one. The inducement system is immediately reactivated and machine operation is disabled after 2 engine operating hours.

Repair case 2 ("good" repair): after disablement of the machine, the operator rectifies the quality of the reagent. However some time afterwards, he refills again with a poor quality reagent. The warning, inducement and counting processes restart from zero.

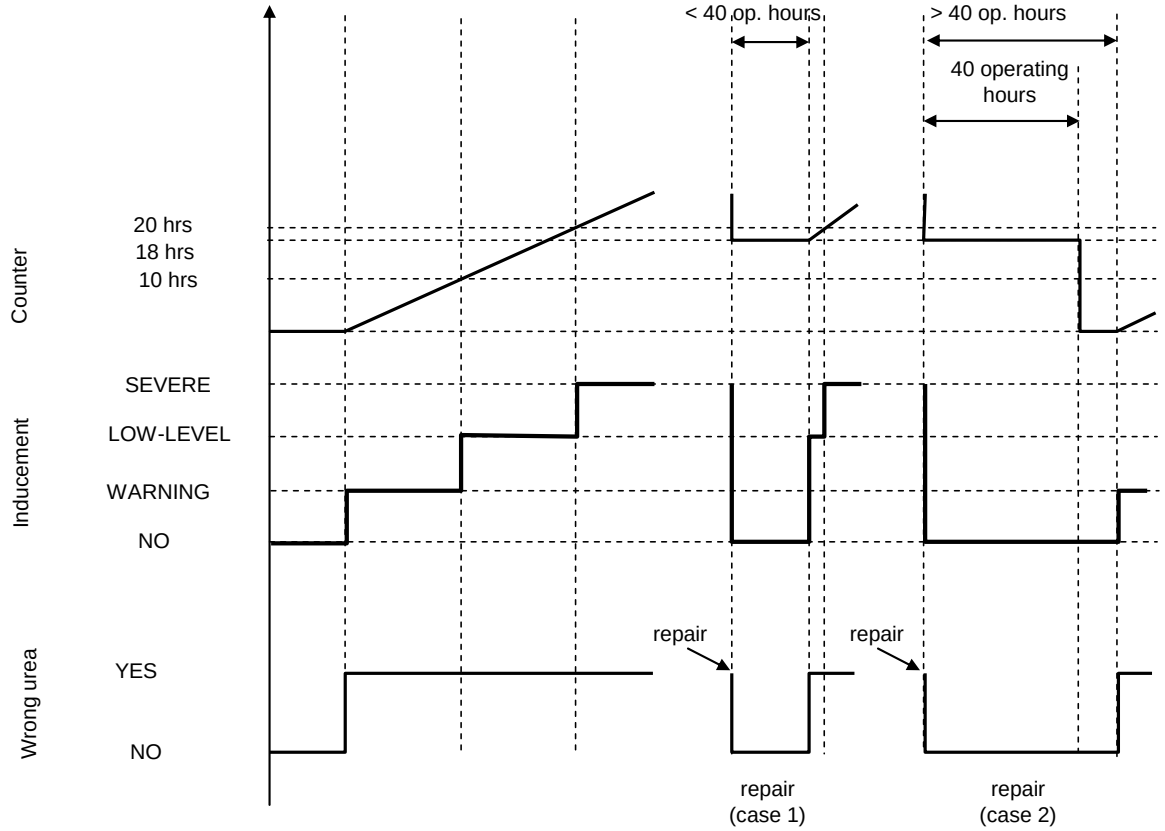


Figure 6

Filling with poor reagent quality

5.4. Figure 7 illustrates three cases of failure of the urea dosing system. This figure also illustrates the process that applies in the case of the monitoring failures described in clause 9. of this Annex.

Use case 1: the operator continues operating the machine in spite of the warning until machine operation is disabled.

Repair case 1 ("good" repair): after disablement of the machine, the operator repairs the dosing system. However some time afterwards, the dosing system fails again. The warning, inducement and counting processes restart from zero.

Repair case 2 ("bad" repair): during the low-level inducement time (torque reduction), the operator repairs the dosing system. Soon after, however, the dosing system fails again. The low-level inducement system is immediately reactivated and the counter restarts from the value it had at the time of repair.

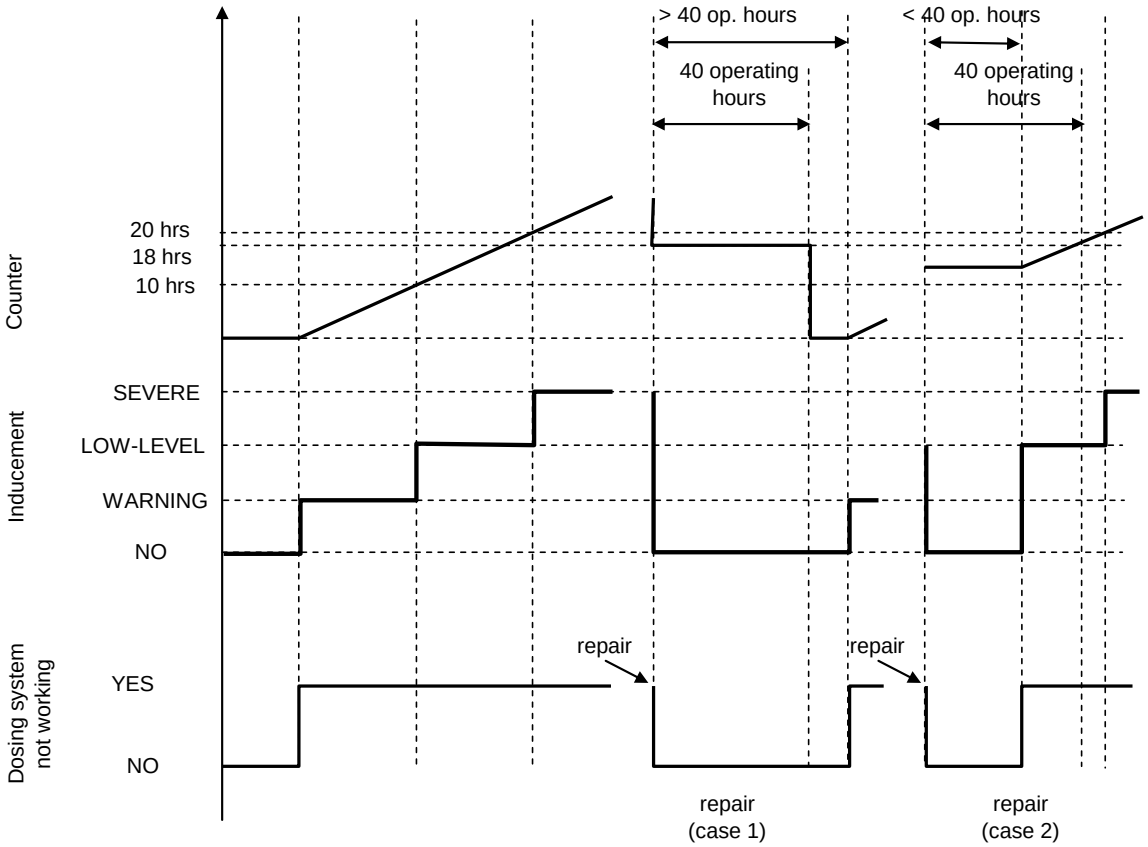


Figure 7

Failure of the reagent dosing system

ANNEX 9 - APPENDIX 3

DEMONSTRATION OF THE MINIMUM ACCEPTABLE REAGENT CONCENTRATION CD_{MIN}

1. The manufacturer shall demonstrate the correct value of CD_{min} during type approval by performing the hot part of the NRTC cycle using a reagent with the concentration CD_{min}.

2. The test shall follow the appropriate NCD cycle(s) or manufacturer defined pre-conditioning cycle, permitting a closed loop NO_x control system to perform adaptation to the quality of the reagent with the concentration CD_{min}.

3. The pollutant emissions resulting from this test shall be lower than the NO_x threshold specified in clause 7.1.1. of this Annex.

ANNEX 10

COP ADMINISTRATIVE PROCEDURE

Administrtative procedure for CoP shall be as per AIS-137 (Part 6) COP Administrative Procedure titled "Administrative Procedure for Type Approval and Conformity of Production for M and N Category Vehicles, Two and Three Wheelers and Agricultural Tractors/Construction Equipment Vehicles (CEVs) / Power Tillers/Combine Harvesters Engines as per CMV Rules 115, 116 and 126 "

ANNEX 11

POWER MEASUREMENT PROCEDURE

1. SCOPE

1.1. This Annex applies to the representation of the curves as a function of engine speed of the power and torque at full load, indicated by the manufacturer for internal combustion engines to be used:

1.1.1. In agricultural tractors, construction equipment vehicles and combine harvesters

1.2. The internal combustion engines belong to one of the following categories:

1.2.1. Reciprocating internal combustion engines (positive-ignition or compression-ignition), but excluding free piston engines;

1.2.2. Rotary piston engines (positive-ignition or compression-ignition).

2. DEFINITIONS

2.1. **"Approval of an engine"** means the approval of an engine type with regard to its gross power measured in accordance with the procedure specified in Appendix 1 to this annex;

2.2. **"Approval of an engine family"** means the approval of the members of an engine family with regard to their gross power in accordance with the procedure specified in Appendix 3 or 4 of this Annex;

2.3. **"Engine type"** means a category of engines which do not differ in such essential engine characteristics as defined in AIS-007;

2.4. **"Engine family"** means a manufacturer's grouping of engines which, through their design, fulfil the grouping criteria laid down in Appendix 3 to this annex;

2.5. **"Parent engine"** means an engine selected from an engine family in such a way that it complies with requirements set out in Appendix 3 of this annex;

2.6. **" Gross power"** means the power obtained on a test bench at the end of the crankshaft or its equivalent at the corresponding engine speed with the auxiliaries and equipment listed in Table 1 of Appendix 1 to this annex, determined under reference atmospheric conditions;

2.7. **"Rated Gross power"** means engine Gross power as declared by the manufacturer at rated speed;

2.8. **"Maximum Gross power"** means the maximum value of the Gross power measured at full engine load;

2.9. **"Rated speed"** means the maximum full load speed allowed by the governor, as designed by the manufacturer, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer;

2.10. **"Maximum Gross power speed"** means the engine speed at which the maximum Gross power is obtained, as specified by the manufacturer;

2.11. **"Maximum torque speed"** means the engine speed at which the maximum torque is obtained, as specified by the manufacturer;

2.12. **"Maximum torque"** means the maximum value of the gross torque measured at full engine load.

3. APPLICATION FOR APPROVAL

3.1. The application for approval of an engine type or an engine family with regard to the measurement of the gross power shall be submitted by the manufacturer or by his duly accredited representative.

3.2. It shall be accompanied by the following documents in triplicate: description of the engine type or engine family comprising all the relevant particulars referred to in AIS-007.

3.3. An engine representative of the engine type to be approved, or the parent engine, in case of an engine family, fitted with the equipment prescribed in Appendix 1 to this annex, shall be submitted to the Test Agency conducting the approval tests.

4. APPROVAL

4.1. If the power of the engine submitted for approval pursuant to this Part was measured according to the specifications of clause 5. below, approval of the engine type or family shall be granted.

5. SPECIFICATIONS AND TESTS

5.1. General

The components liable to affect the power of the engine shall be so designed, constructed and assembled as to enable the engine in normal use, despite the vibrations to which it may be subjected, to comply with the provisions of this Part.

5.2. Description of tests for internal combustion engines

5.2.1. The gross power test shall consist of a run at full throttle for positive-ignition engines and at fixed full-load fuel injection pump setting for compression-ignition engines, the engine being equipped as specified in Table 1 of Appendix 1 to this annex.

5.2.2. Measurements shall be taken at a sufficient number of engine speeds to define correctly the power, torque and specific fuel consumption curves between the lowest and the highest engine speeds recommended by the manufacturer. This range of speeds must include the rotational speeds at which the engine produces its rated gross power, its maximum power and its maximum torque.

5.2.3. The fuel used shall be as specified in gazette Notification

.

5.2.4. Measurements shall be carried out according to the provisions of Appendix 1 to this Annex.

5.2.5. The test report shall contain the results and all the calculations required to determine the gross power, as listed in the Appendix 2 to this Annex together with the characteristics of the engine, as listed in AIS 007.

5.3. Interpretation of Results

5.3.1. Gorss power

The Gross power declared by the manufacturer for the type of engine (or parent engine) shall be accepted if it does not differ by more than the values indicated in the table below, from the corrected values measured by the Test Agency on the engine submitted for testing.

Engine Type	Rated gross power [%]	Other measurement points on the curve [%]	Tolerance for engine speed [%]
General	±2	±4	±1.5

5.3.2. Rated speed

The rated speed declared by the manufacturer shall not deviate by more than 100 min^{-1} from the value measured by the test agency on the engine submitted for testing.

5.3.4. Engine family

In case of compliance of the parent engine to the conditions in clauses 5.3.1. and 5.3.2., the acceptance is automatically extended to all the declared curves of the family members.

6. CONFORMITY OF PRODUCTION

6.1. Engines approved under this Part shall be so manufactured as to conform to the type approved.

6.2. The minimum requirements for conformity of production control procedures set forth in Appendix 4 to this annex shall be complied with.

7. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

7.1. The approval granted in respect of an engine type or an engine family pursuant to this Part may be withdrawn if the requirements set forth in clause 6.1. above are not met or if an engine or an engine family bearing the approval mark does not conform to the type approved.

8. MODIFICATION AND EXTENSION OF APPROVAL OF AN ENGINE TYPE OR ENGINE FAMILY

8.1. Every modification of an engine type or an engine family with regard to the characteristics in AIS-007, as amdemeded form time to time, shall be notified to the Test Agency which approved the engine type or engine family. The Test Agency may then either:

8.1.1. Consider that the modifications made are unlikely to have any appreciable adverse effect and that in any case the engine still complies with the requirements; or

8.1.2. Require a further test report from the Test Agency responsible for conducting the tests.

8.2. Confirmation or refusal of approval, specifying the alterations shall be communicated to the applicant.

ANNEX 11- APEENDIX 1

METHOD FOR MEASURING INTERNAL COMBUSTION ENGINE GROSS POWER

1. These provisions apply to the method for determining the power curve at full load of an internal combustion engine operated under intermittent speed as a function of engine speed and the rated speed and rated gross power of an internal combustion engine under constant speed.

2. TEST CONDITIONS

2.1. The engine shall have been run-in according to the manufacturer's recommendations.

2.2. If the power measurement can be carried out only on an engine with the gearbox mounted, the efficiency of the gearbox shall be taken into account.

2.3. Auxiliaries and equipment

2.3.1. Auxiliaries and equipment to be fitted

During the test, the auxiliaries necessary for the engine operation in the intended application (as listed in Table 1) shall be installed on the test bench as far as possible in the same position as in the intended application.

2.3.2. Auxiliaries and equipment to be removed

Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test. The following non-exhaustive list is given as a sample:

(i) Air compressor for brakes

(ii) Power steering compressor

(iii) Suspension compressor

(iv) Air-conditioning system

Where auxiliaries cannot be removed, the power they absorb in the unloaded condition may be determined and added to the measured engine power (see note h of Table 1). If this value is greater than 3 per cent of the maximum power at the test speed it may verified by the Test Agency.

Table 1
Equipment and Auxiliaries to be Installed for the Test to Determine Engine Power

Number	Equipment and auxiliaries	Fitted for emission test
1	Inlet system	
	Inlet manifold	Yes
	Crankcase emission control system	Yes
	Air flow meter	Yes
	Air filter	Yes[a]
	Inlet silencer	Yes[a]
	Induction-heating device of inlet manifold	Yes, standard production equipment. If possible to be set in the most favourable condition
2	Exhaust system	
	Exhaust aftertreatment	Yes, standard production equipment
	Exhaust manifold	Yes, standard production equipment
	Connecting pipes	Yes[b]
	Silencer	Yes[b]
	Tail pipe	Yes[b]
	Exhaust brake	No[c]
	Pressure charging device	Yes
3	Fuel supply pump	Yes
4	Carburation equipment	
	Carburettor	Yes
	Electronic control system, air flow meter, etc.	Yes
	Equipment for gas engines	
	Pressure reducer	Yes
	Evaporator	Yes
	Mixer	Yes

5	Fuel injection equipment (petrol and diesel)	
	Pre-filter	Yes
	Filter	Yes
	Pump	Yes
	High-pressure pipe	Yes
	Injector	Yes
	Electronic control system, sensors, etc.	Yes
	Governor/control system	Yes
	Automatic full-load stop for the control rack depending on atmospheric conditions	Yes
6	Liquid-cooling equipment	
	Radiator	No
	Fan	No
	Fan cowl	No
	Water pump	Yes[e]
	Thermostat	Yes[f]
7	Air cooling	
	Cowl	No[g]
	Fan or Blower	No[g]
	Temperature-regulating device	No
8	Electrical equipment	
	Generator	Yes[h]
	Spark distribution system	Yes
	Coil or coils	Yes
	Wiring	Yes
	Spark plugs	Yes
	Electronic control system including knock sensor/spark retard system	Yes
9	Pressure charging equipment	

	Compressor driven either directly by the engine and/or by the exhaust gases	Yes
	Charge air cooler	Yes[g, i]
	Coolant pump or fan (engine-driven)	No[g]
	Coolant flow control device	Yes
10	Auxiliary test-bed fan	Yes, if necessary
11	Anti-pollution device	Yes, standard production equipment[j]
12	Starting equipment	Yes or test bed equipment[k]
13	Lubricating oil pump	Yes

[a] The complete inlet system shall be fitted as provided for the intended application:

(i) Where there is a risk of an appreciable effect on the engine power;

(ii) In the case of naturally aspirated spark ignition engines;

(iii) When the manufacturer requests that this should be done.

In other cases, an equivalent system may be used and a check should be made to ascertain that the intake pressure does not differ by more than 100 Pa from the upper limit specified by the manufacturer for a clean air filter.

[b] The complete exhaust system shall be fitted as provided for the intended application:

(i) Where there is a risk of an appreciable effect on the engine power;

(ii) In the case of naturally aspirated spark ignition engines;

(iii) When the manufacturer requests that this should be done.

In other cases, an equivalent system may be installed provided the pressure measured does not differ by more than 1,000 Pa from the upper limit specified by the manufacturer.

[c] If an exhaust brake is incorporated in the engine, the throttle valve shall be fixed in the fully open position.

[d] The fuel feed pressure may be adjusted, if necessary, to reproduce the pressure existing in the particular engine application (particularly when a "fuel return" system is used).

[e] The cooling-liquid circulation shall be operated by the engine water pump only. Cooling of the liquid may be produced by an external circuit, such that the pressure loss of this circuit and the pressure at the pump inlet remain substantially the same as those of the engine cooling system.

[f] The thermostat may be fixed in the fully open position.

[g] When the cooling fan or blower is fitted for the test, the power absorbed shall be added to the results, except for engines where such auxiliaries are an integral part of the engine (i.e.: cooling fans of air cooled engines directly fitted on the crankshaft). The fan or blower power shall be determined at the speeds used for the test either by calculation from standard characteristics or by practical tests.

[h] Minimum power of the generator: the electrical power of the generator shall be limited to that necessary for operation of auxiliaries which are indispensable for engine operation. If the connection of a battery is necessary, a fully charged battery in good condition shall be used.

[i] Charge air-cooled engines shall be tested with charge air cooling, whether liquid - or air-cooled, but if the manufacturer prefers, a test bench system may replace the air cooler. In either case, the measurement of power at each speed shall be made with the maximum pressure drop and the minimum temperature drop of the engine air across the charge air cooler on the test bench system as those specified by the manufacturer.

[j] These may include, for example, exhaust-gas recirculation (EGR system), catalytic converter, thermal reactor, secondary air-supply system and fuel evaporation protecting system.

[k] The power for electrical or other starting systems shall be provided from the test bed.

2.4. Setting conditions

The setting conditions for the test to determine the gross power are indicated in Table 2.

Table 2
Setting Conditions

1. Setting of carburettor(s), evaporator/pressure regulator	In accordance with the manufacturer's production specifications, and used without further alteration for the particular application.
2. Setting of injection pump delivery system	
3. Ignition or injection timing (timing curve)	
4. Governor setting	
5. Emission control devices	
6. Boost Control	

3. DATA TO BE RECORDED

3.1. Data to be recorded are those indicated in clause 4 of the Appendix 2 to this Annex. Performance data shall be obtained under stabilised operating conditions with an adequate fresh air supply to the engine. Combustion chambers may contain deposits, but in limited quantity. Test conditions, such as inlet air temperature, shall be selected as near to reference conditions (see clause 5.2. of this Annex) as possible in order to minimize the magnitude of the correction factor.

3.2. The temperature of the inlet air to the engine shall be measured within the inlet ductwork. The inlet depression measurement shall be made at the same point. The thermometer or thermocouple shall be shielded from fuel spray-back and radiant heat and located directly in the air stream. A sufficient number of locations shall be used to give a representative average of the inlet temperature.

3.3. The inlet depression shall be measured downstream of the entry ducts, air filter, inlet silencer or speed-limiting device (if fitted).

3.4. The absolute pressure at the entry to the engine downstream of the compressor and heat exchanger, if fitted, shall be measured in the inlet manifold and at any other point where pressure has to be measured to calculate correction factors.

3.5. The exhaust back pressure shall be measured at a point at least three pipe diameters downstream from the outlet flange(s) of the exhaust manifold(s) and downstream at the turbocharger(s), if fitted. The location shall be specified.

3.6. No data shall be taken until torque, speed and temperatures have been maintained substantially constant for at least one minute.

3.7. The engine speed during a run or reading shall not deviate from the selected speed by more than ±1 per cent or ±10 min, whichever is greater.

3.8. Observed brake load, fuel consumption and inlet air temperature data shall be taken simultaneously and shall be the average of two stabilised consecutive values which do not vary more than 2 per cent for the brake load.

3.9. The temperature of the coolant at the outlet from the engine shall be kept at the value specified by the manufacturer.

If no temperature is specified by the manufacturer, the temperature shall be 353 K ± 5 K. For air-cooled engines, the temperature at a point indicated by the manufacturer shall be kept within +0/-20 K of the maximum value specified by the manufacturer in the reference conditions.

3.10. For C.I. engines, the fuel temperature shall be measured at the inlet of the fuel injection pump and maintained within 306 - 316 K (33-43 °C) for positive-ignition engines the fuel temperature shall be measured as near as possible to the inlet of the carburettor or assembly of fuel injectors and maintained within 293–303 K (20-30 °C).

3.11. The temperature of the lubricating oil measured in the oil pump or at the outlet from the coil cooler, if fitted, shall be maintained within the limits established by the engine manufacturer.

3.12. An auxiliary regulating system may be used if necessary to maintain the temperatures within the limits specified in clauses 3.9., 3.10. and 3.11. above of this Appendix.

4. ACCURACY OF MEASUREMENTS

4.1. Torque: ±1 per cent of measured torque. The torque measuring system shall be calibrated to take friction losses into account. The accuracy in the lower half of the measuring range of the dynamometer bench may be ±2 per cent of measured torque.

4.2. Engine speed: 0.5 per cent of measured speed.

4.3. Fuel consumption: ±1 per cent of measured consumption.

4.4. Fuel temperature: ±2 K.

4.5. Engine inlet air temperature: ±2 K.

4.6. Barometric pressure: ±100 Pa.

4.7. Depression in inlet system: ±50 Pa.

4.8. Back-pressure in exhaust system: ±200 Pa.

5. POWER CORRECTION FACTORS

5.1. Definition

The power correction factor is the coefficient to determine the engine power under the reference atmospheric conditions specified in 5.2. below.

$$P_o = \alpha P$$

where:

P_o is the corrected power (i.e. power under reference atmospheric conditions)

α is the correction factor (α_a or α_d)

P is the measured power (test power)

5.2. Reference atmospheric conditions

5.2.1. Temperature (T_o): 298 K (25 °C)

5.2.2. Dry pressure (P_{so}): 99 kPa

The dry pressure is based on a total pressure of 100 kPa and a water vapour pressure of 1 kPa.

5.3. Test atmospheric conditions

The atmospheric conditions during the test shall be the following:

5.3.1. Temperature (T)

For positive-ignition engines: 288 K < T < 308 K

For compression-ignition engines: 283 K < T < 313 K

5.3.2. Pressure (p_s)

$$90 \text{ kPa} < p_s < 110 \text{ kPa}$$

5.4. Determination of correction factor α_a and α_d

5.4.1. Naturally aspirated or pressure-charged positive-ignition engine

The correction factor α_a is obtained by applying the formula:

$$\alpha_a = \left(\frac{99}{p_s}\right)^{1.2} * \left(\frac{T}{298}\right)^{0.6}$$

where:

p_s is the total dry atmospheric pressure in kilopascals (kPa); i.e. the total barometric pressure minus water vapour pressure,

T is the absolute temperature in kelvins (K) of the air drawn in by the engine.

Conditions to be complied with in the laboratory

For a test to be valid, the correction factor must be such that

$$0.93 < \alpha_a < 1.07$$

If these limits are exceeded, the corrected value obtained shall be given and the test conditions (temperature and pressure) precisely stated in the test report.

---

1. The test may be carried out in air-conditioned test room where the atmospheric conditions may be controlled

In the case of engines fitted with automatic air temperature control, if the device is such that at full load at 25 °C no heated air is added, the test shall be carried out with the device fully closed. If the device is still operating at 25 °C then the test is made with the device operating normally and the exponent of the temperature term in the correction factor shall be taken as zero (no temperature correction).

5.4.2. Compression-ignition engines - factor α_d

The power correction factor (α_d) for compression-ignition engines at constant fuel rate is obtained by applying the formula:

$$\alpha_d = (f_a)^{fm}$$

where:

f_a is the atmospheric factor

f_m the characteristic parameter for each type of engine and adjustment

5.4.2.1. Atmospheric factor f_a

This factor indicates the effects of environmental conditions (pressure, temperature and humidity) on the air drawn in by the engine. The atmospheric factor formula differs according to the type of engine.

5.4.2.1.1. Naturally aspirated and mechanically pressure charged engines

$$f_a = \left(\frac{99}{p_s}\right) * \left(\frac{T}{298}\right)^{0.7}$$

5.4.2.1.2. Turbocharged engines with or without charge air cooling

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} * \left(\frac{T}{298}\right)^{1.5}$$

5.4.2.2. Engine factor f_m

f_m is a function of qc (fuel flow corrected) as follows:

$f_m = 0.036\ q_c - 1.14$

and

$q_c = q/r$

Where:

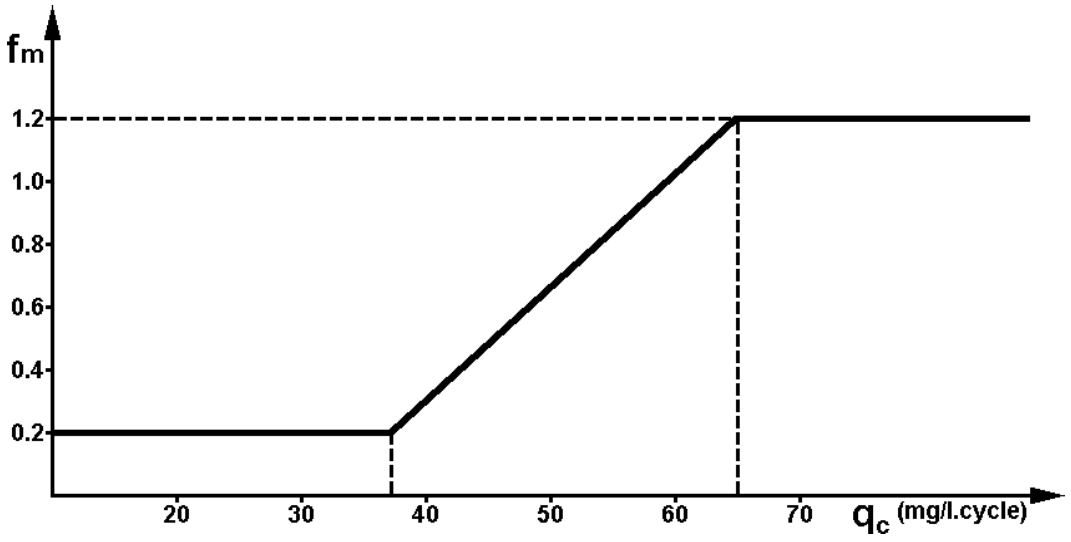
q is the fuel flow in milligram per cycle per litre of total swept volume (mg/(l.cycle))

r is the pressure ratio of compressor outlet and compressor inlet in case of multiple turbochargers r represents the total compression ratio (r = 1 for naturally aspirated engines)

This formula is valid for a value interval of q_c included between 37.2 mg/(l.cycle) and 65 mg/(l.cycle).

For q_c values lower than 37.2 mg/(l.cycle), a constant value of f_m equal to 0.2 ($f_m = 0.2$) will be taken.

For q_c values higher than 65 mg/(l.cycle), a constant value of f_m equal to 1.2 ($f_m = 1.2$) will be taken (see figure):



5.4.2.3. Conditions to be complied with in the laboratory

For a test to be valid, the correction factors α_a must be such that

$$0.93 < \alpha_a < 1.07$$

If these limits are exceeded, the corrected value obtained shall be given and the test conditions (temperature and pressure) precisely stated in the test report.

ANNEX 11 - APPENDIX 2

RESULTS OF TESTS FOR MEASURING GROSS ENGINE POWER

This form shall be completed by the laboratory performing the test.

1. Test conditions

1.1. Location of exhaust back-pressure measuring point

1.2. Location of inlet depression measuring point

1.3. Characteristics of the dynamometer

1.3.1. Make: ..... Model: .....

1.3.2 Type: .....

2. Fuel

2.1. For positive-ignition engines operating on liquid fuel

2.1.1. Make: .....

2.1.2. Specification: .....

2.1.3. Anti-knock additive (lead, etc): .....

2.1.3.1. Type: .....

2.1.3.2. Content: ..... mg/l

2.1.4. Octane number RON: .....(ASTM D 26 99-70)

2.1.4.1. Specify density: .....g/cm^3 at 288 K

2.1.4.2. Lower calorific value: .....kJ/kg

2.2. For positive-ignition engines operating on gaseous fuel

2.2.1. Make: .....

2.2.2. Specification: .....

2.2.3. Storage pressure: .....bar

2.2.4. Utilization pressure: .....bar

2.2.5. Lower calorific value: .....kJ/kg

2.3. For compression-ignition engines operating on gaseous fuels

2.3.1. Feed system: gas

2.3.2. Specification of gas used: .....

2.3.3. Fuel oil/gas proportion: .....

2.3.4. Lower calorific value: .....

2.4. For compression-ignition engines operating on liquid fuel

2.4.1. Make: .....

2.4.2. Specification of fuel used: .....

2.4.3. Cetane number (ASTM D 976-71): .....

2.4.4. Specify density: .....g/cm^3 at 288 K

2.4.5. Lower calorific value:..... kJ/kg

3. Lubricant

3.1. Make:.....

3.2. Specification:.....

3.3. SAE viscosity: .....

4. Detailed results of measurements*

Engine speed, min^{-1}			
Measured torque, Nm			
Measured power, kW			
Measured fuel flow, g/h			
Barometric pressure, kPa			
Water vapour pressure, kPa			
Inlet air temperature, K			
Power to be added for equipment and auxiliaries in excess of Table 1, kW Total, kW	No. 1 No. 2 No. 3		
Power correction factor			
Corrected power, kW			
Corrected torque, Nm			
Corrected specific fuel consumption $g/(kWh)^2$			
Cooling liquid temperature at outlet, K			
Lubricating oil temperature at measuring point, K			
Air temperature after pressure-charger, K [1]			
Fuel temperature at injection pump inlet, K			
Air temperature after charge air cooler, K [1]			
Pressure after pressure-charger, kPa			
Pressure after charge air cooler, kPa			
Inlet depression, Pa			
Exhaust back-pressure, Pa			
Fuel delivery, mm^3/stroke or cycle [1]			

* The characteristic curves of the gross power and the gross torque shall be drawn as a function of the engine speed.

[1] Strike out what does not apply.

[2] Calculated with the gross power for compression-ignition and positive-ignition engines, in the latter case multiplied by the power correction factor.

ANNEX 11 - APPENDIX 3

ESSENTIAL CHARACTERISTICS OF THE ENGINE FAMILY

1. GENERAL

An engine family is characterized by design parameters. These shall be common to all engines within the family. The engine manufacturer may decide which engines belong to an engine family, as long as the membership criteria listed in clause 3 below are respected. The engine family shall be approved by the Test Agency.

2. SPECIAL CASES

2.1. Interactions between parameters

In some cases there may be interaction between parameters, which may cause emissions to change. This shall be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.2. Devices or features having a strong influence on emissions

In case of devices or features, which are not listed in clause 3 below and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer using good engineering judgment, and shall be notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.3. Additional criteria

In addition to the parameters listed in clause 3 below, the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

3. PARAMETERS DEFINING THE ENGINE FAMILY

3.1. Combustion cycle:

(a) 2-stroke cycle;

(b) 4-stroke cycle;

(c) Rotary engine;

(d) Others.

3.2. Fuel type :

(a) Diesel;

(b) Petrol;

(c) Gaseous (NG or LPG).

3.3. Configuration of the cylinders

3.3.1. Position of the cylinders in the block:

(a) V;

(b) In-line;

(c) Radial;

(d) Others (F, W, etc.).

3.3.2. Relative position of the cylinders

Engines with the same block may belong to the same family as long as their bore centre-to-centre dimensions are the same.

3.4. Main cooling medium:

(a) Air;

(b) Water;

(c) Oil.

3.5. Individual cylinder displacement

Within 85 per cent and 100 per cent for engines with a unit cylinder displacement ≥ 0.75 dm^3 of the largest displacement within the engine family.

Within 70 per cent and 100 per cent for engines with a unit cylinder displacement < 0.75 dm^3 of the largest displacement within the engine family.

3.6. Method of air aspiration:

(a) Naturally aspirated;

(b) Pressure charged;

(c) Pressure charged with charge cooler.

3.7. Combustion chamber type/design:

(a) Open chamber;

(b) Divided chamber;

(c) Other types.

3.8. Valves and porting:

(a) Configuration;

(b) Number of valves per cylinder;

(c) Cylinder wall;

(d) Crankcase.

3.9. Fuel supply type

3.9.1. For compression ignition engines:

(a) Pump, (high pressure) line and injector;

(b) In-line pump or distributor pump;

(c) Unit injector;

(d) Common rail.

3.9.2. For positive ignition engines:

(a) Carburettor;

(b) Port fuel injection;

(c) Direct injection.

3.10. Miscellaneous devices:

(a) Exhaust gas recirculation (EGR);

(b) Water injection;

(c) Air injection;

(d) Others.

3.11. Electronic control strategy

The presence or absence of an Electronic Control Unit (ECU) on the engine is regarded as a basic parameter of the family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engines can be expected to satisfy the same emission requirements.

The electronic governing of speed does not need to be in a different family from those with mechanical governing. The need to separate electronic engines from mechanical engines should only apply to the fuel injection characteristics, such as timing, pressure, rate shape, etc.

3.12. Exhaust after-treatment systems

The function and combination of the following devices are regarded as membership criteria for an engine family:

(a) Oxidation catalyst;

(b) $DeNO_x$ system with selective reduction of NO_x (addition of reducing agent);

(c) Other $DeNO_x$ systems;

(d) Particulate trap with passive regeneration;

(e) Particulate trap with active regeneration;

(f) Other particulate traps;

(g) Other devices.

When an engine has been certified without an after-treatment system, whether as a parent engine or as a member of the family, then this engine, when equipped with an oxidation catalyst (not with particulate trap), may be included in the same engine family, if it does not require different fuel characteristics.

If it requires specific fuel characteristics (e.g. particulate traps requiring special fuel additives to ensure the regeneration process), the decision to include it in the same family shall be based on technical elements provided by the manufacturer. These elements shall indicate that the expected emission level of the equipped engine complies with the same limit value as the non-equipped engine.

When an engine has been certified with an after-treatment system, whether as a parent engine or as a member of a family, where the parent engine is equipped with the same after-treatment system, then this engine, when equipped without an after-treatment system, shall not be added to the same engine family.

ANNEX 11 - APPENDIX 4

CHECKS ON CONFORMITY OF PRODUCTION

1. GENERAL

These requirements are consistent with tests to be held to check conformity of production (COP), according to clause 6.2. of this Annex.

2. TEST PROCEDURES

The methods of testing and measuring instruments shall be those described in Apeendix 1 to this Annex.

3. Collection of samples shall be as per AIS-37 (Part 6)

3.1. Case of an engine type

One engine has to be chosen. If after the test of clause 5. below, the engine is not considered as conforming to the requirements of this Annex, two more engines have to be tested.

3.2. Case of a family of engines

In case of an approval granted to a family of engines the COP shall be run on one member of the family, which is not the parent engine. In case of failure of the COP test, the two more engines shall be of the same member type.

4. MEASUREMENT CRITERIA

4.1. Gross power of internal combustion engine

Measurements shall be taken at a sufficient number of engine speeds to define correctly the power and torque curves between the lowest and the highest engine speeds recommended by the manufacturer as defined in clauses 2.9. and 2.11. of this Annex.

Engine type	Rated gross power (torque) [%]	Other measurement points on the curve [%]	Tolerance for engine speed [%]
General	±5	±10	±5

5. EVALUATION OF RESULTS

If the gross power and fuel consumption figures of the second and/or third engine of clause 3. do not fulfil the requirements of clause 4. above, the production shall be considered not to conform to the requirements of this Annex and the provision of clause 7. of this Part shall be put into effect.

ANNEX 11 - APPENDIX 5

TECHNICAL DATA OF REFERENCE FUELS

Test fuel shall be as per Gazette Notification:

ANNEX 12

DETERMINATION OF CO_2 EMISSIONS

1. INTRODUCTION

The provisions and test procedures for reporting CO_2 set out in this Annex shall apply.

2. GENERAL REQUIREMENTS

2.1. CO_2 emissions shall be determined over the hot start NRTC test cycle in accordance with clause 7.8.3. of Annex 4 of this Part.

2.2. The test results shall be reported as cycle averaged brake specific values and expressed in the unit of g/kWh.

3. DETERMINATION OF CO_2 EMISSIONS

3.1. Raw measurement

This paragraph applies, if CO_2 is measured in the raw exhaust gas.

3.1.1. Measurement

CO_2 in the raw exhaust gas emitted by the engine submitted for testing shall be measured with a non-dispersive infrared (NDIR) analyser in accordance with clause 9.4.6. of Annex 4 to this Part.

The measurement system shall meet the linearity requirements of clause 8.1.4. of Annex 4 to this Part.

The measurement system shall meet the requirements of clause 8.1.9. of Annex 4 to this Part.

3.1.2. Data evaluation

The relevant data shall be recorded and stored in accordance with clause 7.8.3.2. of Annex 4 to this Part.

3.1.3. Calculation of cycle averaged emission

If measured on a dry basis, the dry/wet correction in accordance with clause A.8.2.2. of Appendix A. 8 or clause A.7.3.2. of Appendix A. 7 to Annex 4 to this Part shall be applied to the instantaneous concentration values before any further calculation is done.

The mass of CO_2 (g/test) shall be calculated by multiplication of the time aligned instantaneous CO_2 concentrations and exhaust gas flows and integration over the test cycle in accordance with either of the following:

(a) Clause A.8.2.1.2. and clause A.8.2.5. of Appendix A.8 to Annex 4, by using the u values of CO_2 from table A.8.1. or calculating the u values in accordance with clause A.8.2.4.2. of Appendix A. 8 to Annex 4 to this Part;

(b) Clause A.7.3.1. and clause A.7.3.3. of Appendix A.7 to Annex 4 to this Part.

3.2. Dilute measurement

This clause applies, if CO_2 is measured in the dilute exhaust gas.

3.2.1. Measurement

CO_2 in the dilute exhaust gas emitted by the engine submitted for testing shall be measured with a non-dispersive infrared (NDIR) analyser in accordance with clause 9.4.6. of Annex 4 to this Part. Dilution of the exhaust shall be done with filtered ambient air, synthetic air or nitrogen. The flow capacity of the full flow system shall be large enough to completely eliminate water condensation in the dilution and sampling systems.

The measurement system shall meet the linearity requirements of clause 8.1.4. of Annex 4 to this Part.

The measurement system shall meet the requirements of clause 8.1.9. of Annex 4 to this Part.

3.2.2. Data evaluation

The relevant data shall be recorded and stored in accordance with clause 7.8.3.2. of Annex 4 to this Part.

3.2.3. Calculation of cycle averaged emission

If measured on a dry basis, the dry/wet correction in accordance with clause A.8.3.2. of Appendix A.8 or clause A.7.4.2. of Appendix A. 7 to Annex 4 to this Part shall be applied to the instantaneous concentration values before any further calculation is done.

The mass of CO_2 (g/test) shall be calculated by multiplication of the CO_2 concentrations and the diluted exhaust gas flows in accordance with either of the following:

(a) Clause A.8.3.1. and clause A.8.3.4. of Appendix A. 8 to Annex 4 to this Part, by using the u values of CO_2 from table A.8.2. or calculating the u values in accordance with clause A.8.3.3. of Appendix A.8 to Annex 4;

(b) Clause A.7.4.1. and clause A.7.4.3. of Appendix A.7 to Annex 4 to this Part.

Background correction shall be applied in accordance with clause A.8.3.2.4. of Appendix A.8 or clause A.7.4.1. of Appendix A.7 to Annex 4 to this Part.

3.3. Calculation of brake specific emissions

The cycle work needed for the calculation of brake specific CO_2 emissions shall be determined in accordance with clause 7.8.3.4. of Annex 4 to this Part.

The brake specific emissions e_{CO2} (g/kWh) shall be calculated as follows:

$$e_{CO2} = \frac{m_{CO2,hot}}{W_{act,hot}}$$

Where:

$m_{CO2,\ hot}$ is the CO_2 mass emissions of the hot start NRTC (g)

$W_{act,\ hot}$ is the actual cycle work of the hot start NRTC (kWh).

	ANNEX 13 **EMISSION OF VISIBLE POLLUTANTS AT STEADY SPEEDS OVER THE FULL-LOAD CURVE**
1.	**SCOPE** This Annex describes the method of determining emissions of visible pollutants at different steady speeds over the full load curve. The test to be carried out either on an engine or on a vehicle. This Annex is applicable for emission of visible exhaust pollutants from C.I. engines which are intended for fitting to agricultural tractors, construction equipment vehicles and combine harvesters.
2.	**MEASUREMENT PRINCIPLE**
2.1	The opacity of the exhaust gases produced by the engine shall be measured with the engine running under full-load and at steady speed.
2.2	A sufficient number of measurements will be carried out ranging between the maximum rated speed and the minimum rated speed. The extreme points of measurement shall be situated at the limits of interval defined above and one point of measurement will coincide with the speed at which the engine develops its maximum power and the speed at which it develops maximum torque.
3	**TEST CONDITIONS**
3.1	Vehicle or engine:
3.1.1	The engine or the vehicle shall be submitted in good mechanical condition. The engine/vehicle shall have been run in as recommended by the manufacturer.
3.1.2	The engine shall be tested with the equipment prescribed in Table1 of Appendix 1 of Annex 11 of this Part.
3.1.3	The settings of the engine shall be those prescribed by the manufacturer and shown in Appendix 1 of Annex 11 of this Part.
3.1.4	In the case of a test on an engine the power of the engine shall be measured in accordance with Appendix 1 of Annex 11 of this Part and it should meet the requirements of power tolerance given in clause 5.3 of Annex 11. In the case of a test on a vehicle, it should be established that the fuel flow is not less than that declared by the manufacturer.
3.1.5	The exhaust device shall not have any orifice through which the gases emitted by the engine might be diluted. In cases where an engine has several exhaust outlets, these shall be connected to a single outlet in which the opacity measurement shall be made.
3.1.6	The engine shall be in the normal working condition prescribed by the manufacturer. In particular, the cooling water and the oil shall each be at the normal temperature prescribed by the manufacturer.

Table 1

Limit Values Applicable in the Test at Steady Speeds

	Nominal Flow G (l/s)	Light Absorption Coefficient K (1/m)	Nominal Flow G (1/s)	Light Absorption Coefficient K (1/m)
	<=42	2.26	120	1.37
	45	2.19	125	1.345
	50	2.08	130	1.32
	55	1.985	135	1.30
	60	1.90	140	1.27
	65	1.84	145	1.25
	70	1.775	150	1.205
	75	1.72	160	1.19
	80	1.665	165	1.17
	85	1.62	170	1.155
	90	1.575	175	1.14
	95	1.535	180	1.125
	100	1.495	185	1.11
	105	1.465	190	1.095
	110	1.425	195	1.08
	115	1.395	>200	1.065
	The emissions of visible pollutants when tested as detailed in this Annex shall not exceed the limit values of light absorption coefficient given above for various nominal flows:			

3.2 Fuel: The fuel used shall be the reference fuel as specified in the Gazette Notification.

3.3 Test Laboratory

The absolute temperature T of the air (The test may be carried out in air condition test rooms where the atmospheric conditions may be controlled) at the inlet to the engine measured within 0.15 m upstream of the point of entry to the air cleaner, or if no air cleaner is used, within

0.15 m of the air inlet manifold expressed in degrees Kelvin, and the atmospheric pressure Ps, expressed in Kilopascals, shall be measured, and the atmospheric factor fa shall be determined as give below :
Naturally aspirated and mechanically super charged engines:-

$fa = (99/Ps) * (T/298)^{0.7}$

Turbo super charge engines with or without cooling of inlet air

$f = (99/Ps)^{0.7} * (T/298)^{1.5}$

3.3.1 For a test to be recognised as valid, the parameter fa shall be such that $0.98 \leq fa \leq 1.02$.

3.4 Sampling and measuring apparatus:
The light-absorption coefficient of the exhaust gases shall be measured with an opacimeter satisfying the conditions of installation of opacimeter mentioned in Appendix 7 of Chapter 1 of AIS-137(Part 5).

4.0 EVALUATION OF THE ABSORPTION COEFFICIENT

4.1 For each of the engine speeds at which the absorption coefficient is measured pursuant to clause 2.2 of this Annex, the nominal gas flow shall be calculated by means of the following formulae:

for two-stroke engines $G = V * n/60$

for four-stroke engines $G = V * n/120$

Where:

G is the nominal gas flow, in liters per second, (l/s)

V is the cylinder capacity of the engine, in liters, (l)

N is the engine speed, in revolutions per minute (rpm)

4.2 Where the value of the nominal flow is not one of those given in the Table 1 of this Annex above. the limit value applicable shall be obtained by interpolation on the principle of proportional parts.

AIS-137 (Part 7 - A2) : Bharat Stage (CEV/TREM) –V

1. SCOPE

This test procedure applies as per GSR 201(E) for Bharat Stage (CEV/TREM)-V from 1st April, 2024 to all engines falling within the categories set out in clause 1.1 which are installed in or are intended to be installed in category of agricultural tractors, construction equipment vehicles and combine harvesters.

1.1 For the purposes of this Part, the following engine categories, divided into the sub-categories set out in Appendix 1 to this clause, apply:

1.1.1 'category NRE': engines for category of agricultural tractor, construction equipment vehicle and combine harvester operated under costant speed or variable speed.

1.1.2 A variable-speed engine of a particular category may be used in the place of a constant-speed engine of the same category.

CLAUSE 1 – APPENDIX 1

DEFINITION OF ENGINE SUB-CATEGORIES REFERRED TO IN CLAUSE 1

Table 1
Sub-categories of Engine Category NRE Defined in clause 1.1.1

Category	Ignition type	Speed operation	Power range (kW)	Sub-category	Reference power
NRE	CI	variable	0<P<8	NRE-v-1	Maximum gross power
	CI		8≤P<19	NRE-v-2	
	CI		19≤P<37	NRE-v-3	
	CI		37≤P<56	NRE-v-4	
	all		56≤P<130	NRE-v-5	
			130≤P≤560	NRE-v-6	
			P>560	NRE-v-7	
	CI	constant	0<P<8	NRE-c-1	Rated gross power
	CI		8≤P<19	NRE-c-2	
	CI		19≤P<37	NRE-c-3	
	CI		37≤P<56	NRE-c-4	
	all		56≤P<130	NRE-c-5	
			130≤P≤560	NRE-c-6	
			P>560	NRE-c-7	

2. DEFINITIONS AND ABBREVIATIONS

2.1. For the purpose of this Part,

2.1.1. **"Adjustable parameter"** means any device, system, or element of design that someone can adjust (including those which are difficult to access) and that, if adjusted, may affect emissions or engine performance during emissions testing or normal in-use operation. This includes, but is not limited to, parameters related to injection timing and fuelling rate;

2.1.2. **"Adjustment factors"** mean additive (upward adjustment factor and downward adjustment factor) or multiplicative factors to be considered during the periodic (infrequent) regeneration;

2.1.3. **"Ambient temperature"** means, in relation to a laboratory environment (e.g. filter weighing room or chamber), the temperature within the specified laboratory environment;

2.1.4. **"Aqueous condensation"** means the precipitation of water-containing constituents from a gas phase to a liquid phase.;

2.1.5. **"Auxiliary emission control strategy"** or "AECS" means an emission control strategy that is activated and temporarily modifies a Base Emission Control Strategy (BECS) for a specific purpose and in response to a specific set of ambient and/or operating conditions and only remains in operation as long as those conditions exist;

2.1.6. **"Base emission control strategy"** or "BECS" means an emission control strategy that is active throughout the range of torque and speed over which the engine operates, unless an Auxiliary Emission Control Strategy (AECS) is activated;

2.1.7. "**Calibration"** means the process of setting a measurement system's response so that its output agrees with a range of reference signals. Contrast with "*verification*";

2.1.8. **"Calibration gas"** means a purified gas mixture used to calibrate gas analysers.

2.1.9. **"Compression ignition (C.I.) engine"** means an engine which works on the compression-ignition principle ;

2.1.10. **"Constant-speed engine"** means an engine type-approval of which is limited to constant-speed operation, excluding engines the constant-speed governor function of which is removed or disabled; it may be provided with an idle speed that can be used during start-up or shut-down and it may be equipped with a governor that can be set to an alternative speed when the engine is stopped;;

2.1.11. **"Constant-speed non-road steady-state test cycle"** (hereinafter 'constant-speed NRSC') means any of the following non-road steady-state test cycles defined in Appendix A.6 to Annex 4 of this Part: D2, G1, G2 or G3;

2.1.12. **"Constant-speed operation"** means an engine operation with a governor that automatically controls the operator demand to maintain engine speed, even under changing load;

2.1.13 **"Crankcase"** means the enclosed spaces in, or external to, an engine which are connected to the oil sump by internal or external ducts through which gases and vapours can be emitted;

2.1.14. **"Defeat strategy"** means an emission control strategy that reduces the effectiveness of the emission control system under ambient or engine operating conditions encountered either during normal machine operation or outside the approval test procedures;

2.1.15. **"DeNO$_X$ system"** means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO_X) (e.g. passive and active lean NO_X catalysts, NO_X adsorbers and selective catalytic reduction (SCR) systems);

2.1.16. **"Deterioration factors"** means the set of factors that indicate the relationship between emissions at the start and end of the emission durability period;

2.1.17. **"Dew point"** means a measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given

absolute humidity. Dew point is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured;

2.1.18. **"Drift"** means the difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as the instrument was zeroed and spanned just before the test;

2.1.19. **"Dual-fuel engine"** means an engine that is designed to simultaneously operate with a liquid fuel and a gaseous fuel, both fuels being metered separately, the consumed amount of one of the fuels relative to the other one being able to vary depending on the operation;

2.1.20. **"Dual-fuel mode"** means the normal operating mode of a dual-fuel engine during which the engine simultaneously uses liquid fuel and a gaseous fuel at some engine operating conditions;

2.1.21. **"Electronic control unit"** means an engine's electronic device that is part of the emission control system and uses data from engine sensors to control engine parameters;

2.1.22. **"Emission control system"** means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine;

2.1.23. **"Emission control strategy"** means an element or a set of design elements incorporated into the overall design of an engine, or into vehicle of categories A or C or combine harvester in which an engine is installed, and used in controlling emissions;

2.1.24. **"Emission durability period"** or 'EDP' means the number of hours or, where applicable, the distance used to determine the deterioration factors;

2.1.25. **"End-user"** means any natural or legal person, other than the manufacturer or OEM, that is responsible for operating the engine installed in vehicle of categories A or C or combine harvester.

2.1.26. **"Engine family"** means a manufacturer's grouping of engine types which, through their design, have similar exhaust emission characteristics, and respect the applicable emission limit values;;

2.1.27. **"Engine governed speed"** means the engine operating speed when it is controlled by the installed governor;

2.1.28. **"Engine production date"** means the date, expressed as the month and year, on which the engine passes the final check, after it has left the production line, and is ready to be delivered or to be put into stock;

2.1.29. **"Engine type"** means a group of engines which do not differ in such essential engine characteristics as defined in Annex 10 to this part;

2.1.30. **"Exhaust after-treatment system"** means a catalyst, particulate filter, deNO_X system, combined deNO_X particulate filter or any other emission-reducing device that is installed downstream of the engine. This definition excludes exhaust gas recirculation (EGR) and turbochargers, which are considered an integral part of the engine;

2.1.31. **"Exhaust-gas recirculation"** or 'EGR' means a technical device that is part of the emission control system and reduces emissions by routing exhaust gases that have been expelled from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion, except for the use of valve

timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion;

2.1.32. **"Full flow dilution"** means the method of mixing the exhaust gas flow with dilution air prior to separating a fraction of the diluted exhaust gas flow for analysis;

2.1.33. **"Gaseous fuel"** means any fuel which is wholly gaseous at standard ambient conditions (298 K, absolute ambient pressure 101.3 kPa);

2.1.34. **"Gaseous pollutants"** means the following pollutants in their gaseous state emitted by an engine: carbon monoxide (CO), total hydrocarbons (HC) and oxides of nitrogen (NO_X); NO_X being nitric oxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 equivalent;

2.1.35. **"Generating set"** means an independent agricultural tractor, construction equipment vehicle, or combine harvester that is not part of a power train, primarily intended to produce electric power;

2.1.36. **"GER"** (**Gas Energy Ratio)** means, in the case of a dual-fuel engine, the ratio of the energy content of the gaseous fuel over the energy content of both fuels; in the case of a single-fuel engine, GER is defined as being either 1 or 0 according to the type of fuel;

2.1.37. **"Good engineering judgment"** means judgments made consistent with generally accepted scientific and engineering principles and available relevant information;

2.1.38. **"HEPA filter"** means high-efficiency particulate air filters that are rated to achieve a minimum initial particle-removal efficiency of 99.97 per cent using ASTM F 1471–93;

2.1.39. **"High speed "** or 'n_{hi}' means the highest engine speed where 70 per cent of the maximum power occurs;

2.1.40. **"Idle speed"** means the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine;

2.1.41. **"initial entry into service"** means:

a) the first registration, if the registration is compulsory, or,

b) if the registration is compulsory only for road circulation or is not compulsory, the placing on the market;

2.1.42. **"Internal combustion engine" or 'Engine'** means an energy converter, other than a gas turbine, designed to transform chemical energy (input) into mechanical energy (output) with an internal combustion process; it includes, where they have been installed, the emission control system and the communication interface (hardware and messages) between the engine's electronic control unit(s) and any other powertrain or vehicle of categories A or C or combine harvester control unit necessary to comply with this Part;

2.1.43. **"λ-shift factor" or "S_λ"** means an expression that describes the required flexibility of the engine management system regarding a change of the excess-

air ratio λ if the engine is fuelled with a gas composition different from pure methane;

2.1.44. **"Liquid fuel"** means a fuel which exists in the liquid state at standard ambient conditions (298 K, absolute ambient pressure 101,3 kPa);

2.1.45. **"Liquid-fuel mode"** means the normal operating mode of a dual-fuel engine during which the engine does not use any gaseous fuel for any engine operating condition;

2.1.46. **"Low speed"**or 'n_{lo}' means the lowest engine speed where 50 per cent of the maximum power occurs;

2.1.47. Reserved

2.1.48. **"Manufacturer"** means any natural or legal person who is responsible to the Test Agency for all aspects of the engine approval and for ensuring conformity of engine production, whether or not they are directly involved in all stages of the design and construction of the engine which is the subject of the approval process;

2.1.49. **"Manufacturer's representative" or "representative"** means any natural or legal person whom the manufacturer duly appoints by a written mandate to represent it in matters concerning the Test Agency and to act on its behalf in matters covered by this Part;

2.1.50. **"Maximum gross power "** means the highest value of the gross power on the nominal full-load power curve for the engine type;

2.1.51. **"Maximum torque speed"** means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer;

2.1.52. **"Gross power"** means the power in " kW" obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the method described in Annex 12 on the measurement of the gross power, gross torque and specific fuel consumption of internal combustion engines for agricultural tractor, construction equipment vehicle and combine harvester.

2.1.53. Reserved

2.1.54. **"Open crankcase emissions"** means any flow from an engine's crankcase that is emitted directly into the environment;

2.1.55. **"Operator demand"** means an engine operator's input to control engine output;

2.1.56. **"Original equipment manufacturer" or "OEM"** means any natural or legal person that manufactures vehicle of categories A or C or combine harvester;

2.1.57. **"Parent engine"** means an engine type selected from an engine family in such a way that its emissions characteristics are representative of that engine family;

2.1.58. **"Particulate after-treatment system"** means an exhaust after-treatment system designed to reduce emissions of particulate pollutants through a mechanical, aerodynamic, diffusional or inertial separation;

2.1.59. **"Partial flow dilution "** means the method of analysing the exhaust gas whereby a part of the total exhaust gas flow is separated, then mixed with an appropriate amount of dilution air prior to reaching the particulate sampling filter;

2.1.60. **"Particle number" or 'PN'** means the number of solid particles emitted by an engine with a diameter greater than 23 nm;

2.1.61. **"Particulate matter (PM)"** means any material collected on a specified filter medium after diluting. an engine exhaust gas with clean filtered air so that the temperature does not exceed 325 K (52 °C);

2.1.62. **"Particulate pollutants"** means any matter emitted by an engine that is measured as PM or PN;

2.1.63. **"Per cent load"** means the fraction of the maximum available torque at an engine speed;

2.1.64. **"Permanently installed"** means bolted, or otherwise effectively fixed so that it cannot be removed without the use of tools or equipment, to a foundation or an alternative constraint intended to cause the engine to operate in one single location in a building, structure, facility or installation;

2.1.65. Reserved

2.1.66. **"Probe"** means the first section of the transfer line which transfers the sample to next component in the sampling system;

2.1.67. **"Rated gross power"** means the gross power in kW as declared by the manufacturer of an engine at rated speed;

2.1.68. **"Rated speed"** means the maximum full load speed allowed by an engine's governor, as designed by the manufacturer, or, if a governor is not present, the speed at which the maximum gross power is attained by the engine, as specified by the manufacturer;

2.1.69. **"Reagent"** means any consumable or non-recoverable medium required and used for the effective operation of the exhaust after-treatment system;

2.1.70. **"Reference power"** means the gross power that is used to determine the applicable emission limit values for the engine;

2.1.71. **"Regeneration"** means an event during which emissions levels change while the exhaust after-treatment system's performance is being restored by design and which can be classified as continuous regeneration or infrequent (periodic) regeneration;

2.1.72. **"Service mode"** means a special mode of a dual-fuel engine that is activated for the purpose of repairing, or of moving the agricultural tractor, construction equipment vehicle and combine harvester to a safe location when operation in the dual-fuel mode is not possible;

2.1.73. **"SI engine"** means an engine that works on the spark-ignition ('SI') principle;

2.1.74. **"Single-fuel engine"** means an engine that is not a dual-fuel engine;

2.1.75. **"Span"** means to adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 per cent and 100 per cent of the maximum value in the instrument range or expected range of use;

2.1.76. **"Span gas"** means a purified gas mixture used to span gas analysers;

2.1.77. **"Specific emissions"** means the mass emissions expressed in g/kWh;

2.1.78. **"Stationary machinery"** means machinery that is intended to be permanently installed in one location for its first use and is not intended to be moved, by road

or otherwise, except during shipment from the place of manufacture to the place of first installation;

2.1.79. **"Steady-state test cycle"** means a test cycle in which engine speed and torque are held at a finite set of nominally constant values; steady-state tests are either discrete mode tests or ramped-modal tests;

2.1.80. **"Stoichiometric"** means relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen;

2.1.81. **"Storage medium"** means a particulate filter, sample bag, or any other storage device used for batch sampling;

2.1.82. **"Tampering**" means inactivation, adjustment or modification of the emission control system, including any software or other logical control elements of such a system, that has the effect, whether intended or not, of worsening the emissions performance of the engine;

2.1.83. **"Test cycle"** means a sequence of test points, each with a defined speed and torque, to be followed by the engine when being tested under steady state or transient operating conditions;

2.1.84. **"Test interval"** means a duration of time over which brake-specific emissions are determined;

2.1.85. **"Tolerance"** means the interval in which 95 per cent of a set of recorded values of a certain quantity shall lie, with the remaining 5 per cent of the recorded values deviating from the tolerance interval;

2.1.86. **"Transient test cycle"** means a test cycle with a sequence of normalised speed and torque values that vary on a second-by-second basis with time;

2.1.87. **"Type approval"** means the procedure whereby an Test Agency certifies that an engine type or engine family satisfies the technical requirements and relevant administrative provisions of this Part;

2.1.88. **"Updating-recording"** means the frequency at which the analyser provides new, current, values;

2.1.89. **"Variable-speed engine"** means an engine that is not a constant-speed engine;

2.1.90. "*Variable-speed non-road steady-state test cycle*" (hereinafter "variable-speed NRSC") means a non-road steady-state test cycle that is not a constant-speed NRSC;

2.1.91. **"Verification"** means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance. Contrast with "*calibration*";

2.1.92 **"Wall-flow particulate after-treatment system"** means a particulate after-treatment system in which all the exhaust gas is forced to flow through a wall which filters out the solid matter.

2.1.93. **"Wobbe index" or "W"** means the ratio of the corresponding calorific value of a gas per unit volume and the square root of its relative density under the same reference conditions:

$$W = H_{gas} \times \sqrt{\frac{\rho_{air}}{\rho_{gas}}}$$

2.1.94. **"To zero"** means to adjust an instrument in a manner that it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air;

2.1.95. **"Zero gas"** means a gas that yields the value zero as response to its input in an analyser;

2.2. Symbols and abbreviations

2.2.1. Symbols

The symbols are explained in Annex 4, clause 3.2. and specific symbols are found in the corresponding Annexes.

2.2.2. Abbreviations

ASTM	American Society for Testing and Materials
BMD	Bag mini-diluter
BSFC	Brake-specific fuel consumption
CFV	Critical Flow Venturi
CI	Compression-ignition
CLD	Chemiluminescent Detector
CVS	Constant Volume Sampler
De NO_X	NO_X after-treatment system
DF	Deterioration factor
ECM	Electronic control module
EFC	Electronic flow control
EGR	Exhaust gas recirculation
FID	Flame Ionization Detector
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
IBP	Initial boiling point
ISO	International Organization for Standardization
LPG	Liquefied Petroleum Gas
NDIR	Nondispersive infrared (Analyser)
NDUV	Nondispersive ultraviolet (Analyser)
NIST	US National Institute for Standards and Technology
NMC	Non-Methane Cutter
PDP	Positive Displacement Pump
%FS	Per cent of full scale
PFD	Partial Flow Dilution
PFS	Partial Flow System

PTFE	Polytetrafluoroethylene (commonly known as Teflon™)
RMC	Ramped-modal cycle
RMS	Root-mean square
RTD	Resistive temperature detector
SAE	Society of Automotive Engineers
SSV	Subsonic Venturi
UCL	Upper confidence limit
UFM	Ultrasonic flowmeter

3. APPLICATION FOR TYPE APPROVAL

3.1. Application for approval of an engine as a separate technical unit

3.1.1. The application for approval of an engine or an engine family with regard to the level of the emission of gaseous and particulate pollutants shall be submitted by the engine manufacturer or by a duly accredited representative.

3.1.2. It shall be accompanied by the undermentioned documents in 1 set and the following particulars:

A description of the engine type comprising the particulars referred to in AIS-007 of this Part and if applicable the particulars of the engine family as referred to in AIS-007 to this Part.

3.1.3. An engine conforming to the engine type characteristics described in AIS-007 shall be submitted to the Test Agency responsible for conducting the approval tests defined in clause 5. If the Test Agency determines that the submitted engine does not fully represent the engine family described in AIS-007, an alternative and, if necessary, an additional engine shall be submitted for test according to clause 5. below.

4. TYPE APPROVAL PROCESS

4.1. If the engine submitted for approval pursuant to clause 3. of this Part meets the requirements of clause 5. below, approval of that engine type or engine family shall be granted. The Test Agency shall issue the relevant communication as set out in Annex 2.

For the purposes of clarity and easing access to relevant data, the communication includes an addendum containing the most relevant information related with the type-approved engine type or engine family.

In order to receive a type approval of an engine type or engine family, the manufacturer shall demonstrate compliance, of the engine type or engine family with the provisions of this Part set out in clauses 5., 6., 8. and Annexes 4, 7, 8, 9 and 10. The manufacturer shall also ensure the use of reference fuels set out in Annex 6., having regard to Appendix 3 to clause 5 of this Part.

Additionally, in order to receive type approval of a vehicle with an approved engine with regard to emissions or a type approval of a vehicle with regard to emissions the OEM shall ensure compliance with the installation requirements set out in clause 6.

4.2 In case the manufacturer allows the use of commercial fuels that do not correspond to the reference fuels set out in Annex 6, the provisions of Appendix 3 to clause 5 of this Part shall apply.

4.3 Engine labelling

The engine must be affixed with a conformance label meeting the requirements as per Annex 3 of this Part..

4.4 The Test Agency shall put together an information package consisting of the information folder accompanied by the test report and all other documents added by the test agency or by the Test Agency to the information folder in the course of carrying out their functions ('the information package'). The information package shall include an index listing its contents, suitably numbered or otherwise marked so as to clearly identify all the pages and the format of each document, in order to present a record of the successive steps in the management of the type approval, in particular the dates of revisions and updating.

The Test Agency shall ensure that the information contained in the information package is available for a period of at least 25 years following the end of the validity of the type approval concerned.

5. REQUIREMENTS AND TESTS

5.1. General

Engines shall be designed, constructed and assembled so as to enable them to comply with the provisions of this Part.

5.1.1. The technical measures taken by the manufacturer shall be such as to ensure that the gaseous and particulate pollutant emissions are effectively limited, as set out in Appendix 1 to this clause 5., throughout the emission durability period of the engine, as set out in Appendix 2 to clause 5., and under normal conditions of use.

5.1.1.1. For this purpose, the engine final emission test result calculated according to the requirements of clause 5.1.2 shall not exceed the exhaust emission limits set out in Appendix 1 to this clause, when:

(a) tested in accordance with the test conditions and detailed technical procedures set out in Annex 4 to this Part,

(b) using the fuel(s) specifiend in clause 5.1.3.

(c) using the test cycles specified in Appendix A.6 to Annex 4 of this Part.

5.1.2 The final exhaust emission test results for engines subject to this Part shall be calculated by applying all of the following to the laboratory test results:

(a) the emissions of crankcase gases as required by clause 5.7.;

(b) any necessary adjustment factor, where the engine includes an infrequently regenerating exhaust after-treatment system;

(c) in respect of all engines, as a final step in the calculation, deterioration factors appropriate to the emission durability periods specified in Appendix 2 to this clause and calculated according to the prescription set out in Annex 8.

5.1.3 In accordance with Appendix 3. to clause 5 of this Part, the testing of an engine type or engine family to determine whether it meets the emission limits set out

in this Part shall be carried out by using the following reference fuels or fuel combinations, as appropriate:

(a) diesel;

(b) petrol;

(c) petrol/oil mixture, for two stroke SI engines;

(d) natural gas/bio methane;

(e) liquid petroleum gas (LPG);

(f) ethanol.

The engine type or engine family shall, in addition, meet the exhaust emission limits set out in this Part in respect of any other specified fuels, fuel mixtures or fuel emulsions included by a manufacturer in an application for type- approval and described in the Appendix 3 to this clause 5 of this Part.

5.1.4 As regards the conduct of measurements and tests, the technical requirements shall be met in respect of:

(a) apparatus and procedures for the conduct of tests;

(b) apparatus and procedures for emission measurement and sampling;

(c) methods for data evaluation and calculations;

(d) methods for establishing deterioration factors;

(e) methods for taking account of emissions of crankcase gases;

(f) methods for determining and taking account of continuous or infrequent regeneration of exhaust after-treatment systems;

(g) in relation to electronically controlled engines in categories NRE, complying with the emission limits set out in Appendix 1 to this clause and using electronic control to determine both the quantity and timing of injecting fuel or using electronic control to activate, de-activate or modulate the emission control system used to reduce NO_X:

(i) emission control strategies, and shall include the documentation required to demonstrate those strategies;

(ii) NO_X control measures, and shall include the method used to demonstrate those control measures;

(iii) the area associated with the relevant non-road steady-state test cycle, within which the amount by which the emissions are permitted to exceed the emission limits set out in Appendix 1 to this clause is controlled;

(iv) the selection by the Test Agency of additional measurement points from within the control area during the emission bench test.

5.1.5. Any adjustment, repair, disassembly, cleaning or replacement of engine components or systems which are scheduled to be performed on a periodic basis to prevent malfunction of the engine, shall only be done to the extent that is technologically necessary to ensure proper functioning of the emission control system as set out in clause 3.4 of Annex 8.

5.2. Where, in accordance with the parameters defining the engine family laid down in Annex 10, one engine family covers more than one power range, the parent engine (for the purposes of type-approval) and all engine types within the same family (for the purposes of conformity of production) shall, with respect to the applicable power ranges:

(a) meet the most stringent emission limit values;

(b) be tested using the test cycles that correspond to the most stringent emission limit values;

5.3. The technical requirements relating to emission control strategies as set out in Annex 9 to this part shall apply.

5.4. The use of defeat strategies shall be prohibited.

5.5. Engine types and engine families shall be designed and fitted with emission control strategies in such a way as to prevent tampering to the extent possible. For this purpose, clauses 3 and 4 of Annex 9 and Appendix A.3 of Annex 9 shall apply.

5.6 Measurements and tests with regard to the area associated with the non-road steady-state test cycle.

5.6.1. General requirements

This clause shall apply for electronically controlled engines of categories NRE, complying with emission limits set out in Appendix 1 to this clause and using electronic control to determine both the quantity and timing of injecting fuel or using electronic control to activate, de-activate or modulate the emission control system used to reduce NO_X.

This clause sets out the technical requirements relating to the area associated with the relevant NRSC, within which the amount by which that the emissions shall be permitted to exceed the emission limits set out in Appendix 1 to this clause is controlled.

When an engine is tested as set out in test requirements of clause 5.6.4. the emission of gaseous and particulate pollutants sampled at any randomly selected point within the applicable control area set out in clause 5.6.2. shall not exceed the applicable emission limit values in Appendix 1 to this paragraph multiplied by a factor of 2.0.

Clause 5.6.3. sets out the selection by the Test Agency of additional measurement points from within the control area during the emission bench test, in order to demonstrate that the requirements of this clause 5.6.1. have been met.

The manufacturer may request that the Test Agency excludes operating points from any of the control areas set out in clause 5.6.2. during the demonstration set out in clause 5.6.3. The Test Agency may grant this exclusion if the manufacturer can demonstrate that the engine is never capable of operating at such points when used in any vehicle of categories A or C or combine harvester.

The installation instructions provided by the manufacturer to the OEM in accordance with Appendix 1 to clause 6 of this Part shall identify the upper and lower boundaries of the applicable control area and shall include a statement to clarify that the OEM shall not install the engine in such a way that it constrains the engine to operate permanently at only combinations of speed

and torque outside of the control area for the torque curve corresponding to the approved engine type or engine family.

5.6.2. Engine control area

The applicable control area for conducting the engine test shall be the area identified in this clause that corresponds to the applicable NRSC for the engine being tested.

5.6.2.1. Control area for engines tested on NRSC cycle C1

These engines operate with variable-speed and load. Different control area exclusions apply depending upon the (sub-)category and operating speed of the engine.

5.6.2.1.1. Variable-speed engines of category NRE with maximum gross power ≥ 19 kW.

The control area (see Figure 1.) is defined as follows:

upper torque limit: full load torque curve;`

speed range: speed A to n_{hi};

where:

speed A = $n_{lo} + 0.15 \cdot (n_{hi} - n_{lo})$;

n_{hi} = high speed (see clause 2.1.39),

n_{lo} = low speed (see clause 2.1.46).

The following engine operating conditions shall be excluded from testing:

(a) points below 30 per cent of maximum torque;

(b) points below 30 per cent of maximum gross power.

If the measured engine speed A is within ± 3 per cent of the engine speed declared by the manufacturer, the declared engine speeds shall be used. If the tolerance is exceeded for any of the test speeds, the measured engine speeds shall be used.

Intermediate test points within the control area shall be determined as follows:

% torque = per cent of maximum torque;

$$\%speed = \frac{(n - n_{idle})}{(n_{100\%} - n_{idke})} \cdot 100$$

where: $n_{100\%}$ is the 100 per cent speed for the corresponding test cycle.

n_{idle} is the idle speed

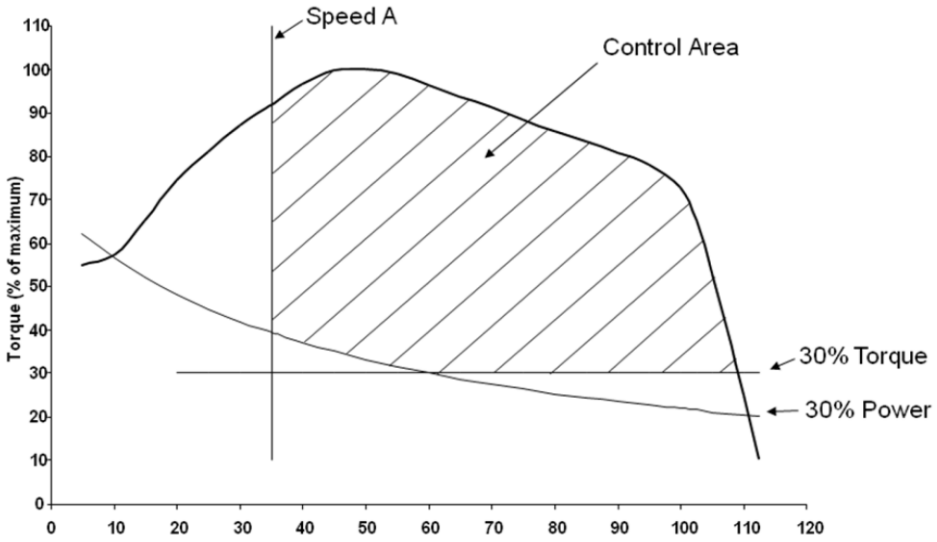


Figure 1.
Control Area for Variable-Speed Engines of Category NRE with Maximum Gross Power ≥ 19 kW

5.6.2.1.2. Variable-speed engines of category NRE with maximum gross power < 19 kW.

The control area specified in clause 5.6.2.1.1. shall apply but with the additional exclusion of the engine operating conditions given in this clause and illustrated in Figures 2. and 3..

(a) for particulate matter only, if the C speed is below 2400 r/min, points to the right of or below the line formed by connecting the points of 30 % of maximum torque or 30 per cent of maximum gross power, whichever is greater, at the B speed and 70 per cent of maximum gross power at the high speed;

(b) for particulate matter only, if the C speed is at or above 2400 r/min, points to the right of the line formed by connecting the points of 30 per cent of maximum torque or 30 per cent of maximum gross power, whichever is greater, at the B speed, 50 per cent of maximum gross power at 2400 r/min, and 70 per cent of maximum gross power at the high speed.

where:

speed B = $n_{lo} + 0.5 \cdot (n_{hi} - n_{lo})$;

speed C = $n_{lo} + 0.75 \cdot (n_{hi} - n_{lo})$.

n_{hi} = high speed (see clause 2.1.39.),

n_{lo} = low speed (see clause 2.1.46.).

If the measured engine speeds A, B and C are within ± 3 % of the engine speed declared by the manufacturer, the declared engine speeds shall be used. If the tolerance is exceeded for any of the test speeds, the measured engine speeds shall be used.

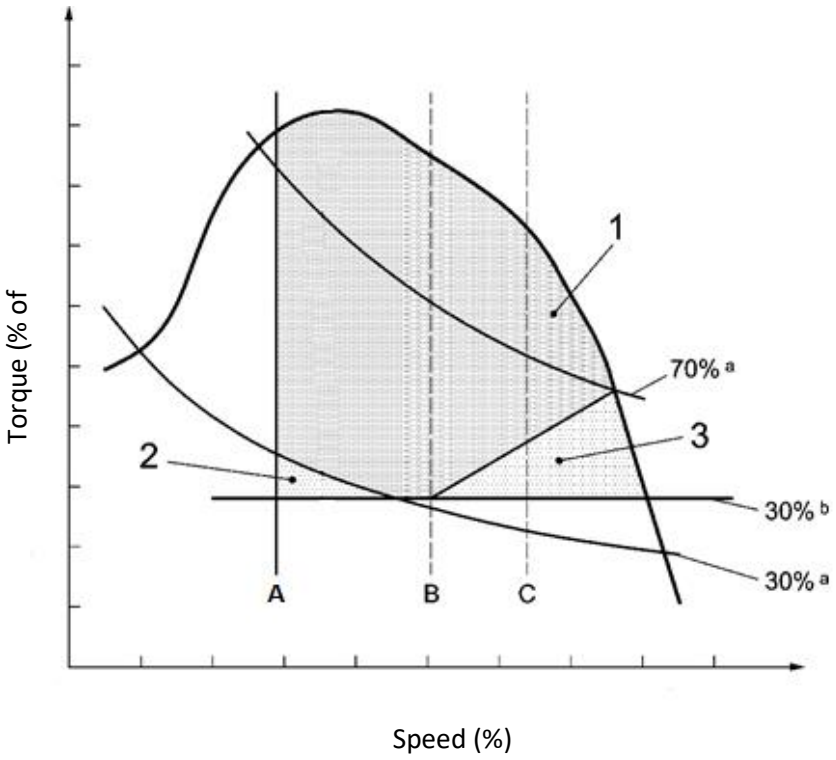


Figure 2.

Control Area for Variable-Speed Engines of Category NRE with Maximum Gross Power < 19 Kwand Speed C < 2400 rpm .

Key

1 Engine Control Area 2 All Emissions Carve-Out

3 PM Carve-Out

[a] per cent of maximum gross power

[b] per cent of maximum torque

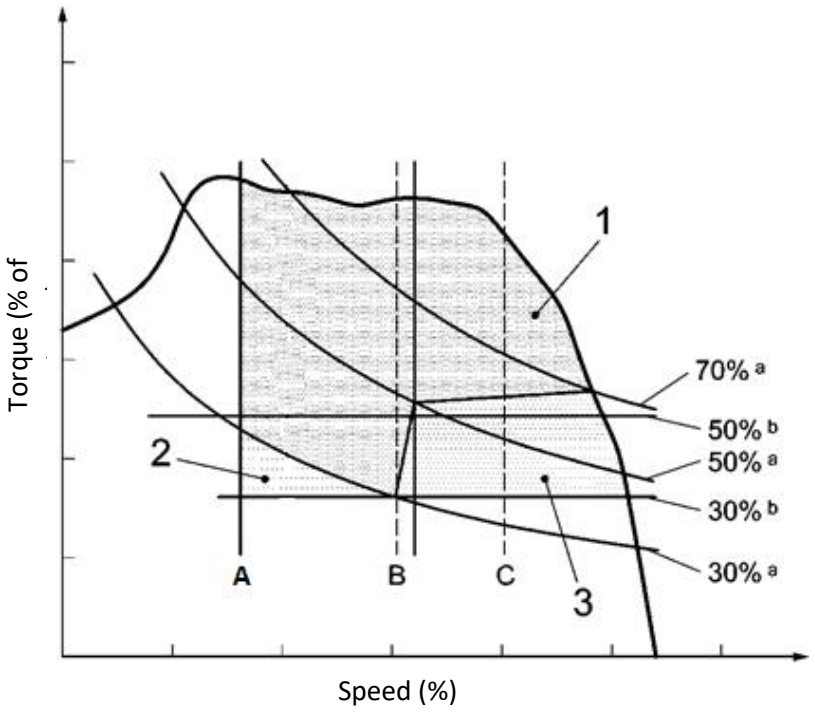


Figure 3.

Control Area for Variable-Speed Engines of Category NRE with Maximum Gross Power < 19 kW and Speed C ≥ 2400 rpm

Key

1 Engine Control Area 2 All Emissions Carve-Out

3 PM Carve-Out [a] Per cent of maximum gross power

[b] Per cent of maximum torque

5.6.2.2. Control area for engines tested on NRSC cycles D2 and G2

These engines are mainly operated very close to their designed operating speed, hence the control area is defined as:

speed: 100 per cent

torque range: 50 per cent to the torque corresponding to maximum power.

5.6.3. Demonstration requirements

The Test Agency shall select random load and speed points within the control area for testing. For engines subject to clause 5.6.2.1. up to three points shall be selected. For engines subject to clause 5.6.2.2. one point shall be selected. The Test Agency shall also determine a random running order of the test points. The test shall be run in accordance with the principal requirements of the NRSC, but each test point shall be evaluated separately.

5.6.3.1. For the purpose of the random selections required in clause 5.6.3., recognised statistical methods of randomization shall be used.

5.6.4. Test requirements

The test shall be carried out immediately after the applicable NRSC as follows:

(a) the test of the randomly selected torque and speed points shall either be carried out immediately after the discrete-mode NRSC test sequence described in sub- clauses (a) to (e) of clause 7.8.1.2. of Annex 4 but before the post test procedures (f) or after the ramped modal non-road steady-state test cycle ("RMC") test sequence described in sub-clauses (a) to (d) of clause 7.8.2.3. of Annex 4 but before the post test procedures (e) as relevant;

(b) the tests shall be carried out as required in sub- clauses (b) to (e) of clause 7.8.1.2. of Annex 4 using the multiple filter method (one filter for each test point) for each of the test points.

(c) a specific emission value shall be calculated (in g/kWh or #/kWh as applicable) for each test point;

(d) emissions values may be calculated on a mass basis using Appendix A.1. of Annex 5 or on a molar basis using Appendix A.2. of Annex 5, but shall be consistent with the method used for the discrete-mode NRSC or RMC test;

(e) for gaseous and PN, if applicable, summation calculations, N_{mode} in equation (A.5-64) or (A.5-136) and (A.5-180) shall be set to 1 and a weighting factor of 1 shall be used;

(f) for particulate calculations the multiple filter method shall be used; for summation calculations, N in equation (A.5-67) shall be set to 1 and a weighting factor of 1 shall be used.

5.6.5 Regeneration

In the case that a regeneration event occurs during or immediately preceding the procedure in clause 5.6.4., upon completion of that procedure the test may be voided at the request of the manufacturer irrespective of the cause of the regeneration. In this case the test shall be repeated. The same torque and speed points shall be used although the running order may be changed. It shall not be deemed necessary to repeat any torque and speed points for which a pass result has already been obtained. The following procedure shall be used for the repeat test:

(a) The engine shall be operated in a manner to ensure that the regeneration event has completed and, where applicable, the soot load in the particulate after-treatment has been re-established;

(b) The engine warm-up procedure shall be performed according to clause 7.8.1.1. of Annex 4;

(c) The test procedure specified in clause 5.6.4. shall be repeated commencing at sub-clause 5.6.4. (b).

5.7 Verifying emissions of crankcase gases

5.7.1. Engines may discharge crankcase emissions into the exhaust upstream of any after treatment device during all operation.

5.7.2 Crankcase emissions that are discharged directly into the ambient atmosphere shall be added to the exhaust emissions during all emission testing. For this purpose the manufacturer shall install the engines so that all crankcase

emission can be routed into the emissions sampling system, according to the requirements set out in clause 6.10. of Annex 4 to this Part.

5.8 Rounding off

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus two additional significant figures, in accordance with IS:2-1960(R2016). No rounding of intermediate values leading to the final brake-specific emission result is permitted

.

CLAUSE 5 - APPENDIX 1
EXHAUST EMISSION LIMITS

Table 1

Emission Limits for Engine Category NRE Defined in clause 1.1.1.

Engine sub-category	Power range	Ignition type	CO	HC	NO_X	PM mass	PN	A
	kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
NRE-v-1 NRE-c-1	0<P<8	CI	8.00	($HC+NO_X$ ≤7.50)		0.40[1]	-	1.10
NRE-v-2 NRE-c-2	8≤P<19	CI	6.60	($HC+NO_X$ ≤7.50)		0.40	-	1.10
NRE-v-3 NRE-c-3	19≤P<37	CI	5.00	($HC+ NO_X$ ≤4.70)		0.015	$1x10^{12}$	1.10
NRE-v-4 NRE-c-4	37≤P<56	CI	5.00	($HC+ NO_X$ ≤4.70)		0.015	$1x10^{12}$	1.10
NRE-v-5 NRE-c-5	56≤P<130	all	5.00	0.19	0.40	0.015	$1x10^{12}$	1.10
NRE-v-6 NRE-c-6	130≤P≤560	all	3.50	0.19	0.40	0.015	$1x10^{12}$	1.10
NRE-v-7 NRE-c-7	P>560	all	3.50	0.19	3.50	0.045	-	6.00

[1] 0.60 for hand-startable, air-cooled direct injection engines

A.1.1. Specific provisions on total hydrocarbon (HC) limits for fully and partially gaseous-fuelled engines

For the sub-categories where an A-factor is defined, the HC limit for fully and partially gaseous-fuelled engines indicated in Table 1is replaced by a limit calculated using the following formula:

$HC = 0.19 + (1.5 \times A \times GER)$

where GER is the average gas energy ratio over the appropriate test cycle. Where both a steady-state and transient test cycle apply, the GER shall be determined from the hot-start transient test cycle. Where more than one steady- state test cycle applies, the average GER shall be determined for each cycle individually.

If the calculated limit for HC exceeds the value of 0.19+A, the limit for HC shall be set to 0.19+A

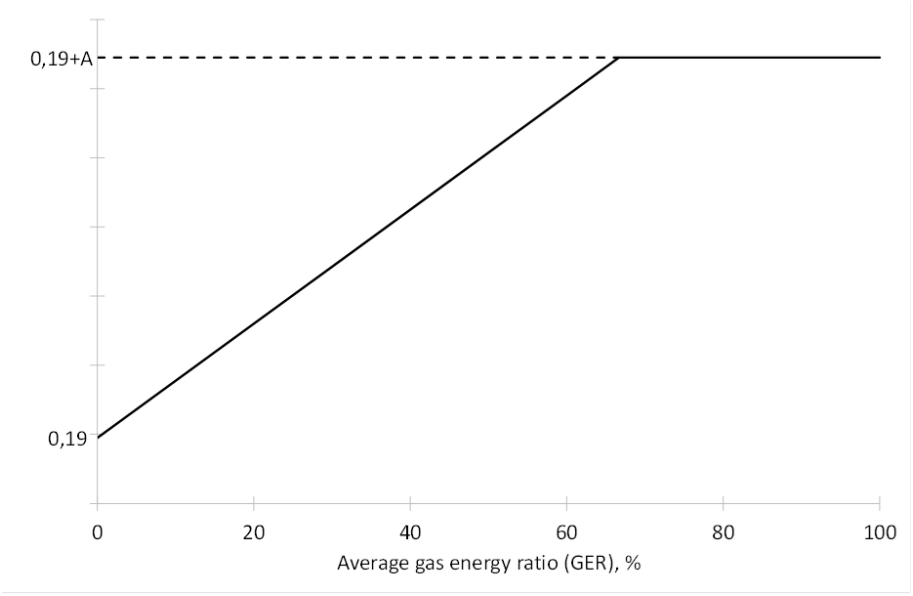


Figure 4.
Diagram showing HC emission limit as function of average GER

For sub-categories with a combined HC and NO_X limit, the combined limit value for HC and NO_X shall be reduced by 0.19 g/kWh and apply for NO_X only.

For non-gaseous-fuelled engines, the formula does not apply.

CLAUSE 5 - APPENDIX 2
EMISSION DURABILITY PERIODS (EDP)

Tables 1 to 18 : Rserved

Table 19

EDP for Engine Category NRE

Category	Ignition type	Speed operation	Power range (kW)	Sub-category	EDP (hours)
NRE	CI	variable	0<P<8	NRE-v-1	3,000
	CI		8≤P<19	NRE-v-2	
	CI		19≤P<37	NRE-v-3	5,000
	CI		37≤P<56	NRE-v-4	8,000
	all		56≤P<130	NRE-v-5	
			130≤P≤560	NRE-v-6	
			P>560	NRE-v-7	
	CI	constant	0<P<8	NRE-c-1	3,000
	CI		8≤P<19	NRE-c-2	
	CI		19≤P<37	NRE-c-3	
	CI		37≤P<56	NRE-c-4	8,000
	all		56≤P<130	NRE-c-5	
			130≤P≤560	NRE-c-6	
			P>560	NRE-c-7	

Tables 20 to 24 : Reserved

CLAUSE 5 - APPENDIX 3

REQUIREMENTS IN RELATION TO ANY SPECIFIED FUELS, FUEL MIXTURES OR FUEL EMULSIONS

A.3.1. REQUIREMENTS FOR ENGINES FUELLED WITH LIQUID FUELS

A.3.1.1. When applying for an approval, manufacturers may select one of the following options with regard to the engine's fuel range:

(a) standard fuel range engine, in accordance with the requirements set out in clause A.3.1.2.; or,

(b) fuel-specific engine, in accordance with the requirements set out in clause A.3.1.3..

A.3.1.2. Requirements for a standard fuel range (diesel, petrol) engine

A standard fuel range engine shall meet the requirements specified in clauses A.3.1.2.1 to A.3.1.2.4.

A.3.1.2.1 The parent engine shall meet the applicable limit values set out in Appendix 1 to clause 5 and the other requirements set out in this Part when the engine is operated on the reference fuels specified in clauses 1.1 or 2.1 of Annex 6.

A.3.1.2.2. In the absence of an international standard for non-road gas-oil, the diesel (non-road gas-oil) reference fuel in Annex 6 shall represent market non-road gas-oils with a sulphur content not greater than 10 mg/kg, cetane number not less than 51 and an Fatty-Acid Methyl Ester ("FAME") content not greater than 7.0 per cent v/v. Except where otherwise permitted in accordance with clauses A.3.1.2.2.1., A.3.1.2.3.. and A.3.1.2.4., the manufacturer shall make a corresponding declaration to the end-users in accordance with the requirements in Appendix 2 to clause 6 that operation of the engine on non-road gas-oil is limited to those fuels with a sulphur content not greater than 10 mg/kg (20 mg/kg at point of final distribution) cetane number not less than 51 and an FAME content not greater than 7.0 per cent v/v. The manufacturer may optionally specify other parameters (e.g. for lubricity).

A.3.1.2.2.1. The engine manufacturer shall not indicate at any time that an engine type or engine family may be operated in India on market fuels other than those that comply with the requirements in this clause unless the manufacturer additionally complies with the requirement in clause A.3.1.2.3..

(a) In the case of petrol, CEN standard EN 228:2012. Lubricating oil may be added according to the specification of the manufacturer;

(b) In the case of diesel (other than non-road gas-oil), CEN standard EN 590:2013;

(c) In the case of diesel (non-road gas-oil), the maximum permissible sulphur content of 10 mg/kg and also both a cetane number not less than 51 and FAME not greater than 7.0 per cent v/v.

A.3.1.2.3. If the manufacturer permits engines to run on additional market fuels other than those identified in clause A.3.1.2.2., such as running on B100 (EN 14214:2012+A1:2014), B20 or B30 (EN16709:2015), or on specific fuels, fuel mixtures or fuel emulsions, all of the following actions shall be taken by the manufacturer in addition to the requirements of clause A.3.1.2.2.1.:

(a) declare, in the information document set out in Annex 1, the specification of the commercial fuels, fuel mixtures or emulsions on which the engine family is capable to run;

(b) demonstrate the capability of the parent engine to meet the requirements of this Part on the fuels, fuel mixtures or emulsions declared;

(c) be liable to meet the requirements of in-service monitoring set out, if any, on the fuels, fuel mixtures or emulsions declared, including any blend between the declared fuels, fuel mixtures or emulsions, and the applicable market fuel identified in clause A.3.1.2.2.1..

A.3.1.3. Requirements for a fuel-specific (ED 95 or E 85) engine

A specific fuel (ED 95 or E 85) engine shall meet the requirements specified in clauses A.3.1.3.1 and A.3.1.3.2..

A.3.1.3.1. For ED 95, the parent engine shall meet the requirements of this Part including the applicable limit values set out in Appendix 1 to clause 5 of this Part when the engine is operated on the reference fuel specified in clause 1.2. of Annex 6.

A.3.1.3.2. For E 85, the parent engine shall meet the requirmeents of this part, including the applicable limit values set out in Appendix 1 to clause 5 of this Part when the engine is operated on the reference fuel specified in clause 2.2 of Annex 6.

A.3.2. REQUIREMENTS FOR ENGINES FUELLED WITH NATURAL GAS/BIOMETHANE (NG) OR LIQUEFIED PETROLEUM GAS (LPG), INCLUDING DUAL-FUEL ENGINES

A.3.2.1. When applying for an approval, manufacturers may select one of the following options with regard to the engine's fuel range:

(a) universal fuel range engine, in accordance with the requirements set out in clause A.3.2.3.;

(b) restricted fuel range engine, in accordance with the requirements set out in clause A.3.2.4.;

(c) fuel-specific engine, in accordance with the requirements set out in clause A.3.2.5..

A.3.2.2. Tables summarizing the requirements for type-approval of natural gas/biomethane fuelled engines, LPG-fuelled engines and dual-fuel engines are provided in clause A.3.3..

A.3.2.3. Requirements for a universal fuel range engine

A.3.2.3.1. In the case of natural gas/biomethane fuelled engines, including dual-fuel engines, the manufacturer shall demonstrate the parent engines capability to adapt to any natural gas/biomethane composition that may occur across the market. That demonstration shall be carried out in accordance with this clause A.3.2.. and, in case of dual-fuel engines, also in accordance with the additional provisions regarding the fuel adaptation procedure set out in clause 6.4. of Annex 7.

A.3.2.3.1.1. In the case of compressed natural gas/biomethane (CNG) there are generally two types of fuel, high calorific fuel (H-gas) and low calorific fuel (L-gas), but with a significant spread within both ranges; they differ significantly in their energy content expressed by the Wobbe Index and in their λ-shift factor (S_λ). Natural gases with a λ-shift factor between 0.89 and 1.08 ($0.89 \leq S_\lambda \leq 1.08$) are considered to belong to H-range, while natural gases with a λ-shift factor between 1,08 and 1.19 ($1.08 \leq S_\lambda \leq 1.19$) are considered to belong to L-range. The composition of the reference fuels reflects the extreme variations of S_λ.

The parent engine shall meet the requirements of this Part on the reference fuels G_R (fuel 1) and G_{25} (fuel 2), as specified in Annex 6, or on the equivalent

fuels created using admixtures of pipeline gas with other gases as specified in Appendix A. 1 to Annex 6, without any manual readjustment to the engine fuelling system between the two tests (self-adaptation is required). One adaptation run is permitted after the change of the fuel. The adaption run shall consist of performing the pre-conditioning for the following emission test according to the respective test cycle. In the case of engines tested on the NRSC, where the pre-conditioning cycle is in-adequate for the engine fuelling to self-adapt an alternative adaption run specified by the manufacturer may be performed prior to pre-conditioning the engine.

A.3.2.3.1.1.1. At the manufacturer's request the engine may be tested on a third fuel (fuel 3) if the λ-shift factor (S_λ) lies between 0.89 (that is the lower range of G_R) and 1.19 (that is the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.

A.3.2.3.1.2. In the case of liquefied natural gas/liquefied biomethane (LNG) the parent engine shall meet the requirements of this Part on the reference fuels G_R (fuel 1) and G_{20} (fuel 2), as specified in Annex 6, or on the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A.1 to Annex 6, without any manual readjustment to the engine fuelling system between the two tests (self-adaptation is required). One adaptation run is permitted after the change of the fuel. The adaption run shall consist of performing the pre-conditioning for the following emission test according to the respective test cycle. In the case of engines tested on the NRSC, where the pre-conditioning cycle is in-adequate for the engine fuelling to self-adapt an alternative adaption run specified by the manufacturer may be performed prior to pre-conditioning the engine.

A.3.2.3.2. In the case of an engine fuelled with compressed natural gas/biomethane (CNG) which is self-adaptive for the range of H-gases on the one hand and the range of L-gases on the other hand, and which switches between the H-range and the L-range by means of a switch, the parent engine shall be tested on the relevant reference fuel as specified in in Annex 6 for each range, at each position of the switch. The fuels are G_R (fuel 1) and G_{23} (fuel 3) for the H-range of gases and G_{25} (fuel 2) and G_{23} (fuel 3) for the L-range of gases, or the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A.1 of Annex 6. The parent engine shall meet the requirements of this Part at both positions of the switch without any readjustment to the fuelling between the two tests at each position of the switch. One adaptation run is permitted after the change of the fuel. The adaption run shall consist of performing the pre-conditioning for the following emission test according to the respective test cycle. In the case of engines tested on the NRSC, where the pre-conditioning cycle is in-adequate for the engine fuelling to self-adapt an alternative adaption run specified by the manufacturer may be performed prior to pre-conditioning the engine.

A.3.2.3.2.1. At the manufacturer's request the engine may be tested on a third fuel instead of G_{23} (fuel 3) if the λ-shift factor (S_λ) lies between 0.89 (that is the lower range of G_R) and 1.19 (that is the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.

A.3.2.3.3. In the case of natural gas/biomethane engines, the ratio of the emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 1}}$$

or,

$$r_a = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 3}}$$

and

$$r_b = \frac{\text{emission result on reference fuel 1}}{\text{emission result on reference fuel 3}}$$

A.3.2.3.4. In the case of LPG the manufacturer shall demonstrate the parent engines capability to adapt to any fuel composition that may occur across the market.

In the case of LPG there are variations in C3/C4 composition. These variations are reflected in the reference fuels. The parent engine shall meet the emission requirements on the reference fuels A and B as specified in Annex 6 without any readjustment to the fuelling between the two tests. One adaptation run is permitted after the change of the fuel. The adaption run shall consist of performing the pre-conditioning for the following emission test according to the respective test cycle. In the case of engines tested on the NRSC, where the pre-conditioning cycle is in-adequate for the engine fuelling to self-adapt an alternative adaption run specified by the manufacturer may be performed prior to pre-conditioning the engine.

A.3.2.3.4.1. The ratio of emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel B}}{\text{emission result on reference fuel A}}$$

A.3.2.4. Requirements for a restricted fuel range engine

A restricted fuel range engine shall meet the requirements specified in clauses A.3.2.4.1. to A.3.2.4.3..

A.3.2.4.1. Exhaust emissions type-approval of an engine running on CNG and laid out for operation on either the range of H-gases or on the range of L-gases

A.3.2.4.1.1. The parent engine shall be tested on the relevant reference fuel, as specified in Annex 6, for the relevant range. The fuels are G_R (fuel 1) and G_{23} (fuel 3) for the H-range of gases and G_{25} (fuel 2) and G_{23} (fuel 3) for the L-range of gases or the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A.1 of Annex 6. The parent engine shall meet the requirements of this Part without any readjustment to the fuelling between the two tests. One adaptation run is permitted after the change of the fuel. The adaption run shall consist of performing the pre-conditioning for the following emission test according to the respective test cycle. In the case of engines tested on the NRSC, where the pre-conditioning cycle is in-adequate for the engine fuelling to self-adapt an alternative adaption run specified by the manufacturer may be performed prior to pre-conditioning the engine.

A.3.2.4.1.2 At the manufacturer's request the engine may be tested on a third fuel instead of G_{23} (fuel 3) if the λ-shift factor (S_λ) lies between 0.89 (that is the lower range of G_R) and 1.19 (that is the upper range of G_{25}), for example when fuel 3 is a market fuel. The results of this test may be used as a basis for the evaluation of the conformity of the production.

A.3.2.4.1.3. The ratio of emission results "r" shall be determined for each pollutant as follows:

$$r = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 1}}$$

or,

$$r_a = \frac{\text{emission result on reference fuel 2}}{\text{emission result on reference fuel 3}}$$

and

$$r_b = \frac{\text{emission result on reference fuel 1}}{\text{emission result on reference fuel 3}}$$

A.3.2.4.2. Exhaust emissions approval of an engine running on natural gas or LPG and designed for operation on one specific fuel composition

A.3.2.4.2.1. The parent engine shall meet the emission requirements on the reference fuels G_R and G_{25} or on the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A.1 of Annex 6 in the case of CNG, on the reference fuels G_R and G_{20} or on the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A. 2 of Annex 6 in the case of LNG, or on the reference fuels A and B in the case of LPG, as specified in Annex 6. Fine-tuning of the fuelling system is allowed between the tests. This fine-tuning will consist of a recalibration of the fuelling database, without any alteration to either the basic control strategy or the basic structure of the database. If necessary the exchange of parts that are directly related to the amount of fuel flow such as injector nozzles is allowed.

A.3.2.4.2.2. In the case of CNG, at the manufacturer's request, the engine may be tested on the reference fuels G_R and G_{23}, or on the reference fuels G_{25} and G_{23}, or on the equivalent fuels created using admixtures of pipeline gas with other gases as specified in Appendix A. 1 of Annex 6, in which case the type-approval is only valid for the H-range or the L-range of gases respectively.

A.3.2.5. Requirements for a fuel-specific engine fuelled with liquefied natural gas/liquefied biomethane (LNG)

A liquefied natural gas/liquefied biomethane specific fuel) engine shall meet the requirements specified in clauses A.3.2.5.1. to A.3.2.5.2..

A.3.2.5.1. Conditions for applying for a fuel-specific engine fuelled with liquefied natural gas/liquefied biomethane (LNG)

A.3.2.5.1.1 The manufacturer can only apply for a fuel-specific type-approval in the case of the engine being calibrated for a specific LNG gas composition resulting in a λ -shift factor not differing by more than 3 per cent from the λ -shift factor of the G_{20} fuel specified in Annex 6, and the ethane content of which does not exceed 1.5 per cent.

A.3.2.5.1.2. In all other cases the manufacturer shall apply for a universal fuel engine according to the specifications set out in clause A.3.2.1.3.2..

A.3.2.5.2. Specific test requirements in the case of a fuel-specific dual-fuel engine (LNG)

A.3.2.5.2.1. In the case of a dual-fuel engine family where the engines are calibrated for a specific LNG gas composition resulting in a λ -shift factor not differing by more than 3 per cent from the λ -shift factor of the G_{20} fuel specified in Annex 6, and the ethane content of which does not exceed 1.5 per cent, the parent

engine shall only be tested on the G_{20} reference gas fuel, or on the equivalent fuel created using an admixture of pipeline gas with other gases, as specified in Appendix 1 of Annex 6.

A.3.2.6. Exhaust emissions approval of a member of a family

A.3.2.6.1. With the exception of the case mentioned in clause A.3.2.6.2., the type approval of a parent engine shall be extended to all family members, without further testing, for any fuel composition within the range for which the parent engine has been type-approved (in the case of engines described in clause A.3.2.5.) or the same range of fuels (in the case of engines described in either clause A.3.2.3. or A.3.2.4.) for which the parent engine has been type-approved.

A.3.2.6.2. If the Test Agency determines that, with regard to the selected parent engine the submitted application does not fully represent the engine family defined in clause 7 of this Part, an alternative and if necessary an additional reference test engine may be selected by the Test Agency and tested.

A.3.2.7. Additional requirements for dual-fuel engines

In order to receive a type-approval of a dual-fuel engine or engine family, the manufacturer shall:

(a) conduct the tests in accordance with Table 25 ;

(b) in addition to the requirements set out in clause A.3.2., demonstrate that the dual-fuel engines are subject to the tests and comply with the requirements set out in Annex 7.

A.3.3. SUMMARY OF APPROVAL PROCESS FOR NATURAL GAS AND LPG FUELLED ENGINES INCLUDING DUAL-FUEL ENGINES

A.3.3.1. Tables 25 o 27 show a summary of the approval process for natural gas fuelled engines and LPG fuelled engines and of the minimum number of tests required for approval of dual-fuel engines.

Tables 20 to 24 : Reserved

Table 25
Type-Approval of Natural Gas Fuelled Engines

	Clause *A.3.2.3: Requirements for an universal fuel range engine*	*Number of test runs*	*Calculation of "r"*	Clause *A.3.2.4: Requirements for a restricted fuel range engine*	*Number of test runs*	*Calculation of "r"*
Refer to clause A.3.2.3.1. NG-engine adaptable to any fuel compositi on	G_R (1) and G_{25} (2) At manufacturer's request engine may be tested on an additional market fuel (3), if S_λ = 0.89 – 1.19	2 (max. 3)	$r = \frac{fuel\ 2\ (G_{25})}{fuel\ 1\ (G_R)}$ and, if tested with an additional fuel; $r_a = \frac{fuel\ 2\ (G_{25})}{fuel\ 3\ (market\ fu}$ and $r_b = \frac{fuel\ 1\ (G_R}{fuel\ 3\ (G_{23}\ or\ mar}$			
Refer to clause A.3.2.3.2. NG-engine which is self-adaptive by a switch	G_R(1) and G_{23} (3) for H and G_{25} (2) and G_{23} (3) for L At manufacturer's request engine may be tested on a market fuel (3) instead of G_{23}, if S_λ = 0.89 – 1.19	2 for the H-range, and 2 for the L-range; at respective position o f switch	$r_b = \frac{fuel\ 1\ (G_R}{fuel\ 3\ (G_{23}\ or\ mar}$ and $r_a = \frac{fuel\ 2\ (G_{2}}{fuel\ 3\ (G_{23}\ or\ mar}$			
Refer to clause A.3. 2.4.1. NG-engine laid out for operation on either H-range gas or L-range gas				G_R(1) and G_{23} (3) for H or G_{25} (2) and G_{23} (3) for L At manufacturer's request engine may be tested on a market fuel (3) instead of G_{23}, if S_λ = 0-89 – 1.19	2 for the H-range or 2 for the L-range 2	$r_b = \frac{fuel\ 1\ (G_R}{fuel\ 3\ (G_{23}\ or\ mar}$ for the H-range or $r_a = \frac{fuel\ 2\ (G_{2}}{fuel\ 3\ (G_{23}\ or\ mar}$ for the L-range

Refer to clause A.3.2.4.2. NG-engine laid out for operation on one specific fuel composition				G_R (1) and G_{25} (2), Fine-tuning between the tests allowed. At manufacturer's request engine may be tested on: G_R (1) and G_{23} (3) for H or G_{25} (2) and G_{23} (3) for L	2 2 for the H-range or 2 for the L-range	

Table 26
Type-approval of LPG fuelled engines

	Clause *A.3.2.3: Requirements for an universal fuel range engine*	*Number of test runs*	*Calculation of "r"*	Clause *A.3.2.4: Requirements for a restricted fuel range engine*	*Number of test runs*	*Calculation of "r"*
Refer to clause A.3.2.3.4. LPG-engine adaptable to any fuel composition	Fuel A and fuel B	2	$r = \frac{fuel\ B}{fuel\ A}$			
Refer to clause A.3.2.4.2. LPG-engine laid out for operation on one specific fuel composition				Fuel A and fuel B, fine-tuning between the tests allowed	2	

Table 27

Minimum number of tests required for type-approval of dual-fuel engines

Dual-fuel type	Liquid-fuel mode	Dual-fuel mode			
		CNG	LNG	LNG_{20}	LPG
1A		Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)
1B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)
2A		Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)
2B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)
3B	Universal (1 test)	Universal or restricted (2 tests)	Universal (2 tests)	Fuel-specific (1 test)	Universal or restricted (2 tests)

6. INSTALLATION ON THE VEHICLE

6.1. Information and instructions intended for OEMs and end-users.

6.1.1. A manufacturer shall not supply to OEMs or end-users any technical information related to the particulars provided for in this Part which diverges from the particulars approved by the Test Agency.

6.1.2. The manufacturer shall make available to OEMs all relevant information and instructions that are necessary for the correct installation of an engine in agricultural tractor or construction equipment vehicle or combine harvester, including a description of any special conditions or restrictions linked to the installation or use of the engine.

6.1.3. The manufacturer shall make available to OEMs all relevant information and necessary instructions intended for the end-user, including a description of any special conditions or restrictions linked to the use of an engine.

6.1.5 Details of the relevant information and instructions for the OEMs are set out in Appendix 1 to clause 6.

6.2. Obligations of OEMs concerning the installation of engines

6.2.1. OEMs shall install approved engines in agricultural tractor, construction equipment vehicle and combine harvester in accordance with the instructions provided by the manufacturer pursuant to clause 6.1.2, and in a manner that does not adversely affect the engine's performance with regard to its gaseous and particulate pollutant emissions.

6.2.2. Where an OEM does not follow the instructions referred to in clause 6.2.1., or modifies an engine in the course of its installation in agricultural tractor, construction equipment vehicle and combine harvester, in a manner that adversely affects the engine's performance with regard to its gaseous and particulate pollutant emissions, that OEM shall be considered to be a manufacturer for the purposes of this Part and shall, in particular, be subject to the obligations laid down in clauses 5, 7, 8 and 9.

6.2.3. OEMs shall install type-approved engines in agricultural tractor, construction equipment vehicle and combine harvester only in accordance with the kinds of exclusive use provided for the engine categories set out in clause 1.1.

6.2.4 Reserved

6.2.5. Details of the relevant information and instructions for the end-users are set out in Appendix 2 to clause 6

CLAUSE 6 - APPENDIX 1

DETAILS OF THE RELEVANT INFORMATION AND INSTRUCTIONS FOR THE OEMS

A.1.1. As required by clause 6.1., the manufacturer shall provide to the OEM all relevant information and instructions to ensure that the engine conforms to the approved engine type when installed in agricultural tractor, construction equipment vehicle and combine harvester. Instructions for this purpose shall be clearly identified to the OEM.

A.1.2. The instructions may be provided on paper or a commonly used electronic format.

A.1.3. Where a number of engines requiring the same instructions are supplied to the same OEM it shall be necessary to provide only one set of instructions.

A.1.4. The information and instructions to the OEM shall include at least:

A.1.4.1. installation requirements to achieve the emissions performance of the engine type, including the emissions control system, that shall be taken into account to ensure the correct operation of the emissions control system;

A.1.4.2. a description of any special conditions or restrictions linked to the installation or use of the engine, as noted on the communication set out in Annex 2;

A.1.4.3. a statement indicating that the installation of the engine shall not permanently constrain the engine to exclusively operate within a power range corresponding to a (sub-)category with gaseous and particulate pollutant emission limits more stringent than the (sub-)category the engine belongs to;

A.1.4.4. for engine families to which clause 5.6 of this Part applies, the upper and lower boundaries of the applicable control area and a statement indicating that the installation of the engine shall not constrain the engine to exclusively operate at speed and load points outside of the control area for the torque curve of the engine;

A.1.4.5. where applicable, design requirements for the components supplied by the OEM that are not part of the engine and are necessary to ensure that, when installed, the engine conforms to the approved engine type;

A.1.4.6. where applicable, design requirements for the reagent tank, including freeze protection, monitoring of reagent level and means to take samples of reagent;

A.1.4.7. where applicable, information on the possible installation of a non-heated reagent system;

A.1.4.8. Reserved

A.1.4.9. where applicable, a statement indicating that the OEM shall provide a warning system as set out in Appendices A.1 and A.2 of Annex 9;

A.1.4.10. where applicable, information on the interface between the engine and agricultural tractor or construction equipment vehicle or combine harvester for the operator warning system, referred to in clause A.1.4.9.;

A.1.4.11. where applicable, information on the interface between the engine agricultural tractor or construction equipment vehicle or combine harvester for the operator inducement system, as set out in Annex 9;

A.1.4.12. where applicable, information on a means to temporarily disable the operator inducement as defined in Annex 9;

A.1.4.13. where applicable, information on the inducement override function as defined in Annex 9;

A.1.4.14. in the case of dual-fuel engines:

(a) a statement indicating that the OEM shall provide a dual-fuel operating mode indicator as described in Appendix A.1. to Annex 7,

(b) a statement indicating that the OEM shall provide a dual-fuel warning system as described in Appendix A.1. to Annex 7,

(c) information on the interface between the engine and the vehicle of categories A or C or combine harvester for the operator indication and warning system, referred to in clause A.1.4.14 (a) and (b) above ;

A.1.4.15. Reserved

A.1.4.16. In the case of a constant-speed engine equipped with alternative speeds as set out in clause 1.1.2.3. of Annex 10:

(a) a statement indicating that the installation of the engine shall ensure that:

i) the engine is stopped prior to resetting the constant-speed governor to an alternative speed; and,

ii) the constant-speed governor is only set to the alternative speeds permitted by the engine manufacturer;

(b) details of each (sub-)category and operating mode (speed operation) for which the engine is type-approved and may be set when installed;

A.1.4.17. In the case that the engine is equipped with an idle speed for start-up and shut-down, a statement indicating that the installation of the engine shall ensure that theconstant-speed governor function is engaged prior to increasing the load-demand to the engine from the no-load setting.

A.1.5. The manufacturer shall provide to the OEM all information and necessary instructions that the OEM shall provide to the end-users in accordance with Appendix 2 to clause 6.

A.1.6 The manufacturer shall provide to the OEM the value of the carbon dioxide (CO2) emissions in g/kWh determined during the type-approval process and recorded in the engine communication. This value shall be provided by the OEM to the end-users accompanied of the following statement: *'This CO2 emission value results from testing over a fixed test cycle under laboratory conditions of an (a parent) engine representative of the engine type (engine family) and shall not imply or express any guarantee of the performance of a particular engine once installed in a type of vehicle category A or C or combine harvester.*

CLAUSE 6 - APPENDIX 2

DETAILS OF THE RELEVANT INFORMATION AND INSTRUCTIONS FOR THE END-USERS

A.2.1. The OEM shall provide to the end-users all information and necessary instructions for the correct operation of the engine in order to maintain the gaseous and particulate pollutant emissions of the engine within the limits of the approved engine type or engine family. Instructions for this purpose shall be clearly identified to the end-users.

A.2.2. The instructions to the end-users shall be:

A.2.2.1. written in a clear and non-technical manner using the same language that is used in the instructions to end-users for agricultural tractor, construction equipment vehicle and combine harvester

A.2.2.2. be provided on paper or, alternatively, a commonly used electronic format;

A.2.2.3. be part of the instructions to end-users for the agricultural tractor or construction equipment vehicle or combine harvester, or, alternatively, a separate document;

A.2.2.3.1. when delivered separately from the instructions to end-users for the agricultural tractor or construction equipment vehicle or combine harvester, be provided in the same form;

A.2.3. The information and instructions to the end-users shall include at least:

A.2.3.1. a description of any special conditions or restrictions linked to the use of the engine, as noted on the type-approval communication;

A.2.3.2. a statement indicating that the engine, including the emissions control system, shall be operated, used and maintained in accordance with the instructions provided to the end-users in order to maintain the emissions performance of the engine within the requirements applicable to the engine's category;

A.2.3.3. a statement indicating that no deliberate tampering with or misuse of the engine emissions control system should take place; in particular with regard to deactivating or not maintaining an exhaust gas recirculation (EGR) or a reagent dosing system.

A.2.3.4. a statement indicating that it is essential to take prompt action to rectify any incorrect operation, use or maintenance of the emissions control system in accordance with the rectification measures indicated by the warnings referred to in clause A.2.3.5. and A.2.3.6.;

A.2.3.5. detailed explanations of the possible malfunctions of the emissions control system generated by incorrect operation, use or maintenance of the installed engine, accompanied by the associated warning signals and the corresponding rectification measures;

A.2.3.6. detailed explanations of the possible incorrect use of the agricultural tractor or construction equipment vehicle or combine harvester that would result in malfunctions of the engine emissions control system, accompanied by the associated warning signals and the corresponding rectification measures;

A.2.3.7. Reserved;

A.2.3.8. Reserved;

A.2.3.9. for agricultural tractor or construction equipment vehicle or combine harvester with an operator warning system, a statement indicating that the operator will be

informed by the operator warning system when the emission control system does not function correctly;

A.2.3.10. for agricultural tractor or construction equipment vehicle or combine harvester with an operator inducement system a statement indicating that ignoring the operator warning signals will lead to the activation of the operator inducement system, resulting in an effective disablement of vehicle of categories A or C or Combine Harvester.

A.2.3.11. for agricultural tractor or construction equipment vehicle or combine harvester with an inducement override function for releasing full engine power justified by safety concerns or to allow for self-healing diagnostics, information about the operation of this function;

A.2.3.12. where applicable, explanations of how the operator warning and inducement systems referred to in clauses A.2.3.9., A.2.3.10. and A.2.3.11. operate, including the consequences, in terms of performance and fault logging, of ignoring the warning system signals and of not replenishing, where used, the reagent or rectifying the problem identified;

A.2.3.13. Reserved;

A.2.3.14. for agricultural tractor or construction equipment vehicle or combine harvester with a means to disable the operator inducement, information about the operation of this function, and a statement indicating that this function shall be only activated in case of emergencies, that any activation will be recorded in the on-board computer log and that national inspection authorities will be able to read these records with a scan tool;

A.2.3.15. information on the fuel(s) necessary to maintain the performance of the emissions control system in particular:

(a) where the engine is to be operated on diesel or non-road gas-oil, a statement indicating that a fuel with sulphur content not greater than 10 mg/kg (20 mg/kg at point of final distribution) cetane number not less than 51 and an FAME content not greater than 7.0 per cent v/v shall be used.

(b) where additional fuels, fuel mixtures or fuel emulsions are compatible with use by the engine, as declared by the manufacturer and stated in the type-approval communication, these shall be indicated;

A.2.3.16. information on the lubrication oil specifications necessary to maintain the performance of the emissions control system;

A.2.3.17. where the emission control system requires a reagent, the characteristics of that reagent, including the type of reagent, information on concentration when the reagent is in solution, operational temperature conditions and reference to international standards for composition and quality, consistent with the specification set-out in the engine type-approval.

A.2.3.18. where applicable, instructions specifying how consumable reagents have to be refilled by the operator between normal maintenance intervals. They shall indicate how the operator should refill the reagent tank and the anticipated frequency of refill, depending upon utilisation of the vehicle of categories A or C or combine harvester.

A.2.3.19. a statement indicating that in order to maintain the emissions performance of the engine, it is essential to use and refill reagent in accordance with the specifications set out in clauses A.2.3.17. and A.2.3.18.;

A.2.3.20. scheduled emission-related maintenance requirements including any scheduled exchange of critical emission-related components;

A.2.3.21. in the case of dual-fuel engines:

(a) where applicable, information on the dual-fuel indicators,

(b) where a dual-fuel engine has operability restrictions in a service mode, a statement indicating that the activation of the service mode will result in an effective disablement of vehicle of categories A or C or combine harvester.

(c) where an inducement override function for releasing full engine power is available, information about the operation of this function shall be provided,

A.2.4 The OEM shall provide to the end-users the value of the carbon dioxide (CO2) emissions in g/kWh determined during the type-approval process and recorded in type-approval certificate accompanied of the following statement: 'This CO2 emission value results from testing over a fixed test cycle under laboratory conditions of an (a parent) engine representative of the engine type (engine family) and shall not imply or express any guarantee of the performance of a particular engine once installed in a type of vehicle category A or C or combine harvester'.

7. ENGINE FAMILY AND ENGINE TYPE

7.1. Parameters defining the engine family

The engine family, as determined by the engine manufacturer shall comply with the criteria set out in Annex 10.

7.2. Choice of the parent engine

The parent engine of the family shall be selected in accordance with the requirements set out in Annex 10.

7.3. Parameters defining an engine type

The technical features of an engine type shall be those defined in its information document drafted in accordance with the template set out in Appendix A.3. to Annex 1.

8. CONFORMITY OF PRODUCTION

8.1 The conformity of production procedures shall comply with those set out in the AIS-137 (Part 6) with the following requirements:

8.2 Every produced agricultural tractor, construction equipment vehicle's and combine harveter's engine of the model approved under this Part shall conform with regard to components affecting the emission of gaseous pollutants by the engine to the vehicle model type approved. The Administrative procedure for carrying out conformity of production test is given in AIS-137 (Part 6)

8.3 Conformity of Production (COP) frequency and selection procedure shall be as per procedure laid down in AIS-137 (Part 6) and as amended time to time. For agricultural tractor, construction equipment and combine harvester with annual production/Import up to 200 numbers (per engine family), it shall be once in two years per family/model. For agricultural tractor, construction equipment vehicle and combine harvester with annual production/Import exceeding 200 numbers (per engine family), it shall be once in every year per family/model. The

sampling size shall be one day's average production subject to a minimum of 10 and maximum of 100. For engine family produced less than 200 in the yearly period sample size may be less than 10.

8.4 The random selection shall be at OEM place where installing engine and exhaust after treatment happens on vehicle.

8.5 An engine, randomly taken from the series is subjected to the mass emission test described in Annex 4. The emissions of the carbon monoxide, the emissions of the hydrocarbons, the emissions of the oxides of nitrogen and the emissions of particulate obtained shall not exceed the amounts shown in the Table 1 in Appendix 1 of clause 5 of this Part., subject to the requirements of clause 5.2. above.

8.6 If the engine taken from the series does not satisfy the requirements of clause 8.5 above the manufacturer may ask for measurements to be performed on a sample of engines of the same specification taken from the series and including the engine originally taken. The manufacturer shall determine the size n of the sample in agreement with the Test Agency. Engines other than the engine originally taken shall be subjected to a test. The arithmetical mean $\left(\bar{x}\right)$ of the results obtained with the sample shall then be determined for each pollutant. The production of the series shall then be deemed to confirm if the following condition is met:

$$\bar{x} + kS \leq l$$

Where:

$S^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$ where x is any one of the individual results obtained with the sample n;

l is the limit value laid down in Table 1 of Appendix 1 of partagraph 5 for each pollutant considered;

k is a statistical factor depending on n and given in the following table:

n	2	3	4	5	6	7	8	9	10
k	0.973	0.613	0.489	0.421	0.376	0.342	0.317	0.296	0.279
n	11	12	13	14	15	16	17	18	19
k	0.265	0.253	0.242	0.233	0.224	0.216	0.210	0.203	0.198

If $n \geq 20$, $k = \frac{0.860}{\sqrt{n}}$

8.7. Non-compliance of gaseous-fuelled engines

In the case of dispute concerning compliance of gaseous-fuelled engines, including dual-fuel engines, when using a market fuel, the tests shall be performed with each reference fuel on which the parent engine has been tested, and, at the request of the manufacturer, with the possible additional third fuel, as referred to in clauses A.3.2.3.1.1.1., A.3.2.3.2.1. and A.3.2.4.1.2. of Appendix 3 to clause 5, on which the parent engine may have been tested. When applicable, the result shall be converted by a calculation, applying the relevant factors "r", "ra" or "rb" as described in clauses A.3.2.3.3., A.3.2.3.4.1. and A.3.2.4.1.3. of Appendix 3 to clause 5. If r, ra or rb are less than 1, no correction shall take place. The measured results and, when applicable, the calculated results shall demonstrate that the engine meets the limit values with all relevant fuels (for example fuels 1, 2 and, if applicable, the third fuel in the case of natural gas/bio-methane engines, and fuels A and B in the case of LPG engines).

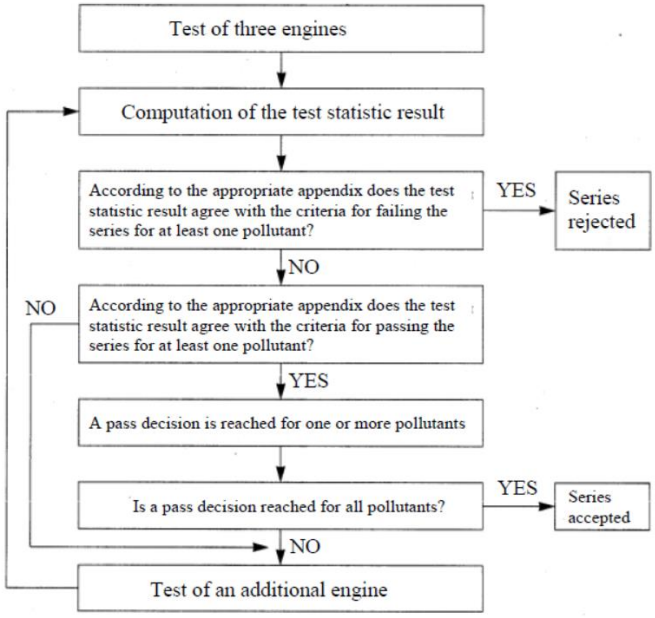


Figure 5.

Schematic flow of production conformity testing

9 PENALTIES FOR NON-CONFORMITY OF PRODUCTION

The approval granted in respect of an engine type or family pursuant to this part may be withdrawn if the requirements laid down in clause 8. above are not complied with or if the engine or engines taken fail to pass the tests prescribed in clause 8.6.

10. MODIFICATIONS AND EXTENSION OF APPROVAL OF THE APPROVED TYPE

10.1. The manufacturer shall inform the Test Agency that granted the type-approval of any change in the particulars recorded in the information package, without delay. In the event of such a change, that Test Agency shall decide which of the procedures laid down in clause 10.2 is to be followed. Where necessary, the Test Agency may decide, after consulting the manufacturer, that a new type-approval is to be granted.

10.1.1 An application for the amendment of type-approval shall be submitted only to the Test Agency that granted the original type-approval.

10.1.2. If the Test Agency finds that, for the purposes of making an amendment, inspections or tests need to be repeated, it shall inform the manufacturer accordingly. The procedures laid down in clause 10.2. shall apply only if, on the basis of those inspections or tests, the Test Agency concludes that the requirements for type-approval continue to be fulfilled.

10.2. Where particulars recorded in the information package have been changed, without requiring inspections or tests to be repeated, such an amendment shall be termed a 'revision'.

In the event of such a revision, the Test Agency shall, without unjustified delay, revise the relevant pages of the information package as necessary, marking each of them to clearly show the nature of the amendment, and it shall also state the date of revision and include a revised index to the information package. A consolidated, updated version of the information package, accompanied by a detailed description of the amendments, shall be deemed to fulfil the requirement of this clause.

10.2.1. An amendment as referred to in clause 10.2 shall be termed an 'extension' where the particulars recorded in the information package have been changed and any of the following occurs:

(a) further inspections or tests are required;

(b) any information included in the communication, with the exception of its attachments, has changed;

(c) a new requirement set out in this Part becomes applicable to the approved engine type or engine family.

10.2.2. In the event of an extension, the Test Agency shall establish an updated communication denoted by an extension number that shall be incremented in accordance with the number of successive extensions previously granted. That communication shall clearly show the reason for the extension and the date of extension.

10.2.3 Whenever pages of the information package are amended or a consolidated, updated version is established, the index to the information package attached to the communication shall be amended accordingly to indicate the date of the most

recent extension or revision, or the date of the most recent consolidation of the updated version.

10.2.4. No amendment to the type-approval of an engine type or engine family shall be required if a new requirement referred to in point (c) of clause 10.2.1. is, from a technical point of view, irrelevant to that engine type or engine family with regard to its emission performance.

10.3. In the event of a revision of a type-approval, the Test Agency shall issue to the applicant, without unjustified delay, the revised documents or the consolidated, updated version, as appropriate, including the revised index to the information package, as referred to in the second subparagraph of clause 10.2.

10.4 In the event of an extension of an type-approval, the Test Agency shall issue to the applicant, without unjustified delay, the updated communication referred to in clause 10.2.2., including the attachments thereto, and the index to the information package.

11. PRODUCTION DEFINITIVELY DISCONTINUED

If the certificate holder wishes to withdraw Type Approval Certificate, he shall so inform the Test Agency at least three months before stoppage of production which granted the type approval. Upon receiving the relevant communication, Test Agency shall inform the manufacturer the acceptance of the communication and provide an acceptance letter.

ANNEX 1 - APPENDIX A.1

TEMPLATES FOR INFORMATION FOLDER AND INFORMATION DOCUMENT

1. INFORMATION FOLDER

The information folder referred to in clause 3 of this Part shall contain the following:

1.1. A list of contents;

1.2. Manufacturer's declaration on adherence to all requirements of this Part in accordance with the template set out in this Appendix;

1.3. Manufacturer's statement on the compliance of the engine type or engine family with the exhaust emission limits set out in Appendix 1 to clause 5 of this Part with regard to specified liquid fuels, fuel mixtures or fuel emulsions other than those set out in clause A.3.1.2.2. of Appendix 3 to clause 5 of this Part;

1.4. For electronically controlled engines of categories NRE, complying with the emission limits set out in Appendix 1 to clause 5 to this Part and using electronic control to determine both the quantity and timing of injecting fuel or using electronic control to activate, de-activate or modulate the emission control system used to reduce NO_X, a complete overview of the emission control strategy, including the base emission control strategy and the means by which every auxiliary control strategy directly or indirectly controls the output variables;

1.4.1. Additional confidential information as set out in Appendix A.2 shall be made available, only for the Test Agency performing the tests and not included in the information folder;

1.5. Where applicable, a full description of the functional operational characteristics of the NO_X control measures and inducement system as referred to in Annex 9 to this Part;

1.5.1. Where applicable, a copy of the demonstration reports set out in clauses A.1.10.5. and A.1.13.4. of Appendix A.1 of Annex 9;

1.5.2 Where applicable, a description of the connection for, and method to read, the records set out at clause A.1.5.2.1.1.(e) of Appendix A.1 of Annex 9;

1.5.3 Where the engine type or engine family is member of a NCD engine family, a justification of its membership together with the information requested in clause 1.5., 1.5.1. and 1.5.2. on the NCD engine family may be supplied alternatively, upon agreement of the Test Agency;

1.6. Where applicable, a full description of the functional operational characteristics of the particulate control measures as referred to in Annex 9 to this Part;

1.6.1. Where applicable, a copy of the demonstration report set out in clause A.2.9.3.6. of Appendix A.2 of Annex 9;

1.6.2 Where applicable, a description of the connection for, and method to read, the records set out at clause A.2.5.2. of Appendix A.2 of Annex 9;

1.6.3 Where the engine type or engine family is a member of a PCD engine family, a justification of its membership together with the information requested in clause 1.6., 1.6.1. and 1.6.2. on the PCD engine family may be supplied alternatively, upon agreement of the Test Agency;

1.7. Manufacturer's declaration, and supporting test reports or data, on deterioration factors as referred to in clause 5 and in Annex 8 of this Part;

1.7.1 Where the engine type or engine family is a member of an engine after-treatment system family, a justification of its membership together with the information requested in clause 1.7 on the after-treatment system family may be supplied alternatively, upon agreement of the Test Agency;

1.8. Where applicable, the manufacturer's declaration, and supporting test reports or data, of the infrequent regeneration adjustment factors referred to in Annex 4 to this Part;

1.8.1 Where the engine type or engine family is a member of an engine-after-treatment system family, a justification of its membership together with the information requested in clause 1.8 on the engine-after-treatment system family may be supplied alternatively, upon agreement of the Test Agency;

1.9. Manufacturer's declaration and supporting data demonstrating that the emission control strategies fitted are designed in such a way as to prevent tampering to the extent possible, as referred to in clause 5.5 of this Part and Appendix A.3 to Annex 9 of this Part.

1.9.1. For engine types and engine families that use an Electronic Control Unit (ECU) as part of the emission control system the information shall include a description of the provisions taken to prevent tampering with and modification of the ECU including the facility for updating using a manufacturer approved programme or calibration;

1.9.2. For engine types and engine families that use mechanical devices as part of the emission control system the information shall include a description of the provisions taken to prevent tampering with and modification of the adjustable parameters of the emission control system. This shall include the tamper resistant components such as carburettor limiter caps or sealing of carburettor screws or special screws not adjustable by user;

1.9.3 In order to place engines from different engine families into the same tamper prevention engine family the manufacturer shall provide confirmation to the Test Agency that the measures used to prevent tampering are similar.

1.10. A description of the physical connector required to receive the torque signal from the engine ECU in case the contracting party requires to conduct in-service monitoring tests, in order to procure such a connector.

1.11. A description of overall quality-assurance management systems for conformity of production in accordance to clause 8. of this Part;

1.12. A list of scheduled emission-related maintenance requirements and the period at which each should occur including any scheduled exchange of critical emission-related components;

1.13. The completed information document as set out in clause 2 of this Appendix ;

1.13.1 Where the particulars appearing in the information document for an engine approval have changed, the manufacturer shall submit revised pages to the Test Agency showing clearly the nature of the change(s) and the date of re-issue;

1.14. All relevant data, drawings, photographs and other information as required in the information document;

2. INFORMATION DOCUMENT

The information document shall have a reference number issued by the applicant.

2.1. All information documents shall contain the following:

2.1.1. the general information set out in Part A of Appendix A.3 of this Anenx;

2.1.2. the information set out in Part B of Appendix A. 3, to identify the common design parameters of all engine types within an engine family or applicable to the engine type where not part of an engine family, intended for type approval;

2.1.3. the information set out in Part C of Appendix A.3 following the format of the matrix set out in clause 2.1.3.1 to identify the items applicable to the parent engine or engine type and the engine types within the engine family, if applicable:

2.1.3.1. Engine type or engine family matrix with example data

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family(if applicable)			
			type 2	type 3	type …	type n
3.1	Engine Identification					
3.1.1	Engine type designation	A01	A02	A03	A04	A05
3.2	Performance Parameters					
3.2.1	Declared rated speed(s) (rpm):	2200	2200	2000	1800	1800
3.10	Miscellaneous devices: Yes/No					
3.10.1	Exhaust gas recirculation (EGR)					
3.10.1.1	Characteristics (cooled/uncooled, high pressure/low pressure, etc.):					
	…	…				

2.1.3.2 Reserved

2.1.3.3. In the case of constant speed engines with multiple rated speeds an additional set column(s) of data for each speed shall be recorded in clause 3.2 (Performance Parameters).

2.2. Explanatory notes on creation of information document:

2.2.1. Upon agreement of the Test Agency, the information in clause 2.1.2 and 2.1.3 may be presented in an alternative format;

2.2.2. Each engine type or the parent engine in the matrix set out in clause 2.1.3.1 shall be identified in accordance with the engine family designation and engine type designation set out in clause 2.3.

2.2.3. Only those clauses of this Annex relevant for the particular engine family, engine types within the engine family or engine type shall be listed; in any case, the list shall adhere to the proposed numbering system,

2.2.4. Where several options separated by forward slash are given for an entry, the unused options shall be struck out, or only the used option(s) shall be shown;

2.2.5. When the same value for or description of a certain engine characteristic applies for several or all members of an engine family the corresponding cells may be merged.

2.2.6. Where a picture, diagram or detailed information is required, a reference to an appendix may be given;

2.2.7. Where a 'type' of a component is requested, the information supplied shall uniquely identify the component; this may be a list of characteristic, a manufacturers' name and part or drawing number, a drawing, or a combination of the aforementioned or other methods that achieves the same result.

2.3. Engine type designation and engine family designation

The manufacturer shall allocate to each engine type and engine family a unique alphanumeric code.

2.3.1. In the case of an engine type, the code is named engine type designation and shall clearly and unequivocally identify those engines presenting a unique combination of technical features for those items set out in Part C of Appendix A.3 to this Annex applicable to the engine type.

2.3.2. In the case of engine types within an engine family, the whole code is named Family-Type or 'FT', and is composed of two sections: the first section is named engine family designation and identifies the engine family; the second section is the engine type designation of each particular engine type within the engine family;

The engine family designation shall clearly and unequivocally identify those engines presenting a unique combination of technical features for those items set out in Parts B and C of Appendix A. 3 to this Annex applicable to the particular engine family.

The FT shall clearly and unequivocally identify those engines presenting a unique combination of technical features for those items set out in Part C of Appendix A.3 to this Annex applicable to the engine type within the engine family.

2.3.2.1. The manufacturer may use the same engine family designation to identify the same engine family under two or more engine categories.

2.3.2.2. The manufacturer shall not use the same engine family designation to identify more than one engine family under the same engine category.

2.3.2.3. Display of the FT

In the FT, a space shall be left between the engine family designation and the engine type designation, as shown in the example below:

'159AF[space]0054'

2.3.3. Number of characters: The number of characters shall not exceed the following:

(a) 15 for the engine family designation;

(b) 25 for the engine type designation;

(c) 40 for the FT.

2.3.4. Characters allowed

The engine type designation and engine family designation shall be made up of Roman letters and/or Arabic numerals;

2.3.4.1. The use of brackets and hyphens is permitted provided they do not replace a letter or a numeral.

2.3.4.2. The use of variable characters is permitted; variable characters shall be denoted by a '#', where the variable character is unknown at the time of notification;

2.3.4.2.1. The reasons for using such variable characters shall be explained to the Test Agency.

ANNEX 1 - APPENDIX A.2

CONFIDENTIAL INFORMATION ON EMISSION CONTROL STRATEGY

A.2.1. This Appendix shall apply to electronically controlled engines, which use electronic control to determine both the quantity and timing of injecting fuel.

A.2.2. Additional information shall be presented to the Test Agency but not annexed to the application for type approval. This information shall include all the parameters modified by any auxiliary emission control strategy and the boundary conditions under which this strategy operates and in particular:

(a) a description of the control logic, of timing strategies and switch points, during all modes of operation for the fuel and other essential systems, resulting in effective emission control (such as exhaust gas recirculation (EGR) or reagent dosing);

(b) a justification for the use of any auxiliary emission control strategy applied to the engine, accompanied by material and test data, demonstrating the effect on exhaust emissions. This justification may be based on test data, sound engineering analysis, or a combination of both;

(c) a detailed description of algorithms or sensors (where applicable) used for identifying, analysing, or diagnosing incorrect operation of the NO_X control system;

(d) a detailed description of algorithms or sensors (where applicable) used for identifying, analysing, or diagnosing incorrect operation of the particulate control system.

A.2.3. The additional information required in clause A.2.2 shall be treated as strictly confidential. It shall be retained by the manufacturer and made available for inspection by the Test Agency at the time of type approval or upon request at any time during the validity of the type approval. In this case, the Test Agency shall treat this information as confidential and shall not disclose it.

ANNEX 1 - APPENDIX A.3

TEMPLATE FOR INFORMATION DOCUMENT

PART A

1.	**GENERAL INFORMATION**
1.1.	Make (trade name(s) of manufacturer): .....
1.2.	Commercial name(s) (if applicable): .....
1.3.	Company name and address of manufacturer:.....
1.4.	Name and address of manufacturer's authorised representative (if any): .....
1.5.	Name(s) and address(es) of assembly/manufacture plant(s): .....
1.6.	Engine type designation/engine family designation/FT: .....
1.7.	Category and sub-category of the engine type/engine family *: NRE-v-1/NRE-v-2/NRE-v-3/NRE-v-4/NRE-v-5/NRE- v-6/NRE-v-7/NRE-c-1/NRE-c-2/NRE-c-3/NRE-c-4/NRE-c-5/NRE-c-6/NRE-c-7
1.8.	Emissions durability period category: Not Applicable/Cat 1 (Consumer products)/Cat 2 (Semi-professional products)/Cat 3 (Professional products)
1.9.	Reserved
1.10.	Reserved
1.11.	Reference power is: rated gross power/maximum gross power
1.12.	Primary NRSC test cycle: C1/C2/D2/G1/G2/G3/
1.13.	Transient test cycle: Not applicable/NRTC/LSI-NRTC
1.14.	Restrictions on use (if applicable):

* Strike through what is not applicable.

PART B

2.	**COMMON DESIGN PARAMETERS OF ENGINE FAMILY (1)**
2.1.	Combustion Cycle: four stroke cycle/two stroke cycle/rotary/other (specify) .....
2.2.	Ignition Type: Compression ignition/spark ignition
2.3.	Configuration of the cylinders
2.3.1.	Position of the cylinders in the block: Single/V/in-line/opposed/radial/other(specify): .....
2.3.2.	Bore centre to centre dimension (mm): .....
2.4.	Combustion chamber type/design
2.4.1.	Open chamber/divided chamber/other(specify)

2.4.2. Valve and porting configuration: .....

2.4.3. Number of valves per cylinder: .....

2.5. Range of swept volume per cylinder (cm^3): .....

2.6. Main Cooling medium: Air/Water/Oil

2.7. Method of air aspiration: naturally aspirated/pressure charged/pressure charged with charge cooler

2.8. Fuel

2.8.1. Fuel Type: Diesel (non-road gas-oil)/Ethanol for dedicated compression ignition engines (ED95)/ Ethanol (E85)/(Natural gas/Biomethane)/Liquid Petroleum Gas (LPG)

2.8.1.1. Sub Fuel type (Natural gas/Biomethane only): Universal fuel — high calorific fuel (H-gas) and low calorific fuel (L-gas)/Restricted fuel — high calorific fuel (H-gas)/Restricted fuel — low calorific fuel (L-gas)/Fuel specific (LNG);

2.8.2. Fuelling arrangement: Liquid-fuel only/Gaseous-fuel only/Dual-fuel type 1A/Dual-fuel type 1B/Dual-fuel type 2A/Dual-fuel type 2B/Dual-fuel type 3B

2.8.3. List of additional fuels, fuel mixtures or emulsions compatible with use by the engine declared by the manufacturer in accordance with Appendix 3 to clause 5 of this Part (provide reference to recognised standard or specification): .....

2.8.4. Lubricant added to fuel: Yes/No

2.8.4.1. Specification: .....

2.8.4.2. Ratio of fuel to oil: .....

2.8.5. Fuel supply type: Pump (high pressure) line and injector/in-line pump or distributor pump/Unit injector/ Common rail/Carburettor)/port injector/direct injector/Mixing unit/other(specify): .....

2.9. Engine management systems: mechanical/electronic control strategy ([2])

2.10. Miscellaneous devices: Yes/No (if yes provide a schematic diagram of the location and order of the devices)

2.10.1. Exhaust gas recirculation (EGR): Yes/No (if yes, complete section 3.10.1 and provide a schematic diagram of the location and order of the devices)

2.10.2. Water injection: Yes/No (if yes, complete section 3.10.2 and provide a schematic diagram of the location and order of the devices)

2.10.3. Air injection: Yes/No (if yes, complete section 3.10.3 and provide a schematic diagram of the location and order of the devices)

2.10.4. Others: Yes/No (if yes specify, complete section 3.10.4 and provide a schematic diagram of the location and order of the devices): .....

2.11. Exhaust after-treatment system: Yes/No (if yes provide a schematic diagram of the location and order of the devices)

2.11.1. Oxidation catalyst: Yes/No

(if yes, complete section 3.11.2)

2.11.2. De NO_X system with selective reduction of NO_X (addition of reducing agent): Yes/No

(if yes, complete section 3.11.3)

2.11.3. Other De NO_X systems: Yes/No

(if yes, complete section 3.11.3)

2.11.4. Three-way catalyst combining oxidation and NO_X reduction: Yes/No

(if yes, complete section 3.11.3)

2.11.5. Particulate after-treatment system with passive regeneration: Yes/No

(if yes, complete section 3.11.4)

2.11.5.1. Wall-flow/non-wall-flow

2.11.6. Particulate after-treatment system with active regeneration: Yes/No

(if yes, complete section 3.11.4)

2.11.6.1. Wall-flow/non-wall-flow

2.11.7. Other particulate after-treatment systems: Yes/No

(if yes, complete section 3.11.4)

2.11.8. Other after-treatment devices (specify):
.....

(if yes, complete section 3.11.5)

2.11.9. Other devices or features that have a strong influence on emissions Yes/No (specify):
.....

(if yes, complete section 3.11.7)

PART C

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.1.	**Engine Identification**						
3.1.1.	Engine type designation						
3.1.2.	Engine type designation shown on engine marking: yes/no						
3.1.3.	Location of the statutory marking:						
3.1.4.	Method of attachment of the statutory marking:						
3.1.5.	Drawings of the location of the engine identification number (complete example with dimensions):						
3.2.	**Performance Parameters**						
3.2.1.	Declared rated speed(s) (rpm):						
3.2.1.1.	Fuel delivery/stroke (mm^3) for diesel engine, fuel flow (g/h) for other engines, at rated gross power:						
3.2.1.2.	Declared rated gross power (kW):						
3.2.2.	Maximum power speed(rpm):						If different from rated speed
3.2.2.1.	Fuel delivery/stroke (mm3) for diesel engine, fuel flow (g/h) for other engines, at maximum gross power:						
3.2.2.2.	Maximum gross power (kW):						If different from rated speed
3.2.3.	Declared maximum torque speed (rpm):						If applicable
3.2.3.1.	Fuel delivery/stroke (mm3) for diesel engine, fuel flow (g/h) for other engines, at maximum torque speed:						
3.2.3.2.	Declared maximum torque (Nm):						If applicable
3.2.4.	Declared 100 % test speed:						If applicable
3.2.5.	Declared Intermediate test speed:						If applicable
3.2.6.	Idle speed (rpm)						If applicable
3.2.7.	Maximum no load speed (rpm):						If applicable
3.2.8	Declared minimum torque (Nm)						If applicable
3.3.	**Run-in procedure**						Optional at choice of manufacturer
3.3.1.	Run-in time:						
3.3.2.	Run-in cycle:						
3.4.	**Engine test**						
3.4.1.	Specific fixture required: Yes/No						For NRSh only

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.4.1.1	Description, including photographs and/or drawings, of the system for mounting the engine on the test bench including the power transmission shaft for connection to the dynamometer:						
3.4.2.	Exhaust mixing chamber permitted by manufacturer: Yes/No						For NRSh only
3.4.2.1.	Exhaust mixing chamber description, photograph and/or drawing:						If applicable
3.4.3.	Manufacturers chosen NRSC: RMC/Discrete mode						
3.4.4.	Reserved						
3.4.5.	Number of pre-conditioning cycles prior to transient test						If applicable, minimum 1.0
3.4.6.	Pre-conditioning for RMC NRSC: Steady-state operation/RMC						
3.4.6.1.	In case of RMC, number of pre-conditioning RMC prior to RMC NRSC test						Minimum 0.5
3.5.	**Lubrication system**						
3.5.1.	Lubricant temperature						If applicable
3.5.1.1.	Minimum (ºC):						
3.5.1.2.	Maximum (ºC):						
3.6.	**Combustion Cylinder**						
3.6.1.	Bore(mm):						
3.6.2.	Stroke(mm):						
3.6.3.	Number of cylinders:						
3.6.4.	Engine total swept volume (cm^3):						
3.6.5.	Swept volume per cylinder as % of parent engine:						If engine family
3.6.6.	Volumetric compression ratio:						Specifytolerance
3.6.7.	Combustion system description:						
3.6.8.	Drawings of combustion chamber and piston crown:						
3.6.9.	Minimum cross sectional area of inlet and outlet ports (mm^2):						
3.6.10.	Valve timing						
3.6.10.1.	Maximum lift and angles of opening and closing in relation to dead centre or equivalent data:						
3.6.10.2.	Reference and/or setting range:						
3.6.10.3.	Variable valve timing system: Yes/No						If applicable and where intake and/or exhaust
3.6.10.3.1.	Type: continuous/(on/off)						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.6.10.3.2.	Cam phase shift angle:						
3.6.11.	Porting configuration						2-stroke only, if applicable
3.6.11.1.	Positon, size and number:						
3.7.	**Cooling system**						Complete relevant section
3.7.1.	Liquid cooling						
3.7.1.1.	Nature of liquid:						
3.7.1.2.	Circulating pumps: Yes/No						
3.7.1.2.1.	type(s):						
3.7.1.2.2.	Drive ratio(s):						If applicable
3.7.1.3.	Minimum coolant temperature at outlet (ºC):						
3.7.1.4.	Maximum coolant temperature at outlet (ºC):						
3.7.2.	Air cooling						
3.7.2.1.	fan: Yes/No						
3.7.2.1.1.	type(s):						
3.7.2.1.2.	Drive ratio(s):						If applicable
3.7.2.2.	Maximum temperature at reference point (ºC):						
3.7.2.2.1.	Reference point location						
3.8.	**Aspiration**						
3.8.1.	Maximum allowable intake depression at 100% engine speed and at 100% load (kPa)						
3.8.1.1.	With clean air cleaner:						
3.8.1.2.	With dirty air cleaner:						
3.8.1.3.	Location, of measurement:						
3.8.2.	Pressure charger(s): Yes/No						
3.8.2.1.	Type(s):						
3.8.2.2.	Description and schematic diagram of the system (e.g. maximum charge pressure,waste gate, VGT, Twin turbo, etc.):						
3.8.3.	Charge air cooler: Yes/No						
3.8.3.1.	Type: air-air/air-water/other(specify)						
3.8.3.2.	Maximum charge air cooler outlet temperature at 100% speed and 100% load (ºC):						
3.8.3.3.	Maximum allowable pressure drop across charge cooler at 100% engine speed and at 100% load (kPa):						
3.8.4.	Intake throttle valve: Yes/No						
3.8.5.	Device for recycling crankcase gases: Yes/No						
3.8.5.1.	If yes, description and drawings:						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.8.5.2.	If no, compliance with clause 5.7. of this Part: Yes/No						
3.8.6.	*Inlet path*						*2-stroke, NRS and NRSh only*
3.8.6.1.	Description of inlet path, (with drawings, photographs and/or part numbers):						
3.8.7.	Air filter						*2-stroke, NRS and NRSh only*
3.8.7.1.	Type:						
3.8.8.	Intake air-silencer						*2-stroke, NRS and NRSh only*
3.8.8.1.	Type:						
3.9.	**Exhaust system**						
3.9.1.	Description of the exhaust system (with drawings, photos and/or part numbers as required):						2 stroke, *NRS and NRSh* only
3.9.2.	Maximum exhaust temperature (ºC):						
3.9.3.	Maximum permissible exhaust backpressure at 100% engine speed and at 100% load (kPa):						
3.9.3.1.	Location of measurement:						
3.9.4.	Exhaust backpressure at loading level specified by manufacturer for variable restriction after-treatment at start of test (kPa):						
3.9.4.1.	Location and speed/load conditions:						
3.9.5.	Exhaust throttle valve: Yes/No						
3.10.	**Miscellaneous devices: Yes/No**						
3.10.1.	Exhaust gas recirculation (EGR)						
3.10.1.1.	Characteristics: cooled/uncooled, high pressure/low pressure/other (specify):						
3.10.2.	Water injection						
3.10.2.1.	Operation principle:						
3.10.3.	Air injection						
3.10.3.1.	Operation principle						
3.10.4.	Others						
3.10.4.1.	Type(s)						
3.11.	**Exhaust after-treatment system**						
3.11.1.	Location						
3.11.1.1.	Place(s) and maximum/minimum distance(s) from engine to first after-treatment device:						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.11.1.2.	Maximum temperature drop from exhaust or turbine outlet to first after-treatment device (ºC) if stated:						
3.11.1.2.1.	Test conditions for measurement:						
3.11.1.3.	Minimum temperature at inlet to first after-treatment device, (ºC) if stated:						
3.11.1.3.1.	Test conditions for measurement:						
3.11.2.	Oxidation catalyst						
3.11.2.1.	Number of catalytic converters and elements:						
3.11.2.2.	Dimensions and volume of the catalytic converter(s):						*Or drawing*
3.11.2.3.	Total charge of precious metals (g):						
3.11.2.4.	Relative concentration of each compound (%):						
3.11.2.5.	Substrate (structure and material):						
3.11.2.6.	Cell density:						
3.11.2.7.	Type of casing for the catalytic converter(s):						
3.11.3.	Catalytic exhaust after-treatment system for NO_X or three way catalyst						
3.11.3.1.	Type:						
3.11.3.2.	Number of catalytic converters and elements:						
3.11.3.3.	Type of catalytic action:						
3.11.3.4.	Dimensions and volume of the catalytic converter(s):						*Or drawing*
3.11.3.5.	Total charge of precious metals (g):						
3.11.3.6.	Relative concentration of each compound (%):						
3.11.3.7.	Substrate (structure and material):						
3.11.3.8.	Cell density:						
3.11.3.9.	Type of casing for the catalytic converter(s):						
3.11.3.10.	Method of regeneration:						If applicable
3.11.3.10.1.	Infrequent regeneration: Yes/No:						If yes, complete section 3.11.6.
3.11.3.11.	Normal operating temperature range (ºC):						
3.11.3.12.	Consumable reagent: Yes/No						
3.11.3.12.1.	Type and concentration of reagent needed for catalytic action:						
3.11.3.12.2.	Lowest concentration of the active ingredient present in the reagent that does not activate warning system (CD_{min}) (%vol):						
3.11.3.12.3.	Normal operational temperature range of reagent:						
3.11.3.12.4.	International standard:						If applicable

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.11.3.13.	NO_X sensor(s): Yes/No						
3.11.3.13.1.	Type:						
3.11.3.13.2.	Location(s)						
3.11.3.14.	Oxygen sensor(s): Yes/No						
3.11.3.14.1.	Type:						
3.11.3.14.2.	Location(s):						
3.11.4.	Particulate after-treatment system						
3.11.4.1.	Type of filtration: wall-flow/ non-wall-flow/other (specify)						
3.11.4.2.	Type:						
3.11.4.3.	Dimensions and capacity of the particulate after-treatment system:						*Or drawing*
3.11.4.4.	Location place(s) and maximum and minimum distance(s) from engine:						
3.11.4.5.	Method or system of regeneration, description and/or drawing:						
3.11.4.5.1.	Infrequent regeneration: Yes/No						If yes, complete section 3.11.6.
3.11.4.5.2.	Minimum exhaust gas temperature for initiating regeneration procedure (ºC):						
3.11.4.6.	Catalytic coating: Yes/No						
3.11.4.6.1.	Type of catalytic action:						
3.11.4.7.	Fuel borne catalyst (FBC): Yes/No						
3.11.4.8.	Normal operating temperature range (ºC):						
3.11.4.9.	Normal operating pressure range (kPa)						
3.11.4.10.	Storage capacity soot/ash (g):						
3.11.4.11.	Oxygen sensor(s): Yes/No						
3.11.4.11.1.	Type:						
3.11.4.11.2.	Location(s):						
3.11.5.	Other after-treatment devices						
3.11.5.1.	Description and operation:						
3.11.6.	Infrequent Regeneration						
3.11.6.1.	Number of cycles with regeneration						
3.11.6.2.	Number of cycles without regeneration						
3.11.7.	Other devices or features						
3.11.7.1.	Type(s)						
3.12.	**Fuel feed for liquid-fuelled CI or, where applicable, dual-fuel engines**						
3.12.1.	Feed pump						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.12.1.1.	Pressure (kPa) or characteristic diagram:						
3.12.2.	Injection system						
3.12.2.1.	Pump						
3.12.2.1.1.	Type(s):						
3.12.2.1.2.	Rated pump speed (rpm):						
3.12.2.1.3.	mm^3 per stroke or cycle at full injection at rated pump speed:						Specify tolerance
3.12.2.1.4.	Torque peak pump speed (rpm):						
3.12.2.1.5.	mm^3 per stroke or cycle at full injection at torque peak pump speed						Specifytolerance
3.12.2.1.6.	Characteristic diagram:						As alternative to entries 3.12.2.1.1. to 3.12.2.1.5.
3.12.2.1.7.	Method used: on engine/on pump bench						
3.12.2.2.	Injection timing						
3.12.2.2.1.	Injection timing curve:						Specify tolerance, if applicable
3.12.2.2.2.	Static Timing:						Specify tolerance
3.12.2.3.	Injection piping						
3.12.2.3.1.	Length(s) (mm):						
3.12.2.3.2.	Internal diameter (mm):						
3.12.2.4.	Common rail: Yes/No						
3.12.2.4.1.	Type:						
3.12.3.	Injector(s)						
3.12.3.1.	Type(s):						
3.12.3.2.	Opening pressure (kPa):						Specify tolerance
3.12.4.	ECU: Yes/No						
3.12.4.1.	Type(s):						
3.12.4.2.	Software calibration number(s):						
3.12.4.3.	Communication standard(s) for access to data stream information: ISO 27145 with ISO 15765-4 (CAN-based)/ISO 27145 with ISO 13400 (TCP/IP-based)/SAE J1939-73						
3.12.5.	Governor						
3.12.5.1.	Type(s):						
3.12.5.2.	Speed at which cut-off starts under full load:						Specify range, if applicable
3.12.5.3.	Maximum no-load speed:						Specify range, if applicable

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.12.5.4.	Idle speed:						Specify range, if applicable
3.12.6.	Cold-start system: Yes/No						
3.12.6.1.	Type(s):						
3.12.6.2.	Description:						
3.12.7.	Fuel temperature at the inlet to the fuel injection pump						
3.12.7.1.	Minimum (ºC):						
3.12.7.2.	Maximum (ºC):						
3.13.	**Fuel feed for liquid fuel spark ignition engine**						
3.13.1.	Carburettor						
3.13.1.1.	Type(s):						
3.13.2.	Port fuel injection:						
3.13.2.1.	single-point / multi-point						
3.13.2.2.	Type(s):						
3.13.3.	Direct injection:						
3.13.3.1.	Type(s):						
3.13.4.	Fuel temperature at location specified by manufacturer						
3.13.4.1.	Location:						
3.13.4.2.	Minimum (ºC)						
3.13.4.3.	Maximum (ºC)						
3.14.	**Fuel feed for gaseous fuel engines or where applicable, dual-fuel engines (in the case of systems laid out in a different manner, supply equivalent information)**						
3.14.1.	Fuel: LPG /NG-H/NG-L /NG-HL/LNG/Fuel specific LNG						
3.14.2.	Pressure regulator(s)/vaporiser (s)						
3.14.2.1.	Type(s)						
3.14.2.2.	Number of pressure reduction stages						
3.14.2.3.	Pressure in final stage minimum and maximum. (kPa)						
3.14.2.4.	Number of main adjustment points:						
3.14.2.5.	Number of idle adjustment points:						
3.14.3.	Fuelling system: mixing unit/gas injection/liquid injection/direct injection						
3.14.3.1.	Mixture strength part						
3.14.3.1.1.	System description and/or diagram and drawings:						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.14.4.	Mixing unit						
3.14.4.1.	Number:						
3.14.4.2.	Type(s):						
3.14.4.3.	Location:						
3.14.4.4.	Adjustment possibilities:						
3.14.5.	Inlet manifold injection						
3.14.5.1.	Injection: single-point/multi-point						
3.14.5.2.	Injection: continuous/simultaneously timed/ sequentially timed						
3.14.5.3.	Injection equipment						
3.14.5.3.1.	Type(s):						
3.14.5.3.2.	Adjustment possibilities:						
3.14.5.4.	Supply pump						If applicable
3.14.5.4.1.	Type(s):						
3.14.5.5.	Injector(s)						
3.14.5.5.1.	Type(s):						
3.14.6.	Direct injection						
3.14.6.1.	Injection pump/pressure regulator						
3.14.6.1.1.	Type(s):						
3.14.6.1.2.	Injection timing (specify):						
3.14.6.2.	Injector(s)						
3.14.6.2.1.	Type(s):						
3.14.6.2.2.	Opening pressure or characteristic diagram :						
3.14.7.	Electronic Control Unit (ECU)						
3.14.7.1.	Type(s):						
3.14.7.2.	Adjustment possibilities:						
3.14.7.3.	Software calibration number(s):						
3.14.8.	Approvals of engines for several fuel compositions						
3.14.8.1.	Self-adaptive feature: Yes/No						
3.14.8.2.	Calibration for a specific gas composition: NG-H/NG-L/NG-HL/ LNG/Fuel specific LNG						
3.14.8.3.	Transformation for a specific gas composition: NG-HT/NG-LT/NG-HLT						
3.14.9.	Fuel temperature pressure regulator final stage						
3.14.9.1.	Minimum ((ºC):						
3.14.9.2.	Maximum ((ºC):						
3.15.	**Ignition system**						

Item Number	Item Description	Parent engine/ engine type	Engine types within the engine family (if applicable)				Explanatory notes (not included in document)
			type 2	type 3	type …	type n	
3.15.1.	Ignition coil(s)						
3.15.1.1.	Type(s):						
3.15.1.2.	Number:						
3.15.2.	Spark plug(s)						
3.15.2.1.	Type(s):						
3.15.2.2.	Gap setting:						
3.15.3.	Magneto						
3.15.3.1.	Type(s):						
3.15.4.	Ignition timing control: Yes/No						
3.15.4.1.	Static advance with respect to top dead centre (crank angle degrees):						
3.15.4.2.	Advance curve or map:						If applicable
3.15.4.3.	Electronic control: Yes/No						

Explanatory notes to Appendix.A.3:

(Footnote markers, footnotes and explanatory notes not to be stated on the information document)

(Whenever options are offered please strikeout or do not mention those not applicable)

In the case of combined catalyst and particulate filter both pertinent sections shall be filled.

([1]) As defined in clause 7. of this Part.

([2]) Refer to clause 2.4.13 in Annex 10 (engine family definition)

ANNEX 2

COMMUNICATION – TYPE APPROVAL AND COP TEMPLATE TO BE ATTACHED HERE BY TEST AGENCIES

SECTION I

1.1. Make (trade name(s) of manufacturer): .....

1.2. Commercial name(s) (if applicable): .....

1.3. Company name and address of manufacturer: .....

1.4. Name and address of manufacturer's authorised representative (if any): .....

1.5. Name(s) and address(es) of assembly/manufacture plant(s): .....

1.6. Engine type designation/engine family designation/FT ([2]): .....

1.7. Category and sub-category of the engine type/engine family ([2]) ([3]): .....

1.8. Emissions durability period category: Not Applicable/Cat 1/Cat 2/Cat 3 ([2])

SECTION II

1. Test Agency responsible for carrying out the test(s): .....

2. Date(s) of the test report(s): .....

3. Number(s) of the test report(s): .....

SECTION III

The undersigned hereby certifies the accuracy of the manufacturer's description in the attached information document of the engine type/engine family ([2]) described above, for which one or more representative samples, selected by the Test Agency, have been submitted as prototypes and that the attached test results apply to the engine type/engine family ([2]).

1. The engine type/engine family ([2]) meets/does not meet ([2]) the requirements laid down in GSR 201(E) dated 5th March, 2018.

2. The approval is granted/extended/refused/withdrawn ([2])

Place: .....
Date: .....

Name and signature: .....

Attachments:

Information folder

Test report(s)

All other documents added by the Test Agency to the information folder in the course of carrying out their functions.

ADDENDUM

Approval number: .....

PART A — CHARACTERISTICS OF THE ENGINE TYPE/ENGINE FAMILY ([2])

2. COMMON DESIGN PARAMETERS OF THE ENGINE TYPE/ENGINE FAMILY (2)

2.1. Combustion Cycle: four stroke cycle/two stroke cycle/rotary/other: ..... (describe) ([2])

2.2. Ignition Type: Compression ignition/spark ignition ([2])

2.3.1. Position of the cylinders in the block: V/in-line/radial/other(describe) ([2])

2.6 Main Cooling medium: Air/Water/Oil ([2])

2.7. Method of air aspiration: naturally aspirated/pressure charged/pressure charged with charge cooler ([2])

2.8.1. Fuel Type(s): Diesel (non-road gas-oil)/Ethanol for dedicated compression ignition engines (ED95)/Petrol (E10)/ Ethanol (E85)/(Natural gas/Biomethane)/Liquid Petroleum Gas (LPG) ([2])

2.8.1.1. Sub Fuel type (Natural gas/Biomethane only): Universal fuel — high calorific fuel (H-gas) and low calorific fuel (L-gas)/Restricted fuel — high calorific fuel (H-gas)/Restricted fuel — low calorific fuel (L-gas)/Fuel specific (LNG);

2.8.2. Fuelling arrangement: Liquid-fuel only/Gaseous-fuel only/Dual-fuel type 1A/Dual-fuel type 1B/Dual-fuel type 2A/Dual-fuel type 2B/Dual-fuel type 3B ([2])

2.8.3. List of additional fuels compatible with use by the engine declared by the manufacturer in accordance with clause A.3.1.2.3. of Appendix A 3 to clause 5 of this Part (provide reference to recognised standard or specification): .....

2.8.4. Lubricant added to fuel: Yes/No ([2])

2.8.5. Fuel supply type: Pump (high pressure) line and injector/in-line pump or distributor pump/Unit injector/ Common rail/Carburettor)/port injector/direct injector/Mixing unit/other(specify) ([2])

2.9. Engine management systems: mechanical/electronic control strategy ([2])

2.10. Miscellaneous devices: Yes/No ([2])

2.10.1. Exhaust gas recirculation (EGR): Yes/No ([2])

2.10.2. Water injection: Yes/No ([2])

2.10.3. Air injection: Yes/No ([2])

2.10.4. Others (specify): .....

2.11. Exhaust after-treatment system: Yes/No ([2])

2.11.1. Oxidation catalyst: Yes/No ([2])

2.11.2. De NO_X system with selective reduction of NO_X (addition of reducing agent): Yes/No ([2])

2.11.3. Other De NO_X systems: Yes/No ([2])

2.11.4. Three-way catalyst combining oxidation and NOx reduction: Yes/No ([2])

2.11.5. Particulate after-treatment system with passive regeneration: Yes/No ([2])

2.11.6. Particulate after-treatment system with active regeneration: Yes/No ([2])

2.11.7. Other particulate after-treatment systems: Yes/No ([2])

2.11.8. Three-way catalyst combining oxidation and NO_X reduction: Yes/No ([2])

2.11.9. Other after-treatment devices (specify): .....

2.11.10. Other devices or features that have a strong influence on emissions (specify): .

3. ESSENTIAL CHARACTERISTICS OF THE ENGINE TYPE(S)

Item Number	**Item Description**	**Parent Engine / Engine type**	**Engine types within the family (if applicable)**		
3.1.1.	Engine Type Designation:				
3.1.2.	Engine type designation shown on engine mark: Yes/No(2)				
3.1.3.	Location of the manufacturer's statutory marking:				
3.2.1.	Declared rated speed (rpm):				
3.2.1.2.	Declared rated gross power (kW):				
3.2.2.	Maximum power speed (rpm):				
3.2.2.2.	Maximum gross power (kW):				
3.2.3.	Declared maximum torque speed (rpm):				
3.2.3.2.	Declared maximum torque (Nm):				
3.6.3.	Number of Cylinders:				
3.6.4.	Engine total swept volume (cm^3):				
3.8.5.	Device for recycling crankcase gases: Yes/No(2)				
3.11.3.12.	Consumable reagent: Yes/No(2)				
3.11.3.12.1.	Type and concentration of reagent needed for catalytic action:				
3.11.3.13.	NO_X sensor(s): Yes/No(2)				
3.11.3.14.	Oxygen sensor: Yes/No(2)				
3.11.4.7.	Fuel borne catalyst (FBC): Yes/No(2)				
Particular conditions to be respected in the installation of the engine on agricultural tractor, construction equipment vehicle and combine harvester:					
3.8.1.1.	Maximum allowable intake depression at 100% engine speed and at 100% load (kPa) with clean air cleaner:				
3.8.3.2.	Maximum charge air cooler outlet temperature at 100% speed and 100% load (deg. C):				
3.8.3.3.	Maximum allowable pressure drop across charge cooler at 100% engine speed and at 100% load (kPa)(if applicable):				

Item Number	Item Description	Parent Engine / Engine type	Engine types within the family (if applicable)		
3.9.3.	Maximum permissible exhaust gas back-pressure at 100% engine speed and at 100% load (kPa):				
3.9.3.1.	Location of measurement:				
3.11.1.2	Maximum temperature drop from exhaust system or turbine outlet to first exhaust after-treatment system (deg. C) if stated:				
3.11.1.2.1.	Test conditions for measurement:				

PART B – TEST RESULTS

3.8. Manufacturer intends to use ECU torque signal for in-service monitoring: Yes/No([2])

3.8.1. Dynamometer torque greater than or equal to 0.93x ECU torque: Yes/No([2])

3.8.2. ECU torque correction factor in case that dynamometer torque less than 0.93x ECU torque:

11.1 Cycle emissions results

Emissions	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X (g/kWh)	PM (g/kWh)	PN #/kWh	Test Cycle[(4)]
NRSC final result with DF.							
NRTC Final test result with DF							

11.2 CO_2 result:

11.3. Reference values in case the Test Agency requires to conduct in-service monitoring tests

11.3.1. NRTC reference work (kWh):

11.3.2. NRTC reference CO2 (g):

Explanatory notes to Annex 2

(Footnote markers, footnotes and explanatory notes not to be stated on the type-approval certificate)

([1]) Reserved

([2]) Strike out the unused options, or only show the used option(s).

([3]) Indicate the applicable option for the category and sub-category in accordance with entry 1.7. of the information document set out in Part A of Appendix A.3 to Annex 1.

([4]) Indicate the used test cycle as prescribed in Appendix A.6 Annex 4 to this Part.

ANNEX 2 - APPENDIX A.1

TEST REPORT

A.1.1. GENERAL REQUIREMENTS

One test report shall be completed for each tests required for the type-approval. Each additional (e.g. a second speed on a constant speed engine) or supplementary test (e.g. another fuel is tested) will require an additional or supplementary test report.

A.1.2. EXPLANATORY NOTES ON CREATION OF A TEST REPORT

A.1.2.1. A test report shall contain at least the information set out in clause A.1.3.

A.1.2.2. Notwithstanding clause A.1.2.1, only those sections or sub-sections relevant for the particular test and for the particular engine family, engine types within the engine family or engine type tested need to be stated in the test report (e.g. if a NRTC is not run this section may be omitted);

A.1.2.3. The test report may contain more information than that requested in clause A.1.2.1 but in any case, shall adhere to the proposed numbering system;

A.1.2.4. Where several options separated by forward slash are given for an entry, the unused options shall be struck out, or only the used option(s) shall be shown;

A.1.2.5. Where a ‘type’ of a component is requested, the information supplied shall uniquely identify the component; this may be a list of characteristic, a manufacturers' name and part or drawing number, a drawing, or a combination of the aforementioned or other methods that achieves the same result.

A.1.2.6. The test report may be delivered on paper on in an electronic format agreed between the manufacturer and Test Agency.

A.1.3 TEMPLATE FOR THE TEST REPORT

TEST REPORT FOR ENGINES OF AGRICULTURAL TRACTORS, CONSTRUCTION EQUIPMENT VEHICLES OR COMBINE HARVESTERS

1. **General Information**

1.1. Make(s) (trade name(s) of manufacturer):.....

1.2. Commercial name(s) (if applicable): .....

1.3. Company name and address of manufacturer: .....

1.4. Name of Test Agency: .....

1.5. Address of Test Agency: .....

1.6. Location of test: .....

1.7. Date of test: .....

1.8. Test report number: .....

1.9. Information document reference number (if available): .....

1.10. Test report type*: Primary test/additional test/supplementary test

1.10.1. Description of the purpose of the test: .....

2. **General engine information (test engine)**

2.1. Engine type designation/engine family designation/FT: .....

2.2. Engine identification number: .....

2.3. Engine Category and subcategory*: NRE-v-1/NRE-v-2/NRE-v-3/NRE-v-4/NRE-v-5/NRE-v-6/NRE-v-7/NRE-c-1/NRE-c-2/NRE-c-3/NRE-c-4/NRE-c-5/NRE-c-6/NRE-c-7/

……
*Strike out what is not applicable.

3. **Documentation and information Check list (primary test only)**

3.1. Engine mapping documentation reference: .....

3.2. Deterioration factor determination documentation reference: .....

3.3. Infrequent regeneration factors determination documentation reference, where applicable: ……

3.4. NO_X control diagnostic demonstration documentation reference, where applicable: .....

3.5. Particulate control diagnostic demonstration documentation reference, where applicable:

3.6. For engine types and engine families that use an ECU as part of the emission control system anti-tampering declaration documentation reference: .....

3.7. For engine types and engine families that use mechanical devices as part of the emission control system anti- tampering and adjustable parameters declaration and demonstration documentation reference: .....

3.8. Manufacturer intends to use ECU torque signal for in-service monitoring: Yes/No

3.8.1. Dynamometer torque greater than or equal to 0.93 × ECU torque: Yes/No

3.8.2. ECU torque correction factor in case that dynamometer torque less than 0.93 × ECU torque: ..

4. **Reference fuel(s) used for test (complete relevant sub- clause(s))**

4.1. Liquid fuel for spark-ignition engines

4.1.1. Make: .....

4.1.2. Type: .....

4.1.3. Octane number RON: .....

4.1.4. Octane number MON: .....

4.1.5. Ethanol content (%): .....

4.1.6. Density at 15 ºC (kg/m3): .....

4.2. Liquid fuel for compression-ignition engines

4.2.1. Make: .....

4.2.2. Type: .....

4.2.3. Cetane number: .....

4.2.4. Fame content (%): .....

4.2.5. Density at 15 ºC (kg/m3): .....

4.3. Gaseous fuel — LPG

4.3.1. Make: .....

4.3.2. Type: .....

4.3.3. Reference fuel type: Fuel A/Fuel B

4.3.4. Octane number MON: .....

4.4. Gaseous fuel- Methane/biomethane

4.4.1. Reference fuel type*: GR/G23/G25/G20

4.4.2. Source of reference gas: specific reference fuel/pipeline gas with admixture

4.4.3. For specific reference fuel

4.4.3.1. Make:.....

4.4.3.2. Type:.....

4.4.4. For pipeline gas with admixture

4.4.4.1. Admixture(s)*: Carbon dioxide/Ethane/Methane/Nitrogen/Propane

4.4.4.2. The value of S_λ for the resulting fuel blend: .....

4.4.4.3. The Methane Number (MN) of the resulting fuel blend:.....

……

*Strike out what is not applicable.

4.5. Dual-fuel engine (in addition to relevant sections above)

4.5.1. Gas energy ratio on test cycle: .....

5. **Lubricant**

5.1. Make(s): .....

5.2. Type(s): .....

5.3. SAE viscosity: .....

5.4. Lubricant and fuel are mixed: yes/no

5.4.1. Percentage of oil in mixture: .....

6. **Engine Speed**

6.1. 100 % speed (rpm): .....

6.1.1. 100 % speed determined by*: Declared rated speed/Declared maximum test speed (MTS)/Measured MTS

6.1.2. Adjusted MTS if applicable (rpm): .....

6.2. Intermediate speed: .....

6.2.1. Intermediate speed determined by: Declared intermediate speed/Measured intermediate speed/60 % of 100 % speed/75 % of 100 % speed/85 % of 100 % speed

6.3. Idle speed: .....

7. **Engine Power**

7.1. Engine driven equipment (if applicable)

7.1.1. Power absorbed at indicated engine speeds by necessary auxiliaries for engine operation that cannot be fitted for the test (as specified by the manufacturer) to be stated in Table 1.

Table 1

Power Absorbed by Engine Auxiliaries

Auxiliary type and identifying details	Power absorbed by auxiliary (kW) at indicated engine speed (complete relevant columns)						
	Idle	63%	80%	91%	Inter-mediate	Max. power	100%
Total ($P_{f,i}$):							

7.1.2. Power absorbed at indicated engine speeds by auxiliaries linked with the operation of the agricultural tractor, construction equipment vehicle or

combine harvester that cannot be removed for the test (as specified by the manufacturer) to be stated in Table 2:

Table 2

Power Absorbed by
Agricultural Tractor, Construction Equipment Vehicle and Combine Harvester Auxiliaries

Auxiliary type and identifying details	Power absorbed by auxiliary (kW) at indicated engine speed (complete relevant columns)						
	Idle	63%	80%	91%	Inter-mediate	Max. power	100%
Total ($P_{r,i}$):							

7.2. Engine gross power to be stated in Table 3:

Table 3
Engine Gross Power

Condition	Engine gross power (kW) at indicated engine speed (complete relevant columns)		
	Intermediate	Max. power	100 %
Reference power measured at specified test speed ($P_{m,i}$)			
Total auxiliary power from Table 1 ($P_{f,i}$)			
Total auxiliary power from Table 2 ($P_{r,i}$)			
Engine gross power $P_i = P_{m,I} – P_{f,i} + P_{r,i}$			

8. CONDITIONS AT TEST

8.1. f_a within range 0.93 to 1.07: Yes/No

8.1.1. If f_a is not within specified range state altitude of test facility and dry atmospheric pressure: ...

8.2. Applicable intake air temperature range*: 20 to 30 °C/– 5 to – 15 °C (snowmobiles only)/ 20 to 35 °C (NRE greater than 560 kW only)

9. INFORMATION CONCERNING THE CONDUCT OF THE NRSC TEST:

9.1. Cycle (mark cycle used with X) to be stated in Table 4:

Table 4
NRSC Test Cycle

Cycle	C1	C2	D2	G1	G2	G3	H
Discrete mode							
RMC						N/A	

9.2. Dynamometer setting (kW) to be stated in Table 5:

Table 5
Dynamometer Setting

% Load at point or % of rated power (as applicable)	Dynamometer setting (kW) at indicated engine speed after adjustment for auxiliary power ([1]) (complete relevant columns)					
	Idle	63%	80%	91%	Intermediate	100%
5%						
10%						
25%						
50%						
75%						
100%						
([1]) The dynamometer setting shall be determined using the procedure set out in clause 7.7.1.3 of Annex 4 to this Part . The auxiliary power in that point shall be determined using the total values set out in Tables 1 and 2 of this Appendix.						

9.3. NRSC Emissions results

9.3.1. Deterioration Factor (DF): calculated/assigned

9.3.2. DF values and the cycle weighted emissions results to be stated in Table 6:

Note: In the event that a discrete mode NRSC is run where the K_{ru} or K_{rd} factors have been established for individual modes then a table showing each mode and the applied K_{ru} or K_{rd} should replace the shown table.

Table 6

NRSC Cycle DF Values and Weighted Emissions Results

	CO	**HC**	**NO_X**	**HC+ NO_X**	**PM**	**PN**
DF mult/add						
Emissions	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X (g/kWh)	PM (g/kWh)	PN #/kWh
Test result with/without regeneration						
k_{ru}/k_{rd} mult/add						
test result with infrequent regeneration adjustment factors (IRAFs)						
Final test result with DF						

9.3.3. Cycle weighted CO_2 (g/kWh):

9.3.4. Cycle average NH_3 (ppm):

9.4. Additional control area test points (if applicable) to be stated in Table 7:

Table 7

Additional Control Area Test Points

Emissions at test point	Engine Speed	Load (%)	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X(g/kWh)	PM (g/kWh)	PN #/kWh
Test result 1								
Test result 2								
Test result 3								

9.5. Sampling systems used for the NRSC test:

9.5.1. Gaseous emissions:

9.5.2. PM:

9.5.2.1. Method: single/multiple filter

9.5.3. Particle number:

10. INFORMATION CONCERNING THE CONDUCT OF THE TRANSIENT TEST (IF APPLICABLE)

10.1. Cycle (mark cycle with X) to be stated in Table 8:

Table 8

Transient Test Cycle

NRTC	
LSI-NRTC	

10.2. Transient test deterioration factors:

10.2.1. Deterioration Factor (DF): calculated/fixed

10.2.2. DF values and the emissions results to be stated in Table 9

10.3 NRTC emission results:

Table 9

DF Values and the Emissions Results for NRTC

	CO	HC	NO_X	HC+ NO_X	PM	PN
DF mult/add						
Emissions	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X(g/kWh)	PM (g/kWh)	PN #/kWh
Cold start						
Hot start test result with/without regeneration						
Weighted test result						
k_{ru}/k_{rd} mult/add						
Weighted test result with IRAFs						
Final test result with DF						

10..3.1. Hot cycle CO_2 (g/kWh):

10.3.2. Cycle average NH_3 (ppm):

10.3.3. Cycle work for hot start test (kWh):

10.3.4. Cycle CO_2 for hot start test (g):

10.4 LSI-NRTC emission results

Table 10

DF Values and the Emissions Results for LSI-NRTC

	CO	**HC**	**NO_X**	**HC+ NO_X**	**PM**	PN
DF mult/add						
Emissions	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X(g/kWh)	PM (g/kWh)	PN #/kWh
test result with/without regeneration						
k_{ru}/k_{rd} mult/add						
Test result with IRAFs						
Final test result with DF						

10.4.1. Cycle CO_2 (g/kWh):

10.4.2. Cycle average NH_3 (ppm):

10.4.3. Cycle work (kWh):

10.4.4. Cycle CO_2 (g):

10.5. Sampling system used for the transient test

10.5.1. Gaseous emissions:

10.5.2. PM:

10.5.3. Particle number:

11. FINAL EMISSIONS RESULTS

11.1 Cycle emissions results to be stated in Table 11.

Table 11

Final Emissions Results

Emissions	CO (g/kWh)	HC (g/kWh)	NO_X (g/kWh)	HC+ NO_X (g/kWh)	PM (g/kWh)	PN #/kWh	Test Cycle(1)
NRSC final test result with DF(2).							
Final transient test result with DF(3)							

11.2 CO_2 result(4):

11.3. Reference values in case the contracting party requires to conduct in-service monitoring tests

11.3.1. NRTC reference work (kWh)(5):

11.3.2. NRTC reference CO2 (g)(6):

Explanatory notes to the test report template

(Footnote markers, footnotes and explanatory notes not to be stated on the test report)

(1) For NRSC note the cycle indicated in clause 9.1.; for transient test note cycle indicated in clause 10.1.

(2) Copy the results from Table 6

(3) Copy the results from Table 9 or 10, as applicable

(4) For an engine type or engine family that is tested on both the NRSC and a transient cycle , indicate the hot cycle CO_2 emissions values from the NRTC noted in clause 10.2.3. or the CO_2 emissions values from the LSI-NRTC noted in clause 10.3.3.. For an engine only tested on an NRSC indicate the CO_2 emissions values given in that cycle from clause 9.3.3..

(5) Where engine is tested on NRTC record value from 10.3.3., otherwise leave blank

(6) Where engine is tested on NRTC record value from 10.3.4., otherwise leave blank

ANNEX 3

LABELLING REQUIREMENTS

1. The engine must be affixed with a conformance label meeting the following requirements.
    a. The label shall be durable and legible
    b. The label shall be affixed on a part necessary for normal operation of the engine and not normally requiring replacement during the life of the engine.
    c. Name and location of the engine manufacturer from where engine is manufactured
    d. Type Approval Test Report number.
    e. Engine Unique Identification Number (Serial Number, etc..)
    f. Engine family and Power band or Power
    g. Month and year of manufacturing
    h. All the above information mentioned in the conformance label must be in English language

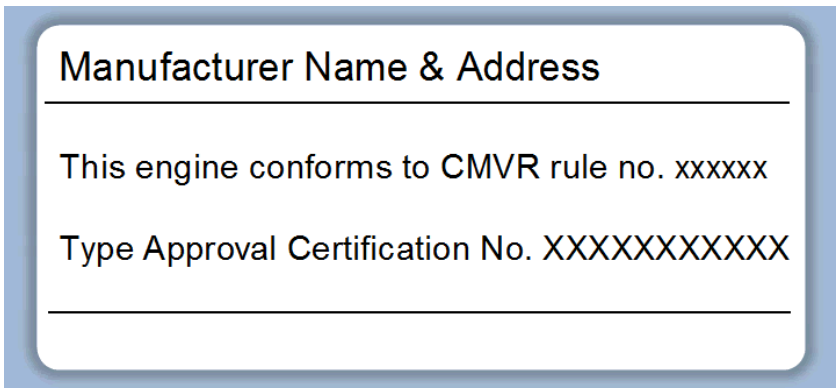
Notes :

For (b), Plant location shall be mentioned either in through CODE via Engine Serial Number or mentioned explicitly in Emission data label. The same shall be mentioned in AIS-007.

Engine Serial Number shall be mentioned in emission label or punched in Engine block as per Manufacturer choices and agree with Test Agency

Power band or Power based on Manufacturer's choice shall be declared in emission label

Manufacturers may choose to mention Month and Year separately in emission label or will have Month and Year as part of Engine Serial Number/Bar Codes.



ANNEX 4

TEST PROCEDURE

1. INTRODUCTION

This Annex describes the method of determining emissions of gaseous and particulate pollutants from the engine to be tested and the specifications related to the measurement equipment.

2. GENERAL OVERVIEW

2.1 This Annex contains the technical provisions needed for conducting an emissions test.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1. Definitions

See clause 2.1. of this Part

3.2. General symbols[1]

Symbol	Unit	Term
a_0	-	*y* intercept of the regression line
a_1	-	Slope of the regression line
α_{sp}	rad/s^2	Derivative of the engine speed at the set point
A/F_{st}	-	Stoichiometric air to fuel ratio
c	ppm, per cent vol	Concentration (also in µmol/mol = ppm)
D	-	Dilution factor
d	m	Diameter
E	per cent	Conversion efficiency
e	g/kWh	Brake specific basis
e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	g/kWh	Specific emission of particulates
e_w	g/kWh	Weighted specific emission
F		F-test statistics

[1] Specific symbols are found in annexes.

Symbol	Unit	Term
F	-	Frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs
f_a	-	Laboratory atmospheric factor
k_r	-	Multiplicative regeneration factor
k_{Dr}	-	downward adjustment factor
k_{Ur}	-	upward adjustment factor
λ	-	Excess air ratio
L	-	Per cent torque
M_a	g/mol	Molar mass of the intake air
M_e	g/mol	Molar mass of the exhaust
M_{gas}	g/mol	Molar mass of gaseous components
m	kg	Mass
m_{gas}	g	Mass of gaseous emissions over the test cycle
m_{PM}	g	Mass of particulate emissions over the test cycle
n	min^{-1}	Engine rotational speed
n_{hi}	min^{-1}	High engine speed
n_{lo}	min^{-1}	Low engine speed
P	kW	Power
P_{max}	kW	Maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer)
P_{AUX}	kW	Declared total power absorbed by auxiliaries fitted for the test
p	kPa	Pressure
p_a	kPa	Dry atmospheric pressure
PF	per cent	Penetration fraction
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mdw}	kg/s	Dilution air mass flow rate on wet basis
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis

Symbol	Unit	Term
q_{mf}	kg/s	Fuel mass flow rate
q_{mp}	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_V	m³/s	Volume flow rate
RF	-	Response factor
r_d	-	Dilution ratio
r^2	-	Coefficient of determination
ρ	kg/m³	Density
σ	-	Standard deviation
S	kW	Dynamometer setting
SEE	-	Standard error of estimate of y on x
T	°C	Temperature
T_a	K	Absolute temperature
T	N·m	Engine torque
T_{sp}	N·m	Demanded torque with "sp" set point
u	-	Ratio between densities of gas component and exhaust gas
t	s	Time
Δt	s	Time interval
t_{10}	s	Time between step input and 10 per cent of final reading
t_{50}	s	Time between step input and 50 per cent of final reading
t_{90}	s	Time between step input and 90 per cent of final reading
V	m³	Volume
W	kWh	Work
y		Generic variable
$\overline{y}$		Arithmetic mean

3.3. Subscripts

abs	Absolute quantity

act	Actual quantity
air	Air quantity
amb	Ambient quantity
atm	Atmospheric quantity
cor	Corrected quantity
CFV	Critical flow venturi
denorm	DeNormalised quantity
dry	Dry quantity
exp	Expected quantity
filter	PM sample filter
i	Instantaneous measurement (e.g. 1 Hz)
i	An individual of a series
idle	Condition at idle
in	Quantity in
leak	Leak quantity
max	Maximum (peak) value
meas	Measured quantity
min	Minimum value
mix	Molar mass of air
out	Quantity out
PDP	Positive displacement pump
ref	Reference quantity
SSV	Subsonic venturi
total	Total quantity
uncor	Uncorrected quantity
vac	Vacuum quantity
weight	Calibration weight
wet	Wet quantity

3.4. Symbols and abbreviations for the chemical components (used also as a subscript)

See clause 2.2.2. of this Part.

3.5. Abbreviations

See clause 2.2.2. of this Part.

4. GENERAL REQUIREMENTS

The engines to be tested shall meet the performance requirements set out in clause 5 when tested in accordance with the test conditions of clause 6. and the test procedure of clause 7.

5. PERFORMANCE REQUIREMENTS

5.1. General requirements

5.1.1. Reserved

5.1.2. Emissions of gaseous and particulate pollutants

The pollutants are represented by:

(a) Oxides of nitrogen, NO_X;

(b) Hydrocarbons, which are expressed as total hydrocarbons, HC (or THC);

(c) Particulate matter, PM;

(d) Particle number, PN.

(e) Carbon monoxide, CO.

The measured values of gaseous and particulate matter pollutants exhausted by the engine refer to the brake-specific emissions in grams per kilowatt-hour (g/kWh), while for particulate number the measured values refers to the brake-specific emissions in number of particles per kilowatt-hour (#/kWh). Other system of units may be used with appropriate conversion.

The gaseous and particulate pollutants that shall be measured are those for which limit values are applicable to the engine sub-category being tested as set out in Appendix 1 to clause 5 of this Part.

The results determined as set out in clause 5.1 of this Part shall not exceed the applicable limit values.

The CO_2 emission values shall be measured and reported for all engine sub-categories.

The mean emission of ammonia (NH_3) shall additionally be measured, as required in accordance with clause 3.4. of Annex 9, when the NO_X control measures that are part of the engine emission control system, include use of a reagent and shall not exceed the values set out in that clause.

The emissions shall be determined on the duty cycles (steady-state and/or transient), as described in clause 7 of this Annex. The measurement systems shall meet the calibration and performance checks set out in clause 8 of this Annex. with the measurement equipment described in clause 9 of this Annex.

Other systems or analysers may be approved by the Test Agency if it is found that they yield equivalent results in accordance with clause 5.1.3 of this Annex.

5.1.3. Equivalency

The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the systems of this annex.

"Results" refer to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics as described in Annex 5, Appendix A.3. obtained under the laboratory test cell and the engine conditions described above. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. The systems to be used for correlation testing shall be subject to the approval by the Test Agency.

5.2. General requirements on the test cycles

5.2.1. The type-approval test shall be conducted using the appropriate non-road steady cycle (NRSC) and, where applicable, non-road transient cycle (NRTC or LSI-NRTC), specified in Appendix A.6. of this Annex.

5.2.2. The technical specifications and characteristics of the NRSC cycles are set out in Appendix A.6.. At the choice of the manufacturer, a NRSC steady-state test may be run as a discrete-mode cycle or, where available, as a ramped-modal cycle (RMC) as set out in clause 7.4.1..

5.2.3. The technical specifications and characteristics of the NRTC and LSI-NRTC cycles are set out in Appendix A.6. of this Annex.

5.2.4. The test cycles specified in clause 7.4. and in Appendix A.6. of this Annex are designed around percentages of maximum torque or power and test speeds that need to be determined for the correct performance of the test cycles:

(a) 100 per cent speed (maximum test speed (MTS) or rated speed)

(b) Intermediate speed(s) as specified in clause 5.2.5.4;

(c) Idle speed, as specified in clause 5.2.5.5..

The determination of the test speeds is set out in clause 5.2.5., the use of torque and power in clause 5.2.6..

5.2.5. Test speeds

5.2.5.1 Maximum test speed (MTS)

The MTS shall be calculated in accordance with clause 5.2.5.1.1. or par clause 5.2.5.1.3..

5.2.5.1.1. Calculation of MTS

In order to calculate the MTS the transient mapping procedure shall be performed in accordance with clause 7.4.. The MTS is then determined from the mapped values of engine speed versus power. MTS shall be calculated by means of one of the following options:

(a) Calculation based upon low speed and high speed values

$$MTS = n_{lo} + 0.95 \cdot (n_{hi} - n_{lo}) \quad \text{(A.4-1)}$$

where:

n_{hi} is the high speed as defined in clause 2.1.39.,

n_{lo} is the low speed as defined in clause 2.1.46.,

(b) Calculation based upon the longest vector method

$$MTS = n_i \quad \text{(A.4-2)}$$

with:

n_i is the average of the lowest and highest speeds at which ($n^2_{normi} + P^2_{normi}$) is equal to 98 per cent of the maximum value of ($n^2_{normi} + P^2_{normi}$)

If there is only one speed at which the value of ($n^2_{normi} + P^2_{normi}$) is equal to 98 per cent of the maximum value of ($n^2_{normi} + P^2_{normi}$):

$$MTS = n_i \quad \text{(A.4-3)}$$

with:

n_i is the speed at which the maximum value of ($n^2_{normi} + P^2_{normi}$) occurs.

where:

n is the engine speed

i is an indexing variable that represents one recorded value of an engine map

n_{normi} is an engine speed Normalised by dividing it by n_{Pmax}

$Pnorm_i$ is an engine power normalised by dividing it by P_{max}

n_{Pmax} is the average of the lowest and highest speeds at which power is equal to 98 per cent of Pmax.

Linear interpolation shall be used between the mapped values to determine:

(i) the speeds where power is equal to 98 per cent of P_{max}. If there is only one speed at which power is equal to 98 per cent of P_{max}, n_{Pmax} shall be the speed at which P_{max} occurs;

(ii) the speeds where ($n^2_{normi} + P^2_{normi}$) is equal to 98 per cent of the maximum value of ($n^2_{normi} + P^2_{normi}$).

5.2.5.1.2. Use of a declared MTS

If the MTS calculated in accordance with clause 5.2.5.1.1. or 5.2.5.1.3. is within ± 3 per cent of the MTS declared by the manufacturer, the declared MTS may be used for the emissions test. If the tolerance is exceeded, the measured MTS shall be used for the emissions test.

5.2.5.1.3. Use of an adjusted MTS

If the falling part of the full load curve has a very steep edge, this may cause problems to drive the 105 per cent speeds of the NRTC test cycle correctly. In this case it is allowed, with prior agreement of the Test Agency, to use an alternative value of MTS determined using one of the following methods:

(a) the MTS may be slightly reduced (maximum 3 %) in order to make correct driving of the NRTC possible.

(b) Calculate an alternative MTS by means of equation (A.4-4):

$$MTS = ((n_{max} - n_{idle})/1.05) + n_{idle} \quad \text{(A.4-4)}$$

where:

n_{max} = is the engine speed at which the engine governor function controls engine speed with operator demand at maximum and with zero load applied ("maximum no-load speed")

n_{idle} = is the idle speed

5.2.5.2. Rated speed

The rated speed is defined in clause 2.1.68 of this Part. Rated speed for variable speed engines subject to an emission test other than those tested on a constant-speed NRSC defined in clause 2.1.11 of this Part. shall be determined

from the applicable mapping procedure set out in clause 7.6. Rated speed for variable-speed engines tested on a constant-speed NRSC shall be declared by the manufacturer according to the characteristics of the engine. Rated speed for constant speed engines shall be declared by the manufacturer according to the characteristics of the governor. Where an engine type equipped with alternative speeds as permitted by clause 2.1.10 of this Part is subject to an emission test, each alternative speed shall be declared and tested.

If the rated speed determined from the mapping procedure in clause 7.6. is within ± 150 rpm of the value declared by the manufacturer for engines of category NRS provided with governor, or within ± 350 rpm or ± 4 per cent for engines of category NRS without governor, whichever is smaller, or within ± 100 rpm for all other engine categories, the declared value may be used. If the tolerance is exceeded, the rated speed determined from the mapping procedure shall be used.

For engines of category NRSh the 100 % test speed shall be within ± 350 rpm of the rated speed declared by the manufacturer.

Optionally, MTS may be used instead of rated speed for any steady state test cycle.

5.2.5.3. Maximum torque speed for variable speed engines

Where required, the maximum torque speed determined from the maximum torque curve established from the applicable engine mapping procedure in clause 7.6.1 or 7.6.2. shall be one of the following:

(a) The speed at which the highest torque was recorded; or,

(b) The average of the lowest and highest speeds at which the torque is equal to 98 per cent of the maximum torque. Where necessary, linear interpolation shall be used to determine the speeds at which the torque is equal to 98 per cent of the maximum torque.

If the maximum torque speed determined from the maximum torque curve is within ± 4 per cent of the maximum torque speed declared by the manufacturer for engines of category NRS or ± 2,5 per cent of the maximum torque speed declared by the manufacturer for all other engine categories, the declared value may be used for the purpose of this Part. If the tolerance is exceeded, the maximum torque speed determined from the maximum torque curve shall be used.

5.2.5.4. Intermediate speed

The intermediate speed shall meet one of the following requirements:

(a) For engines that are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the maximum torque speed if it occurs between 60 per cent and 75 per cent of rated speed;

(b) If the maximum torque speed is less than 60 per cent of rated speed, then the intermediate speed shall be 60 per cent of the rated speed;

(c) If the maximum torque speed is greater than 75 per cent of the rated speed then the intermediate speed shall be 75 per cent of rated speed. Where the engine is only capable of operation at speeds higher than 75 per cent of rated speed the intermediate speed shall be the lowest speed at which the engine can be operated;

(d) For engines that are not designed to operate over a speed range on a full-load torque curve at steady-state conditions, the intermediate speed shall be between 60 per cent and 70 per cent of the rated speed.

(e) For engines to be tested on cycle G1, except for engines of category ATS, the intermediate speed shall be 85 per cent of the rated speed.

(f) For engines of category ATS tested on cycle G1 the intermediate speed shall be 60 per cent or 85 per cent of rated speed based on which is closer to the actual maximum torque speed.

Where the MTS is used in place of rated speed for the 100% test speed, MTS shall also replace rated speed when determining the intermediate speed.

5.2.5.5. Idle speed

The idle speed is the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine.

5.2.5.6. Test speed for constant speed engines

The governors of constant speed engines may not always maintain speed exactly constant. Typically speed can decrease (0.1 to 10) per cent below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power. The test speed for constant speed engines may be commanded by using the governor installed on the engine or using a test-bed speed demand where this represents the engine governor.

Where the governor installed on the engine is used, the 100 per cent speed shall be the engine governed speed as defined in clause 2.1.27 of this Part.

Where a test-bed speed demand signal is used to simulate the governor, the 100 per cent speed at zero load shall be the no-load speed specified by the manufacturer for that governor setting and the 100 per cent speed at full load shall be the rated speed for that governor setting. Interpolation shall be used to determine the speed for the other test modes.

Where the governor has an isochronous operation setting, or the nominal rated speed and no-load speed declared by the manufacturer differ by no more than 3 per cent, a single value declared by the manufacturer may be used for the 100 per cent speed at all load points.

5.2.6. Torque

5.2.6.1. The torque figures given in the test cycles are percentage values that represent, for a given test mode, one of the following:

(a) The ratio of the required torque to the maximum possible torque at the specified test speed (all cycles except D2);

(b) The ratio of the required torque to the torque corresponding to the rated gross power declared by the manufacturer (cycle D2).

6. TEST CONDITIONS

6.1. Laboratory test conditions

The absolute temperature (T_a) of the engine air at the inlet to the engine expressed in Kelvin, and the dry atmospheric pressure (ps), expressed in kPa shall be measured and the parameter f_a shall be determined in accordance with the following provisions and by means of equation (A.4-5) or (A.4-6). If the atmospheric pressure is measured in a duct, negligible pressure losses shall be ensured between the atmosphere and the measurement location, and changes in the duct's static pressure resulting from the flow shall be accounted for. In multi-cylinder engines having distinct groups of intake manifolds, such as in a "V" engine configuration, the average temperature of the distinct groups shall be taken. The parameter fa shall be reported with the test results.

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \cdot \left(\frac{T_a}{298}\right)^{0.7} \qquad \text{(A.4-5)}$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \cdot \left(\frac{T_a}{298}\right)^{1.5} \qquad \text{(A.4-6)}$$

6.1.1. For the test to be considered valid both the following conditions must be met:

(a) f_a shall be within the range $0.93 \leq f_a \leq 1.07$ except as permitted by clause s 6.1.2. and 6.1.4.;

(b) The temperature of intake air shall be maintained to 298 ± 5 K (25 ± 5°C), measured upstream of any engine component, except as permitted by clauses 6.1.3. and 6.1.4., and as required by clauses 6.1.5. and 6.1.6..

6.1.2. Where the altitude of the laboratory in which the engine is being tested exceeds 600 m, with the agreement of the manufacturer, f_a may exceed 1.07 on the condition that p_s shall not be less than 80 kPa.

6.1.3. Where the power of the engine being tested is greater than 560 kW, with the agreement of the manufacturer the maximum value of intake air temperature may exceed 303 K (30°C) on condition that it shall not exceed 308 K (35°C).

6.1.4. Where the altitude of the laboratory in which the engine is being tested exceeds 300 m and the power of the engine being tested is greater than 560 kW, with the agreement of the manufacturer f_a may exceed 1.07 on the condition that p_s shall not be less than 80 kPa and the maximum value of intake air temperature

may exceed 303 K (30°C) on the condition that it shall not exceed 308 K (35°C).

6.1.5. Reserved

6.1.6. Reserved

6.1.6.1. Reserved

6.1.7. It is allowed to use:

(a) an atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell, as long as the equipment for handling intake air maintains ambient pressure, where the engine is tested, within ±1 kPa of the shared atmospheric pressure;

(b) a humidity measurement device to measure the humidity of intake air for an entire test facility that has more than one dynamometer test cell, as long as the equipment for handling intake air maintains dew point, where the engine is tested, within ± 0.5 K of the shared humidity measurement.

6.2. Engines with charge air cooling

(a) A charge-air cooling system with a total intake-air capacity that represents production engines' in-use installation shall be used. Any laboratory charge-air cooling system to minimise accumulation of condensate shall be designed. Any accumulated condensate shall be drained and all drains shall be completely closed before emission testing. The drains shall be kept closed during the emission test. Coolant conditions shall be maintained as follows:

(i) A coolant temperature of at least 293 K (20 °C) shall be maintained at the inlet to the charge-air cooler throughout testing;

(ii) At the rated speed and full load, the coolant flow rate shall be set to achieve an air temperature within ±5 K of the value designed by the manufacturer after the charge-air cooler's outlet. The air-outlet temperature shall be measured at the location specified by the manufacturer. This coolant flow rate set point shall be used throughout testing. If the engine manufacturer does not specify engine conditions or the corresponding charge-air cooler air outlet temperature, the coolant flow rate shall be set at maximum engine power to achieve a charge-air cooler air outlet temperature that represents in-use operation;

(iii) If the engine manufacturer specifies pressure-drop limits across the charge-air cooling system, it shall be ensured that the pressure drop across the charge-air cooling system at engine conditions specified by the manufacturer is within the manufacturer's specified limit(s). The pressure drop shall be measured at the manufacturer's specified locations;

(b) When the MTS defined in clause 5.2.5.1. is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the charge air temperature.

(c) The objective is to produce emission results that are representative of in-use operation. If good engineering judgment indicates that the specifications in this clause would result in unrepresentative testing (such as overcooling of the intake air), more sophisticated set points and controls of charge-air pressure drop, coolant temperature, and flow rate may be used to achieve more representative results.

6.3. Engine power

6.3.1. Basis for emission measurement

The basis of specific emissions measurement is uncorrected gross power as defined in clause 2.1.52. of this Part.

6.3.2. Auxiliaries to be fitted

During the test, the auxiliaries necessary for the engine operation shall be installed on the test bench according to the requirements of Appendix A.2.

Where the necessary auxiliaries cannot be fitted for the test, the power they absorb shall be determined and subtracted from the measured engine power.

6.3.3. Auxiliaries to be removed

Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test.

Where auxiliaries cannot be removed, the power they absorb in the unloaded condition may be determined and added to the measured engine power (see note g in the table of Appendix A.2). If this value is greater than 3 per cent of the maximum power at the test speed it may be verified by the Test Agency. The power absorbed by auxiliaries shall be used to adjust the set values and to calculate the work produced by the engine over the test cycle in accordance with clause 7.7.1.3. or 7.7.2.3.(b) of this Annex.

6.3.4. Determination of auxiliary power

Where applicable, the values of auxiliary power and the measurement/calculation method for determining auxiliary power shall be submitted by the engine manufacturer for the whole operating area of the applicable test cycles, and approved by the Test Agency.

6.3.5 Engine cycle work

The calculation of reference and actual cycle work (see clause 7.8.3.4.) shall be based upon engine power in accordance with clause 6.3.1. In this case, P_f and P_r of equation (A.4-7) are zero, and P equals P_m.

If auxiliaries/equipment are installed in accordance with clauses 6.3.2. and/or 6.3.3., the power absorbed by them shall be used to correct each instantaneous cycle power value $P_{m,i}$, by means of equation (A.4-8):

$$P_i = P_{m,i} - P_{f,i} + P_{r,i} \qquad \text{(A.4-7)}$$

$$P_{AUX} = P_{r,i} - P_{f,i} \quad \text{(A.4-8)}$$

Where:

$P_{m,i}$ is the measured engine power, kW

$P_{f,i}$ is the power absorbed by auxiliaries/equipment to be fitted for the test but that were not installed, kW

$P_{r,i}$ is the power absorbed by auxiliaries/equipment to be removed for the test but that were installed, kW.

6.4. Engine intake air

6.4.1. Introduction

The intake-air system installed on the engine or one that represents a typical in-use configuration shall be used. This includes the charge-air cooling and exhaust gas recirculation systems.

6.4.2. Intake air pressure restriction

An engine air intake system or a test laboratory system shall be used presenting an intake air pressure restriction within ±300 Pa of the maximum value specified by the manufacturer for a clean air cleaner at the rated speed and full load. Where this is not possible due to the design of the test laboratory air supply system a pressure restriction not exceeding the value specified by the manufacturer for a dirty filter shall be permitted subject to prior approval of the Test Agency. The static differential pressure of the restriction shall be measured at the location and at the speed and torque set points specified by the manufacturer. If the manufacturer does not specify a location, this pressure shall be measured upstream of any turbocharger or exhaust gas recirculation system connection to the intake air system. When the MTS defined in clause 5.2.5.1. is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the intake air pressure restriction.

6.5. Engine exhaust system

The exhaust system installed with the engine or one that represents a typical in-use configuration shall be used. The exhaust system shall conform to the requirements for exhaust emissionssampling, as set out in clause 9.3. An engine exhaust system or a test laboratory system shall be used presenting a static exhaust gas backpressure within 80 to 100 per cent of the maximum exhaust gas pressure restriction at the rated speed and full load. The exhaust gas pressure restriction may be set using a valve. If the maximum exhaust gas pressure restriction is 5 kPa or less, the set point shall not be more than 1.0 kPa from the maximum. When the MTS is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the exhaust gas pressure restriction.

6.6. Engine with exhaust after-treatment system

If the engine is equipped with an exhaust after-treatment system that is not mounted directly on the engine, the exhaust pipe shall have the same diameter as found in-use for at least four pipe diameters upstream of the expansion

section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment system shall be the same as in the agricultural tractor, construction equipment vehicle, or combine harvester configuration or within the distance specifications of the manufacturer. Where specified by the manufacturer the pipe shall be insulated to achieve an after-treatment inlet temperature within the specification of the manufacturer. Where other installation requirements are specified by the manufacturer these shall also be respected for the test configuration. The exhaust system back-pressure or pressure restriction shall be set according to clause 6.5.. For exhaust after-treatment devices with variable exhaust gas pressure restriction, the maximum exhaust gas pressure restriction used in clause 6.5. is defined at the after-treatment condition (degreening/ageing and regeneration/loading level) specified by the manufacturer. The after-treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

The emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with an exhaust after-treatment system that requires the consumption of a reagent, the reagent used for all tests shall be declared by the manufacturer.

For engines equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis, as described in clause 6.6.2., emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs. After-treatment systems with a regeneration process that occurs either in a sustained manner or at least once over the applicable transient test cycle or ramped-modal cycle ("continuous regeneration") in accordance with clause 6.6.1. do not require a special test procedure.

6.6.1. Continuous regeneration

For an exhaust after-treatment system based on a continuous regeneration process the emissions shall be measured on an after-treatment system that has been stabilised so as to result in repeatable emissions behaviour. The regeneration process shall occur at least once during the NRTC hot start test, LSI-NRTC or NRSC test, and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust system back-pressure, etc.). In order to demonstrate that the regeneration process is continuous, at least three NRTC hot start tests, LSI-NRTC or NRSC tests shall be conducted. In case of NRTC hot start test, the engine shall be warmed up in accordance with clause 7.8.2.1., the engine shall be soaked according to clause 7.4.2.1.(b) and the first NRTC hot start test shall be run.

The subsequent NRTC hot start tests shall be started after soaking according with clause 7.4.2.1.(b). During the tests, exhaust gas temperatures and pressures shall be recorded (temperature before and after the after-treatment system, exhaust system back-pressure, etc.). The after-treatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test within a sufficient time and the emission results do not scatter by more than ± 25 per cent from the mean value or 0.005 g/kWh, whichever is greater.

6.6.2. Infrequent regeneration

This provision only applies to engines equipped with an exhaust after-treatment system that is regenerated on an infrequent basis, typically occurring in less than 100 hours of normal engine operation. For those engines, either additive or multiplicative factors shall be determined for upward and downward adjustment as referred to in clause 6.6.2.4. ("adjustment factor").

Testing and development of adjustment factors is only required for one applicable transient (NRTC or LSI-NRTC) or RMC NRSC test cycle. The factors that have been developed may be applied to results from the other applicable test cycles including discrete-mode NRSC.

In case that no suitable adjustment factors are available from testing using transient or RMC NRSC test cycles then adjustment factors shall be established using an applicable discrete-mode test. Factors developed using a discrete-mode test cycle shall only be applied to discrete-mode test cycles.

It shall not be required to conduct testing and develop adjustment factors on both RMC and discrete-mode NRSCs.

6.6.2.1. Requirement for establishing adjustment factors using NRTC, LSI-NRTC or RMC NRSC testing

The emissions shall be measured on at least three NRTC hot start tests, LSI-NRTC or ramped-modal cycle (RMC) NRSC tests, one with and two without a regeneration event on a stabilised after-treatment system. The regeneration process shall occur at least once during the NRTC, LSI-NRTC or RMC NRSC test with a regeneration event. If regeneration takes longer than one NRTC, LSI-NRTC or RMC NRSC test, consecutive NRTC, LSI-NRTC or RMC NRSC tests shall be run and emissions continued to be measured without shutting the engine off until regeneration is completed and the average of the tests shall be calculated. If regeneration is completed during any test, the test shall be continued over its entire length.

An appropriate adjustment factor shall be determined for the entire applicable cycle by means of equations (A.4-10) to (A.4-13).

6.6.2.2. Requirement for establishing adjustment factors using discrete-mode NRSC testing

Starting with a stabilised after-treatment system the emissions shall be measured on at least three runs of each test mode of the applicable discrete-mode NRSC on which the conditions for regeneration can be met, one with and two without a regeneration event. The measurement of PM shall be conducted using the multiple filter method described in clause 7.8.1.2.(c). If regeneration has started but is not complete at the end of the sampling period for a specific test mode extend the sampling period shall be extended until regeneration is complete. Where there are multiple runs for the same mode an average result shall be calculated. The process shall be repeated for each test mode.

An appropriate adjustment factor shall be determined by means of equations (A.4-10) to (A.4-13) for those modes of the applicable cycle for which regeneration occurs.

6.6.2.3. General procedure for developing infrequent regeneration adjustment factors (IRAFs)

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust system back-pressure, etc.). The manufacturer shall also provide the frequency of the regeneration event in terms of number of tests during which the regeneration occurs. The exact procedure to determine this frequency shall be agreed by the Test Agency based upon good engineering judgement.

For a regeneration test, the manufacturer shall provide an after-treatment system that has been loaded. Regeneration shall not occur during this engine conditioning phase. As an option, the manufacturer may run consecutive tests of the applicable cycle until the after-treatment system is loaded. Emissions measurement is not required on all tests.

Average emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant tests of the applicable cycle. As a minimum, at least one applicable cycle as close as possible prior to a regeneration test and one applicable cycle immediately after a regeneration test shall be conducted.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO_X emissions, temperature before and after the after-treatment system, exhaust system back-pressure, etc.). During the regeneration process, the applicable emission limits may be exceeded. The test procedure is schematically shown in Figure A.4-1.

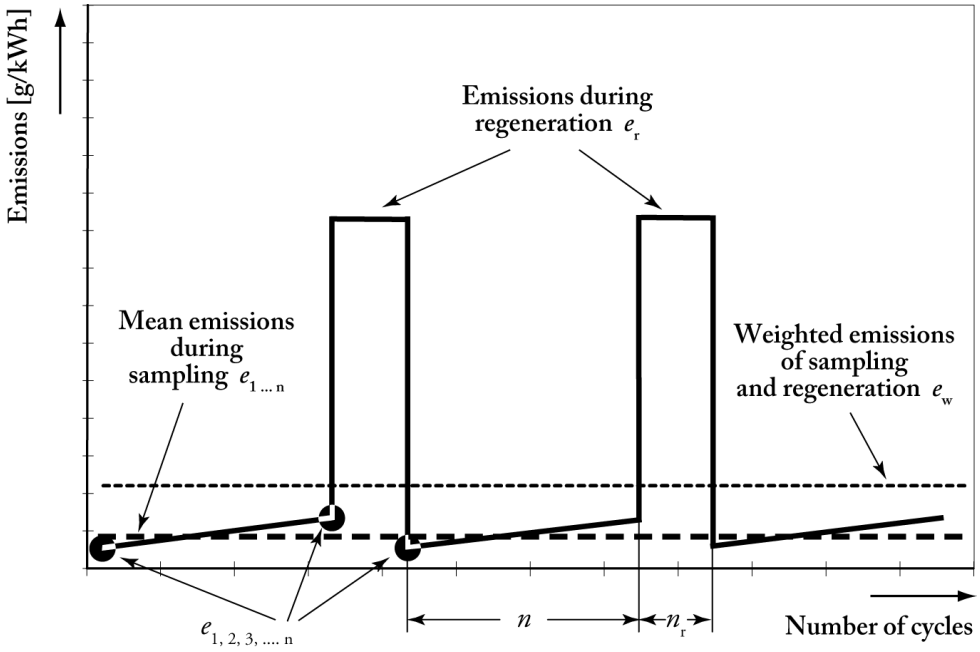


Figure A.4-1.

Scheme of Infrequent Regeneration with *N* Number of Measurements and N_r Number of Measurements During Regeneration

The average specific emission rate related to the test runs conducted according to clauses 6.6.2.1. or 6.6.2.2. [g/kWh or #/kWh] shall be weighted by means of equation (A.4-9) (see Figure 1.):

$$\bar{e}_w = \frac{n \cdot \bar{e} + n_r \cdot \bar{e}_r}{n + n_r} \qquad \text{(A.4-9)}$$

where:

n = number of tests in which regeneration does not occur,

n_r = number of tests in which regeneration occurs (minimum one test),

$\bar{e}$ = average specific emission from a test in which the regeneration does not occur [g/kWh or #/kWh]

$\bar{e}_r$ = average specific emission from a test in which the regeneration occurs [g/kWh or #/kWh]

At the choice of the manufacturer and based on good engineering judgment, the regeneration adjustment factor k_r, expressing the average emission rate, may be calculated either multiplicative or additive for all

gaseous pollutants, and, where there is an applicable limit, for PM and PN, by means of equations (A.4-10) to (A.4-13):

Multiplicative

$$k_{ru,m} = \frac{\bar{e}_w}{\bar{e}} \quad \text{(upward adjustment factor)} \quad \text{(A.4-10)}$$

$$k_{rd,m} = \frac{\bar{e}_w}{\bar{e}_r} \quad \text{(downward adjustment factor)} \quad \text{(A.4-11)}$$

Additive

$$k_{ru,a} = \bar{e}_w - \bar{e} \quad \text{(upward adjustment factor)} \quad \text{(A.4-12)}$$

$$k_{rd,a} = \bar{e}_w - \bar{e}_r \quad \text{(downward adjustment factor)} \quad \text{(A.4-13)}$$

6.6.2.4. Application of adjustment factors

Upward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration does not occur. Downward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration occurs. The occurrence of the regeneration shall be identified in a manner that is readily apparent during all testing. Where no regeneration is identified, the upward adjustment factor shall be applied.

With reference to Annex 5, Appendices A.1 and A.2 on brake specific emission calculations, the regeneration adjustment factor:

(a) When established for an entire weighted cycle, shall be applied to the results of the applicable weighted NRTC, LSI-NRTC and NRSC tests;

(b) When established specifically for the individual modes of the applicable discrete-mode cycle, shall be applied to the results of those modes of the applicable discrete-mode NRSC cycle for which regeneration occurs prior to calculating the cycle weighted emission result. In this case the multiple filter method shall be used for PM measurement;

(c) May be extended to other members of the same engine family;

(d) May be extended to other engine families within the same engine after-treatment system family, as defined in Appendix A.1, with the prior approval of the Test Agency based on technical evidence to be supplied by the manufacturer that the emissions are similar.

The following options shall apply:

(a) A manufacturer may elect to omit adjustment factors for one or more of its engine families (or configurations) because the effect of the regeneration is small, or because it is not practical to identify when regenerations occur. In these cases, no adjustment factor shall be used, and the manufacturer is liable for compliance with the emission limits for all tests, without regard to whether a regeneration occurs;

(b) Upon request by the manufacturer, the Test Agency may account for regeneration events differently than is provided in sub-clause (a).

However, this option only applies for events that occur extremely infrequently, and which cannot be practically addressed using the adjustment factors described in clause 6.6.2.3. of this Annex.

6.7. Cooling system

An engine cooling system with sufficient capacity to maintain the engine, with its intake-air, oil, coolant, block and head temperatures, at normal operating temperatures prescribed by the manufacturer shall be used. Laboratory auxiliary coolers and fans may be used.

6.8. Lubricating oil

The lubricating oil shall be specified by the manufacturer and be representative of lubricating oil available in the market; the specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

6.9. Specification of the reference fuels

The reference fuels are specified in Annex 6.

The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded.

6.10. Crankcase emissions

Crankcase emissions that are discharged directly into the ambient atmosphere shall be added to the exhaust emissions (either physically or mathematically) during all emission testing.

Manufacturers taking advantage of this exception shall install the engines so that all crankcase emission can be routed into the emissions sampling system. For the purpose of this clause, crankcase emissions that are routed into the exhaust upstream of exhaust after-treatment during all operation are not considered to be discharged directly into the ambient atmosphere.

Open crankcase emissions shall be routed into the exhaust system for emission measurement, as follows:

(a) The tubing materials shall be smooth-walled, electrically conductive, and not reactive with crankcase emissions. Tube lengths shall be minimised as far as possible;

(b) The number of bends in the laboratory crankcase tubing shall be minimised, and the radius of any unavoidable bend shall be maximized;

(c) The laboratory crankcase exhaust tubing shall meet the engine manufacturer's specifications for crankcase back pressure;

(d) The crankcase exhaust tubing shall connect into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust system before sampling. The crankcase exhaust tube shall extend into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. The

crankcase exhaust tube's outlet may orient in any direction relative to the raw exhaust flow.

7. TEST PROCEDURES

7.1. Introduction

This clause describes the determination of brake specific emissions of gaseous and particulate pollutants on engines to be tested. The test engine shall be the parent engine configuration for the engine family as specified in Annex 10.

A laboratory emission test consists of measuring emissions and other parameters for the test cycles specified in this annex. The following aspects are treated in this Annex 4:

(a) The laboratory configurations for measuring the brake specific emissions (clause 7.2.);

(b) The pre-test and post-test verification procedures (clause 7.3.);

(c) The test cycles (clause 7.4.);

(d) The general test sequence (clause 7.5.);

(e) The engine mapping (clause 7.6.);

(f) The test cycle generation (clause 7.7.);

(g) The specific test cycle running procedure (clause 7.8.).

7.2. Principle of emission measurement

To measure the brake-specific emissions, the engine shall be operated over the test cycles defined in clause 7.4., as applicable. The measurement of brake-specific emissions requires the determination of the mass of pollutants in the exhaust emissions (i.e. HC, CO, NO_X and PM), the number of particulates in the exhaust emissions (i.e. PN), the mass of CO_2 in the exhaust emissions, and the corresponding engine work.

7.2.1. Mass of constituent

The total mass of each constituent shall be determined over the applicable test cycle by using the following methods:

7.2.1.1. Continuous sampling

In continuous sampling, the constituent's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) exhaust flow rate at the emission sampling location to determine the constituent's flow rate. The constituent's emission is continuously summed over the test interval. This sum is the total mass of the emitted constituent.

7.2.1.2. Batch sampling

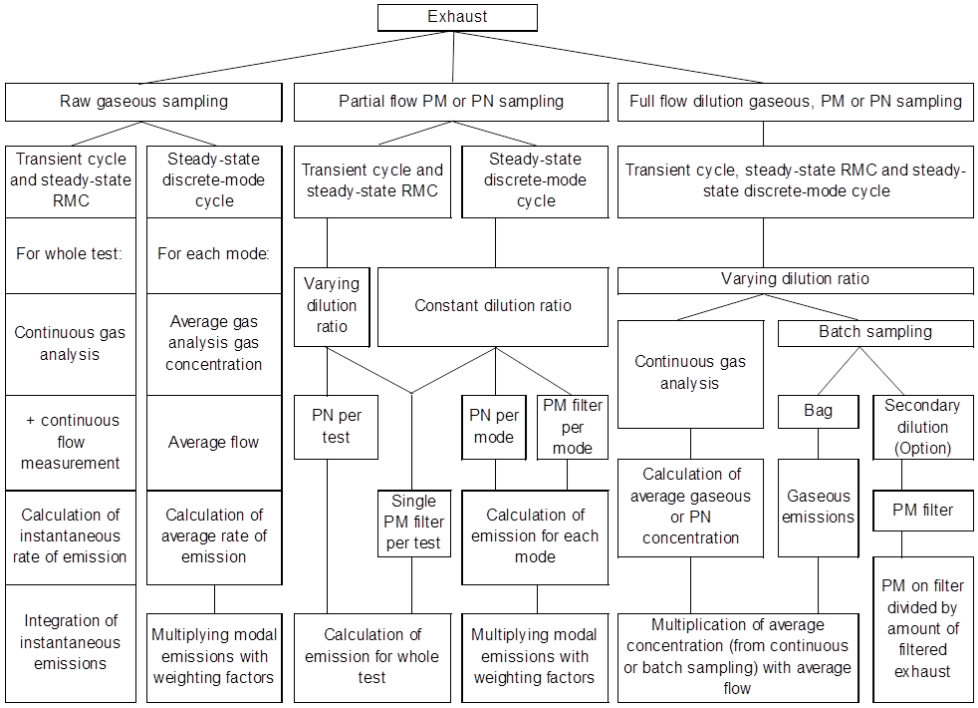
In batch sampling, a sample of raw or diluted exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In

principal the method of emission calculation is done as follows: the batch sampled concentrations are multiplied by the total mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted constituent. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.

7.2.1.3. Combined sampling

Any combination of continuous and batch sampling is permitted (e.g. PM with batch sampling and gaseous emissions with continuous sampling).

The following Figure A.4-2 illustrates the two aspects of the test procedures for measuring emissions: the equipments with the sampling lines in raw and diluted exhaust gas and the operations requested to calculate the pollutant emissions in steady-state and transient test cycles.



Note on Figure 1: The term "Partial flow PM sampling" includes the partial flow dilution to extract only raw exhaust with constant or varying dilution ratio.

Figure A.4-2

Test Procedures for Emission Measurement

7.2.2. Work determination

The work shall be determined over the test cycle by synchronously multiplying speed and brake torque to calculate instantaneous values for engine brake power. Engine brake power shall be integrated over the test cycle to determine total work (see also clause 6.3.5).

7.3. Verification and calibration

7.3.1. Pre-test procedures

7.3.1.1. General requirements for preconditioning the sampling system and the engine

To achieve stable conditions, the sampling system and the engine shall be preconditioned before starting a test sequence as specified in this paragraph.

The intent of engine preconditioning is to manage the representativeness of emissions and emission controls over the duty cycle and to reduce bias in order to meet stable conditions for the following emission test.

Engines fitted with an after-treatment system may be operated prior to cycle-specific preconditioning set out in clauses 7.3.1.1.1 to 7.3.1.1.4 of this Annex, so that the after-treatment system is regenerated and, where applicable, the soot load in the particulate after-treatment system is re-established.

Emissions may be measured during preconditioning cycles, as long as a predefined number of preconditioning cycles are performed and the measurement system has been started according to the requirements of clause 7.3.1.4. of this Annex. The amount of preconditioning shall be identified by the engine manufacturer before starting to precondition. Preconditioning shall be performed as follows, noting that the specific cycles for preconditioning are the same ones that apply for emission testing.

7.3.1.1.1. Preconditioning for cold-start transient cycle (NRTC)

The engine shall be preconditioned by running at least one hot-start transient cycle. Immediately after completing each preconditioning cycle, the engine shall be shut down and the engine-off hot-soak period shall be completed. Immediately after completing the last preconditioning cycle, the engine shall be shut down and the engine cool down described in clause 7.3.1.2. of this Annex shall be started.

7.3.1.1.2. Preconditioning for hot-start transient cycle (hot-start NRTC or LSI-NRTC)

This clause describes the pre-conditioning that shall be applied when it is intended to sample emissions from the hot-start NRTC without running the cold start NRTC, or for the LSI-NRTC. The engine shall be preconditioned by running at least one hot-start NRTC or LSI-NRTC cycle as applicable. Immediately after completing each preconditioning cycle, the engine shall be shut down, and then the next cycle shall be started as soon as practical. It is recommended that the next preconditioning cycle shall be started within 60 seconds after completing the last preconditioning cycle. Where applicable, following the last pre-conditioning cycle the appropriate hot-soak (hot-start NRTC) or cool-down (LSI-NRTC) period shall apply before the engine is started for the emissions test. Where no hot-soak or cool down period applies it is recommended that the emissions test shall be started within 60 seconds after completing the last pre-conditioning cycle.

7.3.1.1.3. Preconditioning for discrete-mode NRSC

For engine categories other than NRS and NRSh the engine shall be warmed-up and run until engine temperatures (cooling water and lube oil) have been stabilised on 50 per cent speed and 50 per cent torque for any discrete-mode NRSC test cycle other than type D2 or G, or nominal engine speed and 50 per

cent torque for any discrete-mode NRSC test cycle D2 or G. The 50 per cent speed shall be calculated in accordance with clause 5.2.5.1. in the case of an engine where MTS is used for the generation of test speeds, and calculated in accordance with clause 7.7.1.3. in all other cases. 50 per cent torque is defined as 50 per cent of the maximum available torque at this speed. The emissions test shall be started without stopping the engine.

For engine categories NRS and NRSh the engine shall be warmed up according to the recommendation of the manufacturer and good engineering judgment. Before emission sampling can start, the engine shall be running on mode 1 of the appropriate test cycle until engine temperatures have been stabilised. The emissions test shall be started without stopping the engine.

7.3.1.1.4. Preconditioning for RMC NRSC

The engine manufacturer shall select one of the following pre-conditioning sequences (a) or (b). The engine shall be pre-conditioned according to the chosen sequence.

(a) The engine shall be preconditioned by running at least the second half of the ramped-modal cycle, based on the number of test modes. The engine shall not be shut down between cycles. Immediately after completing each preconditioning cycle, the next cycle (including the emission test) shall be started as soon as practical. Where possible, it is recommended that the next cycle be started within 60 seconds after completing the last preconditioning cycle.

(b) The engine shall be warmed-up and run until engine temperatures (cooling water and lube oil) have been stabilised on 50 per cent speed and 50 per cent torque for any RMC test cycle other than type D2 or G, or nominal engine speed and 50 per cent torque for any RMC test cycle D2 or G. The 50 per cent speed shall be calculated in accordance with clause 5.2.5.1. of this Annex in the case of an engine where MTS is used for the generation of test speeds, and be calculated in accordance with clause 7.7.1.3. of this Annex in all other cases. 50 per cent torque is defined as 50 per cent of the maximum available torque at this speed.

7.3.1.2. Engine cool down (NRTC)

A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-treatment cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.

7.3.1.3. Verification of HC contamination

If there is any presumption of an essential HC contamination of the exhaust gas measuring system, the contamination with HC may be checked with zero gas and the hang-up may then be corrected. If the amount of contamination of the measuring system and the background HC system has to be checked, it

shall be conducted within 8 hours of starting each test-cycle. The values shall be recorded for later correction. Before this check, the leak check has to be performed and the FID analyser has to be calibrated.

7.3.1.4. Preparation of measurement equipment for sampling

The following steps shall be taken before emission sampling begins:

(a) Leak checks shall be performed within 8 hours prior to emission sampling according to clause 8.1.8.7. below;

(b) For batch sampling, clean storage media shall be connected, such as evacuated bags or tare-weighed filters;

(c) All measurement instruments shall be started according to the instrument manufacturer's instructions and good engineering judgment;

(d) Dilution systems, sample pumps, cooling fans, and the data-collection system shall be started;

(e) The sample flow rates shall be adjusted to desired levels, using bypass flow, if desired;

(f) Heat exchangers in the sampling system shall be pre-heated or pre-cooled to within their operating temperature ranges for a test;

(g) Heated or cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilise at their operating temperatures;

(h) Exhaust dilution system flow shall be switched on at least 10 minutes before a test sequence;

(i) Calibration of gas analysers and zeroing of continuous analysers shall be carried out according to the procedure of the next clause 7.3.1.5. below;

(j) Any electronic integrating devices shall be zeroed or re-zeroed, before the start of any test interval.

7.3.1.5. Calibration of gas analysers

Appropriate gas analyser ranges shall be selected. Emission analysers with automatic or manual range switching are allowed. During a ramped modal or a NRTC test and during a sampling period of a gaseous emission at the end of each mode for discrete mode testing, the range of the emission analysers shall not be switched. Also the gains of an analyser's analogue operational amplifier(s) shall not be switched during a test cycle.

All continuous analysers shall be zeroed and spanned using internationally-traceable gases that meet the specifications of clause 9.5.1. of this Annex FID analysers shall be spanned on a carbon number basis of one (C_1).

7.3.1.6. PM filter preconditioning and tare weighing

The procedures for PM filter preconditioning and tare weighing shall be followed according to clause 8.2.3. of this Annex.

7.3.2. Post-test procedures

The following steps shall be taken after emission sampling is complete:

7.3.2.1. Verification of proportional sampling

For any proportional batch sample, such as a bag sample or PM sample, it shall be verified that proportional sampling was maintained according to clause 8.2.1. For the single filter method and the discrete steady-state test cycle, effective PM weighing factor shall be calculated. Any sample that does not fulfil the requirements of clause 8.2.1. of this Annex shall be voided.

7.3.2.2. Post-test PM conditioning and weighing

Used PM sample filters shall be placed into covered or sealed containers or the filter holders shall be closed, in order to protect the sample filters against ambient contamination. Thus protected, the loaded filters have to be returned to the PM-filter conditioning chamber or room. Then the PM sample filters shall be conditioned and weighted accordingly to clause 8.2.4. of this Annex (PM filter post-conditioning and total weighing procedures).

7.3.2.3. Analysis of gaseous batch sampling

As soon as practical, the following shall be performed:

(a) All batch gas analysers shall be zeroed and spanned no later than 30 minutes after the test cycle is complete or during the soak period if practical to check if gaseous analysers are still stable;

(b) Any conventional gaseous batch samples shall be analysed no later than 30 minutes after the hot-start test cycle is complete or during the soak period;

(c) The background samples shall be analysed no later than 60 minutes after the hot-start test cycle is complete.

7.3.2.4. Drift verification

After quantifying exhaust gases, drift shall be verified as follows:

(a) For batch and continuous gas analysers, the mean analyser value shall be recorded after stabilizing a zero gas to the analyser. Stabilization may include time to purge the analyser of any sample gas, plus any additional time to account for analyser response;

(b) The mean analyser value shall be recorded after stabilizing the span gas to the analyser. Stabilization may include time to purge the analyser of any sample gas, plus any additional time to account for analyser response;

(c) These data shall be used to validate and correct for drift as described in clause 8.2.2. of this Annex.

7.4. Test cycles

The type-approval test shall be conducted using the appropriate non-road steady cycle (NRSC) and, where applicable, non-road transient cycle (NRTC or LSI-NRTC), specified in Appendix A.6 to this Annex. The method for determination of the torque and speed settings for these cycles are laid down in clause 7.7. of this Annex.

7.4.1. Steady-state test cycles

Steady-state test cycles are specified in Appendix A.6 of this Annex as a list of discrete modes (operating points), where each operating point has one value of speed and one value of torque. A steady-state test cycle shall be measured with a warmed up and running engine according to manufacturer's specification. At the choice of the manufacturer, a steady-state test cycle may be run as a discrete-mode cycle or a ramped-modal cycle, as explained in clauses 7.4.1.1. and 7.4.1.2. of this Annex. It shall not be required to conduct an emission test according to both clauses 7.4.1.1. and 7.4.1.2. of this Annex.

7.4.1.1. Steady-state discrete mode test cycles

The steady-state discrete mode test cycles are hot running cycles where emissions shall be started to be measured after the engine is started, warmed up and running as specified in clause 7.8.1.2. of this Annex. Each cycle consists of a number of speed and load modes (with the respective weighing factor for each mode) which cover the typical operating range of the specified engine category.

7.4.1.2. Steady-state ramped test cycles

The ramped modal cycles (RMC) are hot running cycles where emissions shall be started to be measured after the engine is started, warmed up and running as specified in clause 7.8.2.1. of this Annex. The engine shall be continuously controlled by the test bed control unit during the RMC test cycle. The gaseous and particulate emissions shall be measured and sampled continuously during the RMC test cycle in the same way as in a transient cycle.

An RMC is intended to provide a method for performing a steady-state test in a pseudo-transient manner. Each RMC consists of a series of steady state modes with a linear transition between them. The relative total time at each mode and its preceding transition match the weighting of the discrete mode steady state cycles. The change in engine speed and load from one mode to the next one has to be linearly controlled in a time of 20 ± 1 seconds. The mode change time is part of the new mode (including the first mode). In some cases modes are not run in the same order as the discrete model steady state cycles or are split to prevent extreme changes in temperature.

7.4.2. Transient test cycle (NRTC and LSI-NRTC)

The Non-Road Transient Cycle (NRTC) and Large Spark Ignition NRTC (LSI-NRTC) are each specified in Appendix A.6 to this Annex 4 as a second-by-second sequence of normalised speed and torque values. In order to perform the test in an engine test cell, the normalised values shall be converted to their equivalent reference values for the individual engine to be tested, based on specific speed and torque values identified in the engine-mapping curve. The conversion is referred to as denormalisation, and the resulting test cycle is the reference NRTC or LSI-NRTC test cycle of the engine to be tested (see clause 7.7.2. of this Annex).

7.4.2.1. Test sequence for NRTC

A graphical display of the normalised NRTC dynamometer schedule is shown in Annex 5.

The transient test cycle shall be run twice after completion of pre-conditioning (see clause 7.3.1.1.1. of this Annex) in accordance with the following procedure:

(a) the cold-start run shall commence after the engine and aftertreatment systems have cooled down to room temperature after natural engine cool down, or the cold start after forced cool down and the engine, coolant and oil temperatures, aftertreatment systems and all engine control devices are stabilised between 293 K and 303 K (20°C and 30 °C). The measurement of the cold start emissions shall be started with the start of the cold engine;

(b) the hot soak period shall commence immediately upon completion of the cold start phase. The engine shall be shut-down and conditioned for the hot start by soaking it for 20 minutes ± 1 minute

(c) the hot-start run shall commence immediately after the soak period with the cranking of the engine. The gaseous analysers shall be switched on at least 10 s before the end of the soak period to avoid switching signal peaks. The measurement of emissions shall be started in parallel with the start of the hot start phase including the cranking of the engine.

Brake specific emissions expressed in (g/kWh), and, for PN, in (#/kWh) shall be determined by using the procedures of this clause for both the cold and hot start test cycles. Composite weighted emissions shall be computed by weighing the cold start results by 10 per cent and the hot start results by 90 per cent as detailed in Annex 5, Appendices A.1 and A.2.

7.4.2.2. Test sequence for LSI-NRTC

The transient test cycle shall be run once as a hot start test after completion of pre-conditioning (see clause 7.3.1.1.2. of this Annex) in accordance with the following procedure:

(a) the engine shall be started and operated for the first 180 seconds of the duty cycle, then operated at idle without load for 30 seconds. Emissions shall not be measured during this warm-up sequence.

(b) At the end of the 30-second idling period, emissions measurement shall be started and the engine be operated over the entire duty cycle from the beginning (time 0 sec).

Brake specific emissions expressed in (g/kWh) shall be determined by using the procedures detailed in Annex 5, Appendices A.1 and A.2.

If the engine was already operating before the test, use good engineering judgment to let the engine cool down enough so measured emissions will accurately represent those from an engine starting at room temperature. For example, if an engine starting at room temperature warms up enough in three minutes to start closed-loop operation and achieve full catalyst activity, then minimal engine cooling is necessary before starting the next test.

With the prior agreement of the Test Agency, the engine warm-up procedure may include up to 15 minutes of operation over the duty cycle.

7.5. General test sequence

To measure engine emissions the following steps have to be performed:

(a) The engine test speeds and test torques have to be defined for the engine to be tested by measuring the max torque (for constant speed engines) or max torque curve (for variable speed engines) as function of the engine speed;

(b) Normalised test cycles have to be denormalised with the torque (for constant speed engines) or speeds and torques (for variable speed engines) found in the previous sub- clause (a) of this clause;

(c) The engine, equipment, and measurement instruments shall be prepared for the following emission test or test series (cold and hot cycle) in advance;

(d) Pre-test procedures shall be performed to verify proper operation of certain equipment and analysers. All analysers have to be calibrated. All pre-test data shall be recorded;

(e) The engine shall be started (NRTC) or kept running (steady-state cycles and LSI-NRTC) at the beginning of the test cycle and the sampling systems shall be started at the same time;

(f) Emissions and other required parameters shall be measured or recorded during sampling time (for NRTC, LSI-NRTC and steady-state ramped modal cycles throughout the whole test cycle;

(g) Post-test procedures shall be performed to verify proper operation of certain equipment and analysers;

(h) PM filter(s) shall be pre-conditioned, weighed (empty weight), loaded, re-conditioned, again weighed (loaded weight) and then samples shall be evaluated according to pre- (clause 7.3.1.6. of this Annex) and post-test (clause 7.3.2.2. of this Annex) procedures;

(i) Emission test results shall be evaluated.

The following diagram (Figure A.4-3) gives an overview about the procedures needed to conduct NRSC AND NRTC test cycles with measuring exhaust engine emissions.

Test Sequence

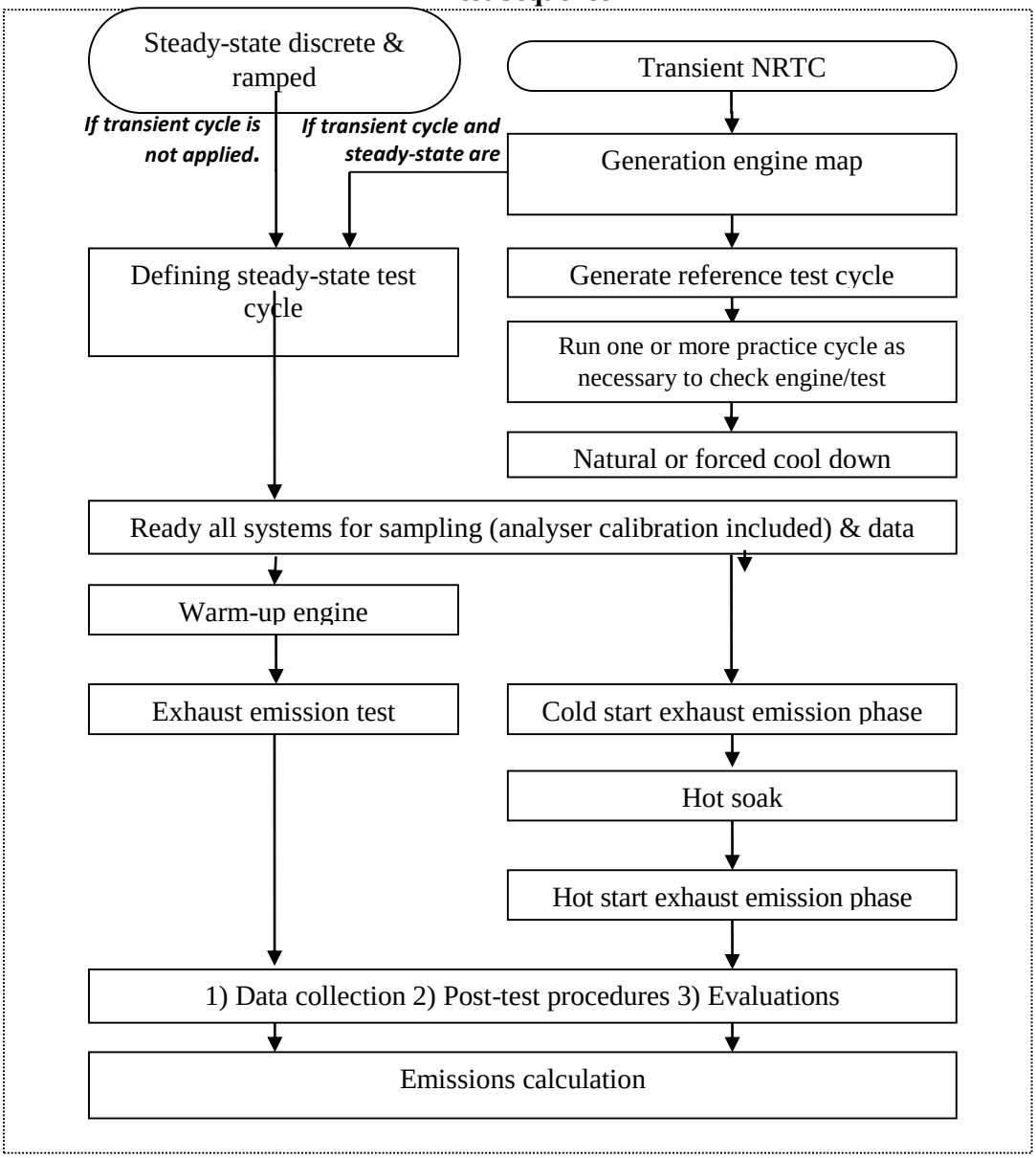


Figure A.4-3

7.5.1. Engine starting, and restarting

7.5.1.1. Engine start

The engine shall be started:

(a) As recommended in the owner's manual using a production starter motor or air-start system and either an adequately charged battery, a suitable power supply or a suitable compressed air source; or

(b) By using the dynamometer to crank the engine until it starts. Typically motor the engine within ±25 per cent of its typical in-use cranking speed

or start the engine by linearly increasing the dynamometer speed from zero to 100 min^{-1} below low idle speed but only until the engine starts.

Cranking shall be stopped within 1 s of starting the engine. If the engine does not start after 15 s of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owner's manual or the service-repair manual describes a longer cranking time as normal.

7.5.1.2. Engine stalling

(a) If the engine stalls anywhere during the cold start run of the NRTC, the entire test shall be voided;

(b) If the engine stalls anywhere during the hot start run of the NRTC, only this run shall be voided. The engine shall be soaked according to clause 7.8.3. of this Annex, and the hot start test repeated. In this case, the cold start run does not need to be repeated;

(c) If the engine stalls anywhere during the LSI-NRTC, the test shall be voided.

(d) If the engine stalls anywhere during the steady-state cycle (discrete or ramped), the test shall be voided and be repeated beginning with the engine warm-up procedure. In the case of PM measurement utilizing the multifilter method (one sampling filter for each operating mode), the test shall be continued by stabilizing the engine at the previous mode for engine temperature conditioning and then initiating measurement with the mode where the engine stalled.

7.5.1.3. Engine operation

The "operator" may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor set point or signal.

7.6. Engine mapping

Before starting the engine mapping, the engine shall be warmed up and towards the end of the warm up it shall be operated for at least 10 minutes at maximum power or according to the recommendation of the manufacturer and good engineering judgment in order to stabilise the engine coolant and lube oil temperatures. When the engine is stabilised, the engine mapping shall be performed.

Where the manufacturer intends to validate the torque signal broadcast by the electronic control unit, of engines so equipped, the verification set out in Appendix A.3 of this Annex shall additionally be performed during the engine mapping.

Except constant speed engines, engine mapping shall be performed with fully open fuel lever or governor using discrete speeds in ascending order. The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = warm idle speed

Maximum mapping speed = n_{hi} x 1.02 or speed where max torque drops off to zero, whichever is smaller.

Where:

n_{hi} is the high speed, defined as the highest engine speed where 70 per cent of the maximum power occurs.

If the highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative one.

7.6.1. Engine mapping for variable speed NRSC

In the case of engine mapping for a variable speed NRSC (only for engines which have not to run the NRTC or LSI-NRTC cycle), good engineering judgment shall be used to select a sufficient number of evenly spaced set-points. At each set-point, speed shall be stabilised and torque allowed to stabilise at least for 15 seconds. The mean speed and torque shall be recorded at each set-point. It is recommended that the mean speed and torque are calculated using the recorded data from the last 4 to 6 seconds. Linear interpolation shall be used to determine the NRSC test speeds and torques if needed. When engines are additionally required to run an NRTC or LSI-NRTC, the NRTC engine mapping curve shall be used to determine steady-state test speeds and torques.

At the choice of the manufacturer the engine mapping may alternatively be conducted according to the procedure in clause 7.6.2. of this Annex.

7.6.2. Engine mapping for NRTC and LSI-NRTC

The engine mapping shall be performed according to the following procedure:

(a) The engine shall be unloaded and operated at idle speed:

(i) For engines with a low-speed governor, the operator demand shall be set to the minimum, the dynamometer or another loading device shall be used to target a torque of zero on the engine's primary output shaft and the engine shall be allowed to govern the speed. This warm idle speed shall be measured;

(ii) For engines without a low-speed governor, the dynamometer shall be set to target a torque of zero on the engine's primary output shaft, and the operator demand shall be set to control the speed to the manufacturer-declared lowest engine speed possible with minimum load (also known as manufacturer-declared warm idle speed);

(iii) The manufacturer declared idle torque may be used for all variable-speed engines (with or without a low-speed governor), if a nonzero idle torque is representative of in-use operation.

(b) Operator demand shall be set to maximum and engine speed shall be controlled to between warm idle and 95 per cent of its warm idle speed. For engines with reference duty cycles, which lowest speed is greater than warm idle speed, the mapping may be started at between the lowest reference speed and 95 per cent of the lowest reference speed;

(c) The engine speed shall be increased at an average rate of 8 ± 1 min^{-1}/s or the engine shall be mapped by using a continuous sweep of speed at a constant rate such that it takes 4 to 6 min to sweep from minimum to maximum mapping speed. The mapping speed range shall be started between warm idle and 95 per cent of warm idle and ended at the highest speed above maximum power at which less than 70 per cent of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g., for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative speed. Engine speed and torque points shall be recorded at a sample rate of at least 1 Hz;

(d) If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternate mapping techniques may be used. These alternate techniques shall satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this clause for reasons of safety or representativeness shall be approved by the Test Agency along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines;

(e) An engine need not be mapped before each and every test cycle. An engine shall be remapped if:

(i) An unreasonable amount of time has transpired since the last map, as determined by good engineering judgement; or

(ii) Physical changes or recalibrations have been made to the engine which potentially affect engine performance; or

(iii) The atmospheric pressure near the engine's air inlet is not within ±5 kPa of the value recorded at the time of the last engine map.

7.6.3. Engine mapping for constant-speed NRSC:

The engine may be operated with a production constant-speed governor or a constant-speed governor maybe simulated by controlling engine speed with an operator demand control system. Either isochronous or speed-droop governor operation shall be used, as appropriate;

7.6.3.1. Rated power check for engines to be tested on cycle D2

The following check shall be conducted:

(a) With the governor or simulated governor controlling speed using operator demand the engine shall be operated at the rated speed and the rated power for as long as required to achieve stable operation;

(b) The torque shall be increased until the engine is unable to maintain the governed speed. The power at this point shall be recorded. Before this check is performed the method to safely determine when this point has been reached shall be agreed between the manufacturer and the Test Agency conducting the check, depending upon the characteristics of the governor. The power recorded shall not exceed the rated gross power as defined in clause 2.1.67. of this Part by more than 12.5 per cent. If

this value is exceeded the manufacturer shall revise the declared rated gross power.

If the specific engine being tested is unable to perform this check due to risk of damage to the engine or dynamometer the manufacturer shall present to the Test Agency robust evidence that maximum power does not exceed the rated power by more than 12.5 %.

7.6.3.2. Mapping procedure for constant speed NRSC

(a) With the governor or simulated governor controlling speed using operator demand, the engine shall be operated at no-load governed speed (at high speed, not low idle) for at least 15 s, , unless the specific engine is unable to perform this task;

(b) The dynamometer shall be used to increase torque at a constant rate. The map shall be conducted such that it takes no less than 2 min to sweep from no-load governed speed to the torque corresponding to rated power for engines to be tested on cycle D2 or to maximum torque in the case of other constant speed test cycles. During the engine mapping actual speed and torque shall be recorded with at least 1 Hz;

(c) In case of a constant speed engine with a governor that can be reset to alternative speeds, the engine shall be tested at each applicable constant speed..

For constant speed engines good engineering judgment shall be used in agreement with the Test Agency to apply other methods to record torque and power at the defined operating speed(s).

For engines tested on cycles other than D2, when both measured and declared values are available for the maximum torque, the declared value may be used instead of the measured value if it is between 95 and 100 % of the measured value.

7.7. Test cycle generation

7.7.1. Generation of steady-state test cycles (NRSC)

This clause shall be used to generate the engine speeds and torques over which the engine shall be operated during steady-state tests with discrete-mode NRSC or RMC.

7.7.1.1. Generation of NRSC test speeds for engines tested with both NRSC and either NRTC or LSI-NRTC.

For engines that are tested with either NRTC or LSI-NRTC in addition to a NRSC, the MTS specified in clause 5.2.5.1. of this Annex shall be used as the 100 per cent speed for both transient and steady state tests.

The MTS shall be used in place of rated speed when determining intermediate speed in accordance with clause 5.2.5.4. of this Annex.

The idle speed shall be determined in accordance with clause 5.2.5.5. of this Annex.

7.7.1.2. Generation of NRSC test speeds for engines only tested with NRSC

For engines that are not tested with a transient (NRTC or LSI-NRTC) test cycle, the rated speed specified in clause 5.2.5.3 shall be used as the 100 per cent speed. The rated speed shall be used to determine the intermediate speed in accordance with clause 5.2.5.4. of this Annex. If the NRSC specifies additional speeds as a percentage they shall be calculated as a percentage of the rated speed. The idle speed shall be determined in accordance with clause 5.2.5.5. of this Annex. With prior approval of the Test Agency , MTS may be used instead of rated speed for the generation of test speeds in this clause.

7.7.1.3. Generation of NRSC torque for each test mode

The per cent torque for each test mode of the chosen test cycle shall be taken from the appropriate NRSC Table of Appendix A.6 of this Annex. The 100 per cent value at a given test speed shall be the measured or declared value taken from the mapping curve generated in accordance with clause 7.6.1, clause 7.6.2. or clause 7.6.3. of this Annex respectively, expressed as power (kW). The engine setting for each test mode shall be calculated by means of equation (A.4-14):

The engine setting for each test mode shall be calculated using the formula:

$$S = \left(\left(P_{max} + P_{AUX} \right) \cdot \frac{L}{100} \right) - P_{AUX} \qquad \text{(A.4-14)}$$

Where:

S = dynamometer setting in kW

P_{max} = maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer) in kW

P_{AUX} = declared total power absorbed by auxiliaries fitted for the test (see clause 6.3.) at the test speed in kW

L = per cent torque

A warm minimum torque that is representative of in-use operation may be declared and used for any torque point that would otherwise fall below this value if the engine type will not normally operate below this minimum torque, for example because it will be connected to a agricultural tractor, construction equipment vehicle or combine harvester that does not operate below a certain minimum torque.

In the case of cycle D2 the manufacturer shall declare the rated gross power and these shall be used as 100 per cent power when generating the test cycle.

7.7.2. Generation of NRTC & LSI-NRTC speed and torque for each test point (denormalisation)

This clause shall be used to generate the corresponding engine speeds and torques over which the engine shall be operated during NRTC or LSI-NRTC tests. Appendix A.6 of this Annex defines applicable test cycles in a normalised format. A normalised test cycle consists of a sequence of paired values for speed and torque per cent.

Normalised values of speed and torque shall be transformed using the following conventions:

(a) The normalised speed shall be transformed into a sequence of reference speeds, nref, in accordance with clause 7.7.2.2. of this Annex;

(b) The normalised torque is expressed as a percentage of the mapped torque from the curve generated according to clause 7.6.2. of this Annex at the corresponding reference speed. These normalised values shall be transformed into a sequence of reference torques, T_{ref}, according to clause 7.7.2.3. of this Annex;

(c) The reference speed and reference torque values expressed in coherent units are multiplied to calculate the reference power values.

7.7.2.1. Reserved

7.7.2.2. Denormalisation of engine speed.

The engine speed shall be denormalised using by means of equation (A.4-15):

$$n_{ref} = \frac{\%speed \times (MTS - n_{idle})}{100} + n_{idle} \quad \text{(A.4-15)}$$

where:

n_{ref} is the reference speed

MTS is the maximum test speed

n_{idle} is the idle speed

%speed is the the value of NRTC or LSI-NRTC normalised speed taken from Appendix A. 6 of this Annex.

7.7.2.3. Denormalisation of engine torque

The torque values in the engine dynamometer schedule of Appendix A. 6 to this Annex 4 are normalised to the maximum torque at the respective speed. The torque values of the reference cycle shall be denormalised, using the mapping curve determined according to clause 7.6.2. of this Annex, by means of equation (A.4 -16):

$$T_{ref} = \frac{\%torque \cdot max.torque}{100} \quad \text{(A.4-16)}$$

for the respective reference speed as determined in clause 7.7.2.2.

Where:

T_{ref} is the reference torque for the respective reference speed

max.torque is the maximum torque for the respective test speed taken from the engine mapping performed in accordance with clause 7.6.2. adjusted where necessary in accordance with sub-clause (b) of this clause.

%torque is the value of NRTC or LSI-NRTC normalised torque taken from Appendix A. 6 to this Annex 4

(a) Declared minimum torque

A minimum torque that is representative of in-use operation may be

declared. For example, if the engine is typically connected to a agricultural tractor, construction equipment vehicle or combine harvester that does not operate below a certain minimum torque, this torque may be declared and used for any load point that would otherwise fall below this value.

(b) Adjustment of engine torque due to auxiliaries fitted for the emissions test

Where auxiliaries are fitted in accordance with Appendix A.2 of this Annex there shall be no adjustment to the maximum torque for the respective test speed taken from the engine mapping performed according to clause 7.6.2. of this Annex.

Where, according to clause 6.3.2. or 6.3.3. of this Annex necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value of T_{max} shall be adjusted by means of equation (A.4-17).

$$T_{max} = T_{map} - T_{AUX} \quad \text{(A.4-17)}$$

with:

$$T_{AUX} = T_r - T_f \quad \text{(A.4-18)}$$

where:

T_{map} is the unadjusted maximum torque for the respective test speed taken from the engine mapping performed in accordance with clause 7.6.2. of this Annex.

T_f is the torque required to drive auxiliaries that should have been fitted but were not installed for the test

T_r is the torque required to drive auxiliaries that should have been removed for the test but were installed for the test

7.7.2.4. Example of denormalisation procedure

As an example, the following test point shall be denormalised:

%speed = 43 per cent

%torque = 82 per cent

Given the following values:

MTS = 2200 min^{-1}

n_{idle} = 600 min^{-1}

results in

$$n_{ref} = \frac{43 \cdot (2200 - 600)}{100} + 600 = 1288 \text{min}^{-1}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1288 min^{-1}

$$T_{ref} = \frac{82 \times 700}{100} = 574 \text{Nm}$$

7.8. Specific test cycle running procedure

7.8.1. Emission test sequence for discrete-mode NRSC

7.8.1.1. Engine warming-up for steady state discrete-mode test cycles

Pre-test procedure according to clause 7.3.1. of this Annex shall be performed, including analiser calibration. The engine shall be warmed-up using the pre-conditioning sequence in clause 7.3.1.1.3. of this Annex. Immediately from this engine conditioning point, the test cycle measurement starts.

7.8.1.2. Performing discrete-mode NRSC

(a) The test shall be performed in ascending order of mode numbers as set out for the relevant test cycle (Appendix A.6 to this Annex.);

(b) Each mode has a mode length of at least 10 minutes. In each mode the engine shall be stabilised for at least 5 minutes. Gaseous emissions, and, where applicable, PN, shall be sampled for 1 to 3 minutes at the end of each mode and PM emissions shall be sampled according to clause (c);

Notwithstanding the first sub-clause, when either testing spark ignition engines using cycles G1, G2 or G3 or when conducting measurements according to clause 5.6 of this Part, each mode has a mode length of at least 3 minutes. In this case gaseous emissions, and, where applicable, PN, shall be sampled for at least the last 2 minutes of each mode and PM emissions shall be sampled according to clause (c);

The mode length and sampling time may be extended to improve accuracy.

The mode length shall be recorded and reported.

(c) For PM emissions, the sampling may be done either with the single filter method or with the multiple filter method. Since the results of the methods may differ slightly, the method used shall be declared with the results;

For the single filter method the modal weighing factors specified in the test cycle procedure and the actual exhaust flow shall be taken into account during sampling by adjusting sample flow rate and/or sampling time, accordingly. It is required that the effective weighing factor of the PM sampling is within ±0.005 of the weighing factor of the given mode;

Sampling shall be conducted as late as possible within each mode. For the single filter method, the completion of particulate sampling shall be coincident within ±5 s with the completion of the gaseous emission measurement. The sampling time per mode shall be at least 20 s for the single filter method and at least 60 s for the multifilter method. For systems without bypass capability, the sampling time per mode shall be at least 60 s for single and multiple filter methods;

(d) The engine speed and load, intake air temperature, fuel flow and where applicable air or exhaust gas flow shall be measured for each mode at

the same time interval which is used for the measurement of the gaseous concentrations;

Any additional data required for calculation shall be recorded.

(e) If the engine stalls or the emission sampling is interrupted at any time after emission sampling begins for a discrete mode and the single filter method, the test shall be voided and be repeated beginning with the engine warm-up procedure. In the case of PM measurement utilizing the multifilter method (one sampling filter for each operating mode), the test shall be continued by stabilizing the engine at the previous mode for engine temperature conditioning and then initiating measurement with the mode where the engine stalled;

(f) Post-test procedures according to clause 7.3.2. of this Annex shall be performed.

7.8.1.3. Validation criteria

During each mode of the given steady-state test cycle after the initial transition period, the measured speed shall not deviate from the reference speed for more than ±1 per cent of rated speed or ±3 min^{-1}, whichever is greater except for idle which shall be within the tolerances declared by the manufacturer. The measured torque shall not deviate from the reference torque for more than ±2 per cent of the maximum torque at the test speed.

7.8.2. Emission test sequence for RMC

7.8.2.1. Engine warming-up

Pre-test procedure according to clause 7.3.1. of this Annex shall be performed, including analiser calibration. The engine shall be warmed-up using the pre-conditioning sequence in clause 7.3.1.1.4. of this Annex. Immediately after this engine conditioning procedure, if the engine speed and torque are not already set for the first mode of the test they shall be changed in a linear ramp of 20 ± 1 s to the first mode of the test. In between 5 to 10 s after the end of the ramp, the test cycle measurement shall start.

7.8.2.2. Performing a ramped modal test cycle

The test shall be performed in the order of mode numbers as set out for the test cycle (see Appendix A.6 of this Annex) Where there is no RMC available for the specified NRSC the discrete-mode NRSC procedure set out in clause 7.8.1. of this Annex shall be followed.

The engine shall be operated for the prescribed time in each mode. The transition from one mode to the next shall be done linearly in 20 s ± 1 s following the tolerances prescribed in clause 7.8.2.4. of this Annex.

For ramped modal cycles, reference speed and torque values shall be generated at a minimum frequency of 1 Hz and this sequence of points shall be used to run the cycle. During the transition between modes, the denormalised reference speed and torque values shall be linearly ramped between modes to generate reference points. The normalised reference torque values shall not be linearly ramped between modes and then denormalised. If the speed and torque ramp runs through a point above the engine's torque curve, it shall be continued to command the reference torques and it shall be allowed for the operator demand to go to maximum.

Over the whole RMC test cycle (during each mode and including the ramps between the modes), the concentration of each gaseous pollutant shall be measured and where there is an applicable limit the PM and PN be sampled. The gaseous pollutants may be measured raw or diluted and be recorded continuously; if diluted, they can also be sampled into a sampling bag. The particulate sample shall be diluted with conditioned and clean air. One sample over the complete test procedure shall be taken, and , in the case of PM, collected on a single PM sampling filter.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the complete cycle.

7.8.2.3. Emission test sequence:

(a) Execution of the RMC, sampling exhaust gases, recording data, and integrating measured values shall be started simultaneously;

(b) Speed and torque shall be controlled to the first mode in the test cycle;

(c) If the engine stalls anywhere during the RMC execution, the test shall be voided. The engine shall be pre-conditioned and the test repeated;

(d) At the end of the RMC, sampling shall be continued, except for PM sampling, operating all systems to allow system response time to elapse. Then all sampling and recording shall be stopped, including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the test cycle shall be indicated in the recorded data;

(e) Post-test procedures according to clause 7.3.2. of this Annex shall be performed.

7.8.2.4. Validation criteria

RMC tests shall be validated using the regression analysis as described in clauses 7.8.3.3. and 7.8.3.5. of this Annex. The allowed RMC tolerances are given in the following Table A.4-1. Note that the RMC tolerances are different from the NRTC tolerances of Table A.4-2. When conducting testing of engines of reference power greater than 560 kW the regression line tolerances of Table A.4-2 and the point deletion of Table A.4-3 may be used.

Table A.4-1

RMC Regression Line Tolerances

	Speed	*Torque*	*Power*
Standard error of estimate (*SEE*) of *y* on *x*	max 1 % of rated speed	max 2 % of maximum engine torque	max 2 % of maximum engine power
Slope of the regression line, a_1	0.99 to 1.01	0.98 to 1.02	0.98 to 1.02
Coefficient of determination, r^2	min 0.990	min 0.950	min 0.950
y intercept of the regression line, a_0	±1 % of rated speed	±20 Nm or 2 % of maximum torque, whichever is greater	±4 kW or 2 % of maximum power, whichever is greater

In case of running the RMC test not on a transient test bed, where the second by second speed and torque values are not available, the following validation criteria shall be used.

At each mode the requirements for the speed and torque tolerances are given in clause 7.8.1.3. of this Annex. For the 20 s linear speed and linear torque transitions between the RMC steady-state test modes (clause 7.4.1.2. of this Annex) the following tolerances for speed and load shall be applied for the ramp, the speed shall be held linear within ±2 per cent of rated speed. The torque shall be held linear within ±5 per cent of the maximum torque at rated speed.

7.8.3. Transient test cycle (NRTC and LSI-NRTC)

Reference speeds and torques commands shall be sequentially executed to perform the NRTC and LSI-NRTC . Speed and torque commands shall be issued at a frequency of at least 5 Hz. Because the reference test cycle is specified at 1 Hz, the in between speed and torque commands shall be linearly interpolated from the reference torque values generated from cycle generation.

Small denormalised speed values near warm idle speed may cause low-speed idle governors to activate and the engine torque to exceed the reference torque even though the operator demand is at a minimum. In such cases, it is recommended to control the dynamometer so it gives priority to follow the reference torque instead of the reference speed and let the engine govern the speed.

Under cold-start conditions engines may use an enhanced-idle device to quickly warm up the engine and aftertreatment devices. Under these conditions, very low normalised speeds will generate reference speeds below this higher enhanced idle speed. In this case it is recommended controlling the

dynamometer so it gives priority to follow the reference torque and let the engine govern the speed when the operator demand is at minimum.

During an emission test, reference speeds and torques and the feedback speeds and torques shall be recorded with a minimum frequency of 1 Hz, but preferably of 5 Hz or even 10 Hz. This larger recording frequency is important as it helps to minimise the biasing effect of the time lag between the reference and the measured feedback speed and torque values.

The reference and feedback speeds and torques maybe recorded at lower frequencies (as low as 1 Hz), if the average values over the time interval between recorded values are recorded. The average values shall be calculated based on feedback values updated at a frequency of at least 5 Hz. These recorded values shall be used to calculate cycle-validation statistics and total work.

7.8.3.1. Performing an NRTC transient cycle test

Pre-test procedures according to clause 7.3.1. of this Annex shall be performed, including analyser calibration.

Testing shall be started as follows:

The test sequence shall commence immediately after the engine has started from cooled down condition specified in clause 7.3.1.2. of this Annex in case of the cold-start NRTC test or from hot soak condition in case of the hot-start NRTC test. The sequence in clause 7.4.2.1. of this Annex shall be followed.

Data logging, sampling of exhaust gases and integrating measured values shall be initiated simultaneously at the start of the engine. The test cycle shall be initiated when the engine starts and shall be executed according to the schedule of Appendix A.6. of this Annex.

At the end of the cycle, sampling shall be continued, operating all systems to allow system response time to elapse. Then all sampling and recording shall be stopped, including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the test cycle shall be indicated in the recorded data.

Post-test procedures according to clause 7.3.2. of this Annex shall be performed.

7.8.3.2. Performing an LSI-NRTC test

Pre-test procedures according to clause 7.3.1. of this Annex shall be performed, including pre-conditioning and analiser calibration.

Testing shall be started as follows:

The test shall commence according to the sequence given in clause 7.4.2.2. of this Annex.

Data logging, sampling of exhaust gas and integrating measured values shall be initiated simultaneously with the start of the LSI-NRTC at the end of the 30-second idle period specified in clause 7.4.2.2(b) of this Annex. The test cycle shall be executed according to the schedule of Appendix A.6 of this Annex.

At the end of the cycle, sampling shall be continued, operating all systems to allow system response time to elapse. Then all sampling and recording shall be stopped, including the recording of background samples. Finally, any integrating devices shall be stopped and the end of the test cycle shall be indicated in the recorded data.

Post-test procedures according to clause 7.3.2. of this Annex shall be performed.

7.8.3.3. Cycle validation criteria for transient (NRTC and LSI-NRTC) test cycle

In order to check the validity of a test, the cycle-validation criteria in this clause shall be applied to the reference and feedback values of speed, torque, power and overall work.

7.8.3.4. Calculation of cycle work

Before calculating the cycle work, any speed and torque values recorded during engine starting shall be omitted. Points with negative torque values have to be accounted for as zero work. The actual cycle work W_{act} (kWh) shall be calculated based on engine feedback speed and torque values. The reference cycle work W_{ref} (kWh) shall be calculated based on engine reference speed and torque values. The actual cycle work W_{act} is used for comparison to the reference cycle work W_{ref} and for calculating the brake specific emissions (see clause 7.2. of this Annex).

W_{act} shall be between 85 per cent and 105 per cent of W_{ref}.

7.8.3.5. Validation statistics (see Annex 5, Appendix A.3.)

Linear regression between the reference and the feedback values shall be calculated for speed, torque and power.

To minimise the biasing effect of the time lag between the reference and feedback cycle values, the entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque shall be shifted by the same amount in the same direction.

The method of least squares shall be used, with the best-fit equation having the form:

$$y = a_1 x + a_0 \qquad \text{(A.4-19)}$$

where:

y = feedback value of speed (min^{-1}), torque (Nm), or power (kW)

a_1 = slope of the regression line

x = reference value of speed (min^{-1}), torque (Nm), or power (kW)

a_0 = y intercept of the regression line

The standard error of estimate (SEE) of y on x and the coefficient of determination (r^2) shall be calculated for each regression line (Annex 4, Appendix A.2.).

It is recommended that this analysis be performed at 1 Hz. For a test to be considered valid, the criteria of Table A.4-2 below shall be met.

Table A.4-2

Regression Line Tolerances

	Speed	Torque	Power
Standard error of estimate (*SEE*) of *y* on *x*	≤ 5.0 per cent of maximum test speed	≤ 10.0 per cent of maximum mapped torque	≤ 10.0 per cent of maximum mapped power
Slope of the regression line, a_1	0.95 to 1.03	0.83 to 1.03	0.89 to 1.03
Coefficient of determination, r^2	minimum 0.970	minimum 0.850	minimum 0.910
y intercept of the regression line, a_0	≤ 10 per cent of idle	±20 Nm or ±2 per cent of maximum torque whichever is greater	±4 kW or ±2 per cent of maximum power whichever is greater

For regression purposes only, point deletions are permitted where noted in Table A.4-3 below before doing the regression calculation. However, those points shall not be deleted for the calculation of cycle work and emissions. An idle point is defined as a point having a normalised reference torque of 0 per cent and a normalised reference speed of 0 per cent. Point deletion may be applied to the whole or to any part of the cycle; points to which the point deletion is applied have to be specified.

Table A.4-3

Permitted Point Deletions from Regression Analysis

Event	*Conditions (n = engine speed, T = torque)*	*Permitted point deletions*
Minimum operator demand (idle point)	$n_{ref} = n_{idle}$ and $T_{ref} = 0$ and $T_{act} > (T_{ref} - 0.02\ T_{maxmappedtorque})$ and $T_{act} < (T_{ref} + 0.02\ T_{maxmappedtorque})$	speed and power
Minimum operator demand	$n_{act} \leq 1.02\ n_{ref}$ and $T_{act} > T_{ref}$ or $n_{act} > n_{ref}$ and $T_{act} \leq T_{ref}$' or $n_{act} > 1.02\ n_{ref}$ and $T_{ref} < T_{act} \leq (T_{ref} + 0.02\ T_{maxmappedtorque})$	power and either torque or speed
Maximum operator demand	$n_{act} < n_{ref}$ and $T_{act} \geq T_{ref}$ or $n_{act} \geq 0.98\ n_{ref}$ and $T_{act} < T_{ref}$ or $n_{act} < 0.98\ n_{ref}$ and $T_{ref} > T_{act} \geq (T_{ref} - 0.02\ T_{maxmappedtorque})$	power and either torque or speed

Where:

n_{ref} is the reference speed (see clause 7.7.2. of this Annex)

n_{idle} is the idle speed

n_{act} is the actual (measured) speed

T_{ref} is the reference torque (see clause 7.7.2. of this Annex)

T_{act} is the actual (measured) torque

$T_{maxmappedtorque}$ is the highest value of torque on the full-load torque curve mapped according to clause 7.6. of this Annex.

8. MEASUREMENT PROCEDURES

8.1. Calibration and performance checks

8.1.1. Introduction

This clause describes required calibrations and verifications of measurement systems. See clause 9.4. of this Annex for specifications that apply to individual instruments.

Calibrations or verifications shall be generally performed over the complete measurement chain.

If a calibration or verification for a portion of a measurement system is not specified, that portion of the system shall be calibrated and its performance verified at a frequency consistent with any recommendations from the measurement system manufacturer and consistent with good engineering judgment.

Internationally recognized-traceable standards shall be used to meet the tolerances specified for calibrations and verifications.

8.1.2. Summary of calibration and verification

Table A.4-4 summarizes the calibrations and verifications described in this clause and indicates when these have to be performed.

Table A.4-4

Summary of Calibration and Verifications

Type of calibration or verification	Minimum frequency[a]
8.1.3.: Accuracy, repeatability and noise	Accuracy: Not required, but recommended for initial installation. Repeatability: Not required, but recommended for initial installation. Noise: Not required, but recommended for initial installation.

Type of calibration or verification	Minimum frequency[a]
8.1.4.: Linearity verification	Speed: Upon initial installation, within 370 days before testing and after major maintenance. Torque: Upon initial installation, within 370 days before testing and after major maintenance. Clean gas and diluted exhaust flows: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Gas analysers: Upon initial installation, within 35 days before testing and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Stand-alone pressure and temperature: Upon initial installation, within 370 days before testing and after major maintenance.
8.1.5.: Continuous gas analyser system response and updating-recording verification – for gas analysers not continuously compensated for other gas species	Upon initial installation or after system modification that would effect response.
8.1.6.: Continuous gas analyser system response and updating-recording verification – for gas analysers continuously compensated for other gas species	Upon initial installation or after system modification that would effect response.
8.1.7.1.: Torque	Upon initial installation and after major maintenance.
8.1.7.2.: Pressure, temperature, dew point	Upon initial installation and after major maintenance.
8.1.8.1.: Fuel flow	Upon initial installation and after major maintenance.
8.1.8.2.: Intake flow	Upon initial installation and after major maintenance.
8.1.8.3.: Exhaust flow	Upon initial installation and after major maintenance.

Type of calibration or verification	Minimum frequency[a]
8.1.8.4.: Diluted exhaust flow (CVS and PFD)	Upon initial installation and after major maintenance.
8.1.8.5.: CVS/PFD and batch sampler verification[b]	Upon initial installation, within 35 days before testing, and after major maintenance. (Propane check)
8.1.8.5.8: Sample dryer verification	For thermal chillers: upon installation and after major maintenance. For osmotic membranes: upon installation, within 35 days of testing and after major maintenance
8.1.8.8.: Vacuum leak	Before each laboratory test according to clause 7.1.
8.1.9.1.: CO_2 NDIR H_2O interference	Upon initial installation and after major maintenance.
8.1.9.2.: CO NDIR CO_2 and H_2O interference	Upon initial installation and after major maintenance.
8.1.10.1.: FID calibration THC FID optimisation and THC FID verification	Calibrate, optimise, and determine CH_4 response: upon initial installation and after major maintenance. Verify CH_4 response: upon initial installation, within 185 days before testing, and after major maintenance.
8.1.10.2.: Raw exhaust FID O_2 interference	For all FID analysers: upon initial installation, and after major maintenance. For THC FID analysers: upon initial installation, after major maintenance, and after FID optimisation according to 8.1.10.1.
8.1.11.1.: CLD CO_2 and H_2O quench	Upon initial installation and after major maintenance.
8.1.11.3.: NDUV HC and H_2O interference	Upon initial installation and after major maintenance.
8.1.11.4.: Sample dryer NO_2 penetration (chiller)	Upon initial installation and after major maintenance.
8.1.11.5.: NO_2-to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
8.1.12.1.: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.

Type of calibration or verification	Minimum frequency[a]

[a] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

[b] The CVS verification is not required for systems that agree within ±2 per cent based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

8.1.3. Verifications for accuracy, repeatability, and noise

The performance values for individual instruments specified in Table A.4-8 are the basis for the determination of the accuracy, repeatability, and noise of an instrument.

It is not required to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

8.1.4. Linearity verification

8.1.4.1. Scope and frequency

A linearity verification shall be performed on each measurement system listed in Table A.4-5 at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification shall consist of introducing a series of at least 10 reference values to a measurement system, unless otherwise specified. The measurement system quantifies each reference value. The measured values shall be collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table A.4-5.

8.1.4.2. Performance requirements

If a measurement system does not meet the applicable linearity criteria in Table A.4-5, the deficiency shall be corrected by re-calibrating, servicing, or replacing components as needed. The linearity verification shall be repeated after correcting the deficiency to ensure that the measurement system meets the linearity criteria.

8.1.4.3. Procedure

The following linearity verification protocol shall be used:

(a) A measurement system shall be operated at its specified temperatures, pressures, and flows;

(b) The instrument shall be zeroed as it would before an emission test by introducing a zero signal. For gas analysers, a zero gas shall be used that meets the specifications of clause 9.5.1. of this Annex and it shall be introduced directly at the analyser port;

(c) The instrument shall be spanned as it would before an emission test by introducing a span signal. For gas analysers, a span gas shall be used that meets the specifications of clause 9.5.1. of this Annex and it shall be introduced directly at the analyser port;

(d) After spanning the instrument, zero shall be checked with the same signal which has been used in sub- clause (b) of this clause. Based on the zero reading, good engineering judgment shall be used to determine whether or not to re-zero and or re-span the instrument before proceeding to the next step;

(e) For all measured quantities manufacturer recommendations and good engineering judgment shall be used to select the reference values, y_{refi}, that cover the full range of values that are expected during emission testing, thus avoiding the need of extrapolation beyond these values. A zero reference signal shall be selected as one of the reference values of the linearity verification. For stand-alone pressure and temperature linearity verifications, at least three reference values shall be selected. For all other linearity verifications, at least ten reference values shall be selected;

(f) Instrument manufacturer recommendations and good engineering judgment shall be used to select the order in which the series of reference values will be introduced;

(g) Reference quantities shall be generated and introduced as described in clause 8.1.4.4. of this annex. For gas analysers, gas concentrations known to be within the specifications of clause 9.5.1. of this Annex shall be used and they shall be introduced directly at the analyser port;

(h) Time for the instrument to stabilise while it measures the reference value shall be allowed;

(i) At a recording frequency of at least the minimum frequency, as specified in Table A.4-7, the reference value shall be measured for 30 s and the arithmetic mean of the recorded values, $\overline{y}_i$ recorded;

(j) Steps in sub- clauses (g) through (i) of this clause shall be repeated until all reference quantities are measured;

(k) The arithmetic means $\overline{y}_i$, and reference values, y_{refi}, shall be used to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table A.4-5. The calculations described in Appendix A.3 to Annex 5 shall be used.

8.1.4.4. Reference signals

This clause describes recommended methods for generating reference values for the linearity-verification protocol in clause 8.1.4.3. of this Annex. Reference values shall be used that simulate actual values, or an actual value shall be introduced and measured with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems shall be internationally traceable.

For temperature measurement systems with sensors like thermocouples, RTDs, and thermistors, the linearity verification may be performed by removing the sensor from the system and using a simulator in its place. A simulator that is independently calibrated and cold junction compensated, as necessary shall be used. The internationally traceable simulator uncertainty scaled to temperature shall be less than 0.5 per cent of maximum operating temperature T_{max}. If this

option is used, it is necessary to use sensors that the supplier states are accurate to better than 0.5 per cent of T_{max} compared to their standard calibration curve.

8.1.4.5. Measurement systems that require linearity verification

Table A.4-5 indicates measurement systems that require linearity verifications. For this table the following provisions shall apply.

(a) A linearity verification shall be performed more frequently if the instrument manufacturer recommends it or based on good engineering judgment;

(b) "min" refers to the minimum reference value used during the linearity verification;

Note that this value may be zero or a negative value depending on the signal;

(c) "max" generally refers to the maximum reference value used during the linearity verification. For example for gas dividers, x_{max} is the undivided, undiluted, span gas concentration. The following are special cases where "max" refers to a different value:

(i) For PM balance linearity verification, m_{max} refers to the typical mass of a PM filter;

(ii) For torque linearity verification, T_{max} refers to the manufacturer's specified engine torque peak value of the highest torque engine to be tested.

(d) The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for the slope a_1 means $0.98 \leq a_1 \leq 1.02$;

(e) These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust gas as described 8.1.8.5. for the propane check or for systems that agree within ±2 per cent based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust gas;

(f) a_1 criteria for these quantities shall be met only if the absolute value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value;

(g) Stand-alone temperatures include engine temperatures and ambient conditions used to set or verify engine conditions; temperatures used to set or verify critical conditions in the test system; and temperatures used in emissions calculations:

(i) These temperature linearity checks are required. Air intake; aftertreatment bed(s) (for engines tested with aftertreatment devices on cycles with cold start criteria); dilution air for PM sampling (CVS, double dilution, and partial flow systems); PM sample; and chiller sample (for gaseous sampling systems that use chillers to dry samples);

(ii) These temperature linearity checks are only required if specified by the engine manufacturer. Fuel inlet; test cell charge air cooler air outlet (for engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler); test cell charge air cooler coolant inlet (for engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler); and

oil in the sump/pan; coolant before the thermostat (for liquid cooled engines);

(h) Stand-alone pressures include engine pressures and ambient conditions used to set or verify engine conditions; pressures used to set or verify critical conditions in the test system; and pressures used in emissions calculations:

(i) Required pressure linearity checks are: intake air pressure restriction; exhaust back pressure; barometer; CVS inlet gage pressure (if measurement using CVS); chiller sample (for gaseous sampling systems that use chillers to dry samples);

(ii) Pressure linearity checks that are required only if specified by the engine manufacturer: test cell charge air cooler and interconnecting pipe pressure drop (for turbo-charged engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler) fuel inlet; and fuel outlet.

Table A.4-5

Measurement Systems that require Linearity Verifications

Measurement System	Quantity	Minimum verification frequency	Linearity Criteria			
			$\lvert x_{min} \cdot (a_1 - 1) + a_0 \rvert$	a	SEE	r^2
Engine speed	n	Within 370 days before testing	≤ 0.05 % n_{max}	0.98-1.02	≤ 2 % n_{max}	≥ 0.990
Engine torque	T	Within 370 days before testing	≤ 1 % T_{max}	0.98-1.02	≤ 2 % T_{max}	≥0.990
Fuel flow rate	q_m	Within 370 days before testing	≤ 1 % $q_{m,\,max}$	0.98-1.02	≤ 2 % $q_{m,\,max}$	≥0.990
Intake-air flow rate ([1])	q_V	Within 370 days before testing	≤ 1 % $q_{V,\,max}$	0.98-1.02	≤ 2 % $q_{V,\,max}$	≥0.990
Dilution air flow rate ([1])	q_V	Within 370 days before testing	≤ 1 % $q_{V,\,max}$	0.98-1.02	≤ 2 % $q_{V,\,max}$	≥0.990
Diluted exhaust flow rate ([1])	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Raw exhaust flow rate ([1])	q_V	Within 185 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Batch sampler flow rates ([1])	q_V	Within 370 days before testing	≤1 % $q_{V,\,max}$	0.98-1.02	≤2 % $q_{V,\,max}$	≥0.990
Gas dividers	x/x_{span}	Within 370 days before testing	≤0.5 % x_{max}	0.98-1.02	≤2 % x_{max}	≥0.990
Gas analysers	x	Within 35 days before testing	≤0.5 % x_{max}	0.99-1.01	≤1 % x_{max}	≥0.998
PM balance	m	Within 370 days before testing	≤1 % m_{max}	0.99-1.01	≤1 % m_{max}	≥0.998
Stand-alone pressures	p	Within 370 days before testing	≤1 % p_{max}	0.99-1.01	≤1 % p_{max}	≥0.998

Analog-to-digital conversion of stand-alone temperature signals	*T*	Within 370 days before testing	≤1 % T_{max}	0.99-1.01	≤1 % T_{max}	≥0.998
([1]) Molar flow rate may be used instead of standard volumetric flow rate as the term representing 'quantity'. In this case maximum molar flow rate may be used instead of the maximum standard volumetric flow rate in the corresponding linearity criteria.						

8.1.5. Continuous gas analyser system-response and updating-recording verification

This clause describes a general verification procedure for continuous gas analyser system response and update recording. See clause 8.1.6. below for verification procedures for compensation type analysers.

8.1.5.1. Scope and frequency

This verification shall be performed after installing or replacing a gas analyser that is used for continuous sampling. Also this verification shall be performed if the system is reconfigured in a way that would change system response. This verification is needed for continuous gas analysers used for transient (NRTC and LSI- NRTC) test cycles or ramped-modal testing but is not needed for batch gas analyser systems or for continuous gas analyser systems used only for testing with a discrete-mode NRSC.

8.1.5.2. Measurement principles

This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyser systems shall be optimised such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that continuous gas analyser systems meet a minimum response time.

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analysers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The devices for gas switching shall have a specification to perform the switching in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent full scale (FS).

The concentration trace of each single gas component shall be recorded.

8.1.5.3. System requirements

(a) The system response time shall be ≤ 10 s with a rise time of ≤ 5 s or with a rise and fall time of ≤ 5 s each for all measured components (CO, NO_X, CO_2 and HC) and all ranges used.

All data (concentration, fuel and air flows) have to be shifted by their measured response times before performing the emission calculations given in Annex 5.

(b) To demonstrate acceptable updating and recording with respect to the system's overall response, the system shall meet one of the following criteria:

(i) The product of the mean rise time and the frequency at which the system records an updated concentration shall be at least 5. In any case the mean rise time shall be no more than 10 s;

(ii) The frequency at which the system records the concentration shall be at least 2 Hz (see also Table A.4-7).

8.1.5.4. Procedure

The following procedure shall be used to verify the response of each continuous gas analyser system:

(a) The analyser system manufacturer's start-up and operating instructions for the instrument setup shall be followed. The measurement system shall be adjusted as needed to optimise performance. This verification shall be run with the analyser operating in the same manner as used for emission testing. If the analyser shares its sampling system with other analysers, and if gas flow to the other analysers will affect the system response time, then the other analysers shall be started up and operated while running this verification test. This verification test may be run on multiple analysers sharing the same sampling system at the same time. If analogue or real-time digital filters are used during emission testing, those filters shall be operated in the same manner during this verification;

(b) For equipment used to validate system response time, minimal gas transfer line lengths between all connections are recommended to be used, a zero-air source shall be connected to one inlet of a fast-acting 3-way valve (2 inlets, 1 outlet) in order to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. Normally the gas flow rate is higher than the probe sample flow rate and the excess is overflowed out the inlet of the probe. If the gas flow rate is lower than the probe flow rate, the gas concentrations shall be adjusted to account for the dilution from ambient air drawn into the probe. Binary or multi-gas span gases may be used. A gas blending or mixing device may be used to blend span gases. A gas blending or mixing device is recommended when blending span gases diluted in N_2 with span gases diluted in air;

Using a gas divider, an NO–CO–CO_2–C_3H_8–CH_4 (balance N_2) span gas shall be equally blended with a span gas of NO_2, balance purified synthetic air. Standard binary span gases may be also be used, where applicable, in place of blended NO-CO-CO_2-C_3H_8-CH_4, balance N_2 span gas; in this case separate response tests shall be run for each analyser. The gas divider outlet shall be connected to the other inlet of the 3-way valve. The valve outlet shall be connected to an overflow at

the gas analyser system's probe or to an overflow fitting between the probe and transfer line to all the analysers being verified. A setup that avoids pressure pulsations due to stopping the flow through the gas blending device shall be used. Any of these gas constituents if they are not relevant to the analysers for this verification shall be omitted. Alternatively the use of gas bottles with single gases and a separate measurement of response times is allowed;

(c) Data collection shall be done as follows:

(i) The valve shall be switched to start the flow of zero gas;

(ii) Stabilisation shall be allowed for, accounting for transport delays and the slowest analyser's full response;

(iii) Data recording shall be started at the frequency used during emission testing. Each recorded value shall be a unique updated concentration measured by the analyser; interpolation or filtering may not be used to alter recorded values;

(iv) The valve shall be switched to allow the blended span gases to flow to the analysers. This time shall be recorded as t_0;

(v) Transport delays and the slowest analyser's full response shall be allowed for;

(vi) The flow shall be switched to allow zero gas to flow to the analyser. This time shall be recorded as t_{100};

(vii) Transport delays and the slowest analyser's full response shall be allowed for;

(viii) The steps in sub- clauses (c) (iv) through (vii) of this clause shall be repeated to record seven full cycles, ending with zero gas flowing to the analysers;

(ix) Recording shall be stopped.

8.1.5.5. Performance evaluation

The data from sub-clause (c) of clause 8.1.5.4. of this Annex shall be used to calculate the mean rise time, $T_{10–90}$ for each of the analysers.

(a) If it is chosen to demonstrate compliance with sub- clauses (b) (i) of clause 8.1.5.3. of this Annex, the following procedure has to be applied: The rise times (in s) shall be multiplied by their respective recording frequencies in Hertz (1/s). The value for each result shall be at least 5. If the value is less than 5, the recording frequency shall be increased or the flows adjusted or the design of the sampling system shall be changed to increase the rise time as needed. Also digital filters may be configured to increase rise time;

(b) If it is choosen to demonstrate compliance with sub- clauses (b) (ii) of clause 8.1.5.3., the demonstration of compliance with the requirements of sub-clause (b) (ii) of clause 8.1.5.3. is sufficient.

8.1.6. Response time verification for compensation type analysers

8.1.6.1. Scope and frequency

This verification shall be performed to determine a continuous gas analyser's response, where one analyser's response is compensated by another's to quantify a gaseous emission. For this check water vapour shall be considered to be a gaseous constituent. This verification is required for continuous gas analysers used for transient (NRTC and LSI-NRTC) test cycles or RMC. This verification is not needed for batch gas analysers or for continuous gas analysers that are used only for discrete-mode NRSC testing. This verification does not apply to correction for water removed from the sample done in post-processing This verification shall be performed after initial installation (i.e. test cell commissioning). After major maintenance, clause 8.1.5. may be used to verify uniform response provided that any replaced components have gone through a humidified uniform response verification at some point.

8.1.6.2. Measurement principles

This procedure verifies the time-alignment and uniform response of continuously combined gas measurements. For this procedure, it is necessary to ensure that all compensation algorithms and humidity corrections are turned on.

8.1.6.3. System requirements

The general response time and rise time requirement given in sub- clause (a) of 8.1.5.3. is also valid for compensation type analysers. Additionally, if the recording frequency is different than the update frequency of the continuously combined/compensated signal, the lower of these two frequencies shall be used for the verification required by sub- clause (b) (i) of clause 8.1.5.3. of this Annex.

8.1.6.4. Procedure

All procedures given in sub- clauses (a) to (c) of clause 8.1.5.4. of this Annex shall be used. Additionally also the response and rise time of water vapour has to be measured, if a compensation algorithm based on measured water vapour is used. In this case at least one of the used calibration gases (but not NO_2) has to be humidified as follows:

If the system does not use a sample dryer to remove water from the sample gas, the span gas shall be humidified by flowing the gas mixture through a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling by bubbling it through distilled water. If the system uses a sample dryer during testing that has passed the sample dryer verification check, the humidified gas mixture may be introduced downstream of the sample dryer by bubbling it through distilled water in a sealed vessel at 298 ± 10 K (25 ± 10 °C), or a temperature greater than the dew point. In all cases, downstream of the vessel, the humidified gas shall be maintained at a temperature of at least 5 K (5 ºC) above its local dew point in the line. Note that it is possible to omit any of these gas constituents if they are not relevant to the analysers for this verification. If any of the gas constituents are not susceptible to water compensation, the response check for these analysers may be performed without humidification.

8.1.7. Measurement of engine parameters and ambient conditions

Internal quality procedures shall be applied, which are traceable to recognised national or international standards. Otherwise the following procedures apply.

8.1.7.1. Torque calibration

8.1.7.1.1. Scope and frequency

All torque-measurement systems including dynamometer torque measurement transducers and systems shall be calibrated upon initial installation and after major maintenance using, among others, reference force or lever-arm length coupled with dead weight. Good engineering judgment shall be used to repeat the calibration. The torque transducer manufacturer's instructions shall be followed for linearizing the torque sensor's output. Other calibration methods are permitted.

8.1.7.1.2. Dead-weight calibration

This technique applies a known force by hanging known weights at a known distance along a lever arm. It shall be made sure that the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. At least six calibration-weight combinations shall be applied for each applicable torque-measuring range, spacing the weight quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. Each weight's force shall be determined by multiplying its internationally-traceable mass by the local acceleration of Earth's gravity.

8.1.7.1.3. Strain gage or proving ring calibration

This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used as part of the reference torque determination) or by operating the dynamometer at different torques. At least six force combinations shall be applied for each applicable torque-measuring range, spacing the force quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the force output from the reference meter (such as a strain gage or proving ring) by its effective lever-arm length, which is measured from the point where the force measurement is made to the dynamometer's rotational axis. It shall be made sure that this length is measured perpendicular to the reference meter's measurement axis and perpendicular to the dynamometer's rotational axis.

8.1.7.2. Pressure, temperature, and dew point calibration

Instruments shall be calibrated for measuring pressure, temperature, and dew point upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

For temperature measurement systems with thermocouple, RTD, or thermistor sensors, the calibration of the system shall be performed as described in clause 8.1.4.4. of this Annex for linearity verification.

8.1.8. Flow-related measurements

8.1.8.1. Fuel flow calibration

Fuel flowmeters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.2. Intake air flow calibration

Intake air flowmeters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.3. Exhaust flow calibration

Exhaust flowmeters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

8.1.8.4. Diluted exhaust flow (CVS) calibration

8.1.8.4.1. Overview

(a) This clause describes how to calibrate flowmeters for diluted exhaust constant-volume sampling (CVS) systems;

(b) This calibration shall be performed while the flowmeter is installed in its permanent position. This calibration shall be performed after any part of the flow configuration upstream or downstream of the flowmeter has been changed that may affect the flowmeter calibration. This calibration shall be performed upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (*i.e.*, propane check) in clause 8.1.8.5. of this Annex;

(c) A CVS flowmeter shall be calibrated using a reference flowmeter such as a subsonic venturi flowmeter, a long-radius flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flowmeter. A reference flowmeter shall be used that reports quantities that are internationally-traceable within ±1 per cent uncertainty. This reference flowmeter's response to flow shall be used as the reference value for CVS flowmeter calibration;

(d) An upstream screen or other restriction that could affect the flow ahead of the reference flowmeter may not be used, unless the flowmeter has been calibrated with such a restriction;

(e) The calibration sequence described under this clause 8.1.8.4. of this Annex refers to the molar based approach. For the corresponding sequence used in the mass based approach, see Annex 5 Appendix A.1.

(f) CFV or SSV may alternatively be removed from its permanent position for calibration as long as the following requirements are met when installed in the CVS:

(1) Upon installation of the CFV or SSV into the CVS, good engineering judgment shall be applied to verify that any leaks have not been introduced between the CVS inlet and the venturi.

(2) After ex-situ venturi calibration, all venturi flow combinations must be verified for CFVs or at minimum of 10 flow points for an SSV using the propane check as described in clause 8.1.8.5. of this Annex. The result of the propane check for each venturi flow point may not exceed the tolerance in clause 8.1.8.5.6. of this Annex.

(3) In order to verify the ex-situ calibration for a CVS with more than a single CFV, the following verification shall be conducted:

(i) A constant flow device shall be used to deliver a constant flow of propane to the dilution tunnel.

(ii) The hydrocarbon concentrations shall be measured at a minimum of 10 separate flow rates for an SSV flowmeter, or at all possible flow combinations for a CFV flowmeter, while keeping the flow of propane constant.

(iii) The concentration of hydrocarbon background in the dilution air shall be measured at the beginning and end of this test. The average background concentration from each measurement at each flow point must be subtracted before performing the regression analysis in clause (iv) below.

(iv) A power regression has to be performed using all the paired values of flow rate and corrected concentration to obtain a relationship in the form of $y = a \times x^b$, using the concentration as the independent variable and the flow rate as the dependent variable. For each data point, the calculation of the difference between the measured flow rate and the value represented by the curve fit is required. The difference at each point must be less than ± 1 per cent of the appropriate regression value. The value of b must be between – 1.005 and – 0.995. If the results do not meet these limits, corrective actions consistent with clause 8.1.8.5.1(a) of this Annex must be taken.

8.1.8.4.2. PDP calibration

A positive-displacement pump (PDP) shall be calibrated to determine a flow-versus-PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Unique equation coefficients shall be determined for each speed at which the PDP is operated. A PDP flowmeter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure A.4- 4;

(b) Leaks between the calibration flowmeter and the PDP shall be less than 0.3 per cent of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point;

(c) While the PDP operates, a constant temperature at the PDP inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(d) The PDP speed is set to the first speed point at which it is intended to calibrate;

(e) The variable restrictor is set to its wide-open position;

(f) The PDP is operated for at least 3 min to stabilise the system. Then by continuously operating the PDP, the mean values of at least 30 s of sampled data of each of the following quantities are recorded:

(i) The mean flow rate of the reference flowmeter, $\bar{q}_{Vref}$;

(ii) The mean temperature at the PDP inlet, $T_{in;}$

(iii) The mean static absolute pressure at the PDP inlet, $p_{in;}$

(iv) The mean static absolute pressure at the PDP outlet, $p_{out;}$

(v) The mean PDP speed, n_{PDP};

(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the PDP, p_{in};

(h) The steps in sub- clauses (f) and (g) of this clause shall be repeated to record data at a minimum of six restrictor positions reflecting the full range of possible in-use pressures at the PDP inlet;

(i) The PDP shall be calibrated by using the collected data and the equations in Annex 5;

(j) The steps in sub-clauses (f) through (i) of this clause shall be repeated for each speed at which the PDP is operated;

(k) The equations in Annex 5 Appendix A.2 (molar based approach) or A.1 (mass based approach) shall be used to determine the PDP flow equation for emission testing;

(l) The calibration shall be verified by performing a CVS verification (*i.e.*, propane check) as described in clause 8.1.8.5. below;

(m) The PDP may not be used below the lowest inlet pressure tested during calibration.

8.1.8.4.3. CFV calibration

A critical-flow venturi (CFV) shall be calibrated to verify its discharge coefficient, C_d, at the lowest expected static differential pressure between the CFV inlet and outlet. A CFV flowmeter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure A.4-4;

(b) The blower shall be started downstream of the CFV;

(c) While the CFV operates, a constant temperature at the CFV inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(d) Leaks between the calibration flowmeter and the CFV shall be less than 0.3 per cent of the total flow at the highest restriction;

(e) The variable restrictor shall be set to its wide-open position. In lieu of a variable restrictor the pressure downstream of the CFV may be varied by varying blower speed or by introducing a controlled leak. Note that some blowers have limitations on non-loaded conditions;

(f) The CFV shall be operated for at least 3 min to stabilise the system. The CFV shall continue operating and the mean values of at least 30 s of sampled data of each of the following quantities shall be recorded:

(i) The mean flow rate of the reference flowmeter, $\bar{q}_{Vref}$;

(ii) Optionally, the mean dew point of the calibration air, T_{dew}. See Annex 5 for permissible assumptions during emission measurements;

(iii) The mean temperature at the venturi inlet, T_{in};

(iv) The mean static absolute pressure at the venturi inlet, p_{in};

(v) The mean static differential pressure between the CFV inlet and the CFV outlet, Δp_{CFV};

(g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the CFV, p_{in};

(h) The steps in sub- clauses (f) and (g) of this clause shall be repeated to record mean data at a minimum of ten restrictor positions, such that the fullest practical range of Δp_{CFV} expected during testing is tested. It is not required to remove calibration components or CVS components to calibrate at the lowest possible restrictions;

(i) C_d and the lowest allowable pressure ratio r shall be determined as described in Annex 5;

(j) C_d shall be used to determine CFV flow during an emission test. The CFV shall not be used below the lowest allowed r, as determined in Annex 5;

(k) The calibration shall be verified by performing a CVS verification (i.e., propane check) as described in clause 8.1.8.5. of this Annex;

(l) If the CVS is configured to operate more than one CFV at a time in parallel, the CVS shall be calibrated by one of the following:

(i) Every combination of CFVs shall be calibrated according to this clause and Annex 5. See Annex 5 for instructions on calculating flow rates for this option;

(ii) Each CFV shall be calibrated according to this clause and Annex 5. See Annex 5 for instructions on calculating flow rates for this option.

8.1.8.4.4. SSV calibration

A subsonic venturi (SSV) shall be calibrated to determine its calibration coefficient, C_d , for the expected range of inlet pressures. An SSV flowmeter shall be calibrated as follows:

(a) The system shall be connected as shown in Figure A.4-4;

(b) The blower shall be started downstream of the SSV;

(c) Leaks between the calibration flowmeter and the SSV shall be less than 0.3 per cent of the total flow at the highest restriction;

(d) While the SSV operates, a constant temperature at the SSV inlet shall be maintained within ±2 per cent of the mean absolute inlet temperature, T_{in};

(e) The variable restrictor or variable-speed blower shall be set to a flow rate greater than the greatest flow rate expected during testing. Flow rates may not be extrapolated beyond calibrated values, so it is recommended that it is made certain that a Reynolds number, *Re*, at the SSV throat at the greatest calibrated flow rate is greater than the maximum *Re* expected during testing;

(f) The SSV shall be operated for at least 3 min to stabilise the system. The SSV shall continue operating and the mean of at least 30 s of sampled data of each of the following quantities shall be recorded:

(i) The mean flow rate of the reference flowmeter, $\bar{q}_{Vref}$;

(ii) Optionally, the mean dew point of the calibration air, T_{dew}. See Annex 5 for permissible assumptions;

(iii) The mean temperature at the venturi inlet, T_{in};

(iv) The mean static absolute pressure at the venturi inlet, p_{in};

(v) Static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, Δp_{SSV};

(g) The restrictor valve shall be incrementally closed or the blower speed decreased to decrease the flow rate;

(h) The steps in sub- clauses (f) and (g) of this clause shall be repeated to record data at a minimum of ten flow rates;

(i) A functional form of C_d versus *Re* shall be determined by using the collected data and the equations in Appendices A.1 and A.2 to Annex 5;

(j) The calibration shall be verified by performing a CVS verification (i.e., propane check) as described in clause 8.1.8.5. of this Annex below using the new C_d versus *Re* equation;

(k) The SSV shall be used only between the minimum and maximum calibrated flow rates;

(l) The equations in Annex 5 Appendix A.1 (mass based approach) or Annex 5, Appendix A.2 (molar based approach) shall be used to determine SSV flow during a test.

8.1.8.4.5. Ultrasonic calibration (reserved)

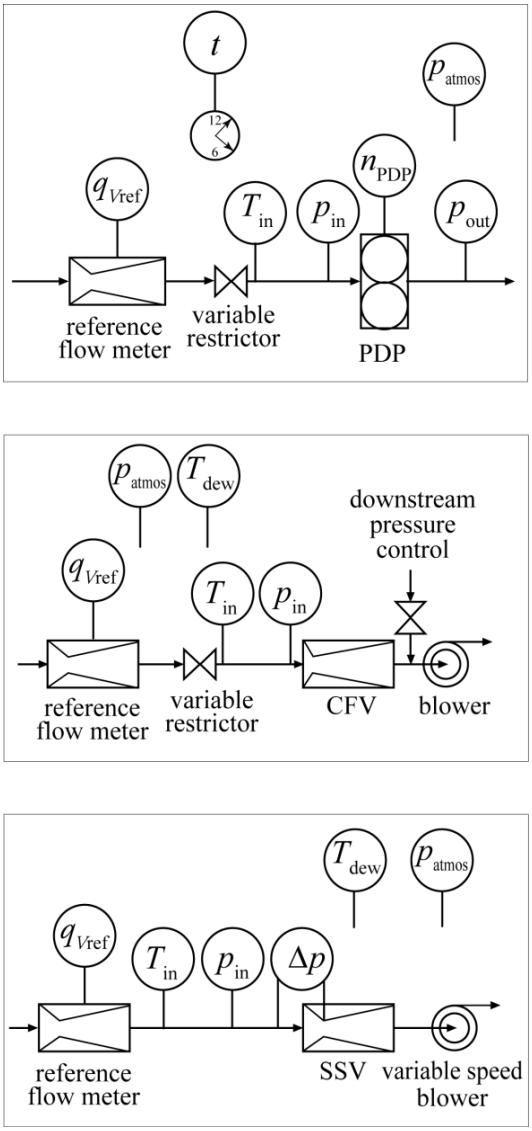


Figure A.4-4

Schematic Diagrams for
Diluted Exhaust Flow CVS Calibration

8.1.8.5. CVS and batch sampler verification (propane check)

8.1.8.5.1. Introduction

(a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in sub- clause (f) of this clause. Using good engineering judgment and safe practices, this check may be performed

using a gas other than propane, such as CO_2 or CO. A failed propane check might indicate one or more problems that may require corrective action, as follows:

(i) Incorrect analyser calibration. The FID analyser shall be re-calibrated, repaired, or replaced;

(ii) Leak checks shall be performed on CVS tunnel, connections, fasteners, and HC sampling system according to clause 8.1.8.7. of this Annex;

(iii) The verification for poor mixing shall be performed in accordance with clause 9.2.2. of this Annex;

(iv) The hydrocarbon contamination verification in the sample system shall be performed as described in clause 7.3.1.3. of this Annex;

(v) Change in CVS calibration. An in-situ calibration of the CVS flowmeter shall be performed as described in clause 8.1.8.4. of this Annex;

(vi) Other problems with the CVS or sampling verification hardware or software. The CVS system, CVS verification hardware, and software shall be inspected for discrepancies;

(b) A propane check uses either a reference mass or a reference flow rate of C_3H_8 as a tracer gas in a CVS. If a reference flow rate is used, any non-ideal gas behaviour of C_3H_8 in the reference flowmeter shall be accounted for. See or Appendix A.1 to Annex 5 (mass based approach) or Appendix A.2 to Annexes 5 (molar based approach) which describe how to calibrate and use certain flowmeters. No ideal gas assumption may be used in clause 8.1.8.5. and Annex 5. The propane check compares the calculated mass of injected C_3H_8 using HC measurements and CVS flow rate measurements with the reference value.

8.1.8.5.2. Method of introducing a known amount of propane into the CVS system

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to Annex 5. Either of the following two techniques shall be used.

(a) Metering by means of a gravimetric technique shall be done as follows: A mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ±0.01 g. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated;

(b) Metering with a critical flow orifice shall be done as follows: A known quantity of pure gas (carbon monoxide or propane) shall be fed into the

CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

8.1.8.5.3. Preparation of the propane check

The propane check shall be prepared as follows:

(a) If a reference mass of C_3H_8 is used instead of a reference flow rate, a cylinder charged with C_3H_8 shall beobtained. The reference cylinder's mass of C_3H_8 shall be determined within ±0.5 per cent of the amount of C_3H_8 that is expected to be used;

(b) Appropriate flow rates shall be selected for the CVS and C_3H_8;

(c) A C_3H_8 injection port shall be selected in the CVS. The port location shall be selected to be as close as practical to the location where engine exhaust is introduced into the CVS. The C_3H_8 cylinder shall be connected to the injection system;

(d) The CVS shall be operated and stabilised;

(e) Any heat exchangers in the sampling system shall be pre-heated or pre-cooled;

(f) Heated and cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilise at operating temperature;

(g) If applicable, a vacuum side leak verification of the HC sampling system shall be performed as described in clause 8.1.8.7.

8.1.8.5.4. Preparation of the HC sampling system for the propane check

Vacuum side leak check verification of the HC sampling system may be performed according to sub- clause (g) of this clause. If this procedure is used, the HC contamination procedure in clause 7.3.1.3. may be used. If the vacuum side leak check is not performed according to sub- clause (g), then the HC sampling system shall be zeroed, spanned, and verified for contamination, as follows:

(a) The lowest HC analyser range that can measure the C_3H_8 concentration expected for the CVS and C_3H_8 flow rates shall be selected;

(b) The HC analyser shall be zeroed using zero air introduced at the analyser port;

(c) The HC analyser shall be spanned using C_3H_8 span gas introduced at the analyser port;

(d) Zero air shall be overflowed at the HC probe or into a fitting between the HC probe and the transfer line;

(e) The stable HC concentration of the HC sampling system shall be measured as overflow zero air flows. For batch HC measurement, the

batch container (such as a bag) shall be filled and the HC overflow concentration measured;

(f) If the overflow HC concentration exceeds 2 µmol/mol, the procedure may not be advanced until contamination is eliminated. The source of the contamination shall be determined and corrective action taken, such as cleaning the system or replacing contaminated portions;

(g) When the overflow HC concentration does not exceed 2 µmol/mol, this value shall be recorded as x_{HCinit} and it shall be used to correct for HC contamination as described in Annex 5, Appendix A.1 (mass based approach) or Annex 5, Appendix A.2 (molar based approach).

8.1.8.5.5. Propane check performance

(a) The propane check shall be performed as follows:

(i) For batch HC sampling, clean storage media, such as evacuated bags shall be connected;

(ii) HC measurement instruments shall be operated according to the instrument manufacturer's instructions;

(iii) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded;

(iv) Any integrating devices shall be zeroed;

(v) Sampling shall begin and any flow integrators shall be started;

(vi) C_3H_8 shall be released at the rate selected. If a reference flow rate of C_3H_8 is used, the integration of this flow rate shall be started;

(vii) C_3H_8 shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8;

(viii) The C_3H_8 cylinder shall be shut off and sampling shall continue until it has been accounted for time delays due to sample transport and analyser response;

(ix) Sampling shall be stopped and any integrators shall be stopped;

(b) In case the metering with a critical flow orifice is used, the following procedure may be used for the propane check as the alternative method of the previous sub- clause;

(i) For batch HC sampling, clean storage media, such as evacuated bags shall be connected;

(ii) HC measurement instruments shall be operated according to the instrument manufacturer's instructions;

(iii) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded;

(iv) Any integrating devices shall be zeroed;

(v) The contents of the C_3H_8 reference cylinder shall be released at the rate selected;

(vi) Sampling shall begin, and any flow integrators started after confirming that HC concentration is to be stable;

(vii) The cylinder's contents shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8;

(viii) Any integrators shall be stopped;

(ix) The C_3H_8 reference cylinder shall be shut off.

8.1.8.5.6. Evaluation of the propane check

Post-test procedure shall be performed as follows:

(a) If batch sampling has been used, batch samples shall be analysed as soon as practical;

(b) After analysing HC, contamination and background shall be corrected for;

(c) Total C_3H_8 mass based on the CVS and HC data shall be calculated as described in Annex 5, using the molar mass of C_3H_8, M_{C3H8}, instead the effective molar mass of HC, M_{HC};

(d) If a reference mass (gravimetric technique) is used, the cylinder's propane mass shall be determined within ±0.5 per cent and the C_3H_8 reference mass shall be determined by subtracting the empty cylinder propane mass from the full cylinder propane mass. If a critical flow orifice (metering with a critical flow orifice) is used, the propane mass shall be determined as flow rate multiplied by the test time;

(e) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±3.0 per cent of the reference mass, the CVS passes this verification.

8.1.8.5.7. PM secondary dilution system verification

When the propane check is to be repeated to verify the PM secondary dilution system, the following procedure from sub- clauses (a) to (d) shall be used for this verification:

(a) The HC sampling system shall be configured to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, HC may be sampled from the batch sampler pump's exhaust. Caution shall be used when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flowmeter will cause a false failure of the propane check;

(b) The propane check shall be repeated as described in this clause, but HC shall be sampled from the batch sampler;

(c) C_3H_8 mass shall be calculated, taking into account any secondary dilution from the batch sampler;

(d) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±5 per cent of the reference mass, the batch sampler passes this verification. If not, corrective action shall be taken.

8.1.8.5.8. Sample dryer verification

If a humidity sensor for continuous monitoring of dew point at the sample dryer outlet is used this check does not apply, as long as it is ensured that the dryer outlet humidity is below the minimum values used for quench, interference, and compensation checks.

(a) If a sample dryer is used as allowed in clause 9.3.2.3.1. of this Annex to remove water from the sample gas, the performance shall be verified upon installation, after major maintenance, for thermal chiller. For osmotic membrane dryers, the performance shall be verified upon installation, after major maintenance, and within 35 days of testing;

(b) Water can inhibit an analyser's ability to properly measure the exhaust component of interest and thus is sometimes removed before the sample gas reaches the analyser. For example water can negatively interfere with a CLD's NO_X response through collisional quenching and can positively interfere with an NDIR analyser by causing a response similar to CO;

(c) The sample dryer shall meet the specifications as determined in clause 9.3.2.3.1. of this Annex for dew point, T_{dew}, and absolute pressure, p_{total}, downstream of the osmotic-membrane dryer or thermal chiller;

(d) The following sample dryer verification procedure method shall be used to determine sample dryer performance, or good engineering judgment shall be used to develop a different protocol:

(i) polytetrafluoroethylene (‘PTFE’) or stainless steel tubing shall be used to make necessary connections;

(ii) N_2 or purified air shall be humidified by bubbling it through distilled water in a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling;

(iii) The humidified gas shall be introduced upstream of the sample dryer;

(iv) The humidified gas temperature downstream of the vessel shall be maintained at least 5 K (5 ºC) above its dew point;

(v) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the inlet of the sample dryer to verify that the dew point is the highest that was estimated during emission sampling;

(vi) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the outlet of the sample dryer;

(vii) The sample dryer meets the verification if the result of sub-clause (d)(vi) of this clause is less than the dew point corresponding to the sample dryer specifications as determined

in clause 9.3.2.3.1. of this Annex plus 2 K (+2 °C) or if the mol fraction from sub- clause (d)(vi) is less than the corresponding sample dryer specifications plus 0.002 mol/mol or 0.2 volume per cent. Note for this verification, sample dew point is expressed in absolute temperature, Kelvin.

8.1.8.6. Periodic calibration of the partial flow PM and associated raw exhaust gas measurement systems

8.1.8.6.1. Specifications for differential flow measurement

For partial flow dilution systems to extract a proportional raw exhaust sample, the accuracy of the sample flow q_{mp} is of special concern, if not measured directly, but determined by differential flow measurement as set out in equation (A.4-20):

$$q_{mp} = q_{mdew} - q_{mdw} \quad \text{(A.4-20)}$$

Where:

q_{mp} = sample mass flow rate of exhaust gas into partial flow dilution system

q_{mdw} = dilution air mass flow rate (on wet basis)

q_{mdew} = diluted exhaust gas mass flow rate on wet basis

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ±5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of q_{mp} can be obtained by either of the following methods:

(a) The absolute accuracies of q_{mdew} and q_{mdw} are ±0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios;

(b) Calibration of q_{mdw} relative to q_{mdew} is carried out such that the same accuracies for q_{mp} as in (a) are obtained. For details see clause 8.1.8.6.2. of this Annex;

(c) The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO_2. Accuracies equivalent to method (a) for q_{mp} are required;

(d) The absolute accuracy of q_{mdew} and q_{mdw} is within ±2 per cent of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0.2 per cent and the linearity error is within ±0.2 per cent of the highest q_{mdew} observed during the test.

8.1.8.6.2. Calibration of differential flow measurement

The partial flow dilution system to extract a proportional raw exhaust sample shall be periodically calibrated with an accurate flowmeter traceable to international and/or national standards. The flowmeter or the flow measurement instrumentation shall be calibrated in one of the following

procedures, such that the probe flow q_{mp} into the tunnel shall fulfil the accuracy requirements of clause 8.1.8.6.1. of this Annex.

(a) The flowmeter for q_{mdw} shall be connected in series to the flowmeter for q_{mdew}, the difference between the two flowmeters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed;

(b) A calibrated flow device shall be connected in series to the flowmeter for q_{mdew} and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flowmeter for q_{mdw}, and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 15, relative to q_{mdew} used during the test;

(c) The transfer line TL (see Figure A.4-5) shall be disconnected from the exhaust and a calibrated flow measuring device with a suitable range to measure q_{mp} shall be connected to the transfer line. q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 15. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and dilution air flow is passed through the corresponding meters as in the actual test;

(d) A tracer gas, shall be fed into the exhaust transfer line TL. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_X. After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 15. The accuracy of the sample flow shall be determined from the dilution ratio r_d by means of equation (A.4-21):

$$q_{mp} = q_{mdew} / r_d \qquad \text{(A.4-21)}$$

The accuracies of the gas analysers shall be taken into account to guarantee the accuracy of q_{mp}.

8.1.8.6.3. Special requirements for differential flow measurement

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex 5 **4**, Appendix A.5 **4** shall be applied. The carbon flow rates shall be calculated according to equations of Annex 5 ~~4,~~ Appendix A.5 **4**. All carbon flow rates shall agree to within 5 per cent.

8.1.8.6.3.1. Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way.

The accuracy of the flowmeters shall be checked by the same method as used for calibration (see clause 8.1.8.6.2. of this Annex) for at least two points, including flow values of q_{mdw} that correspond to dilution ratios between 5 and 15 for the q_{mdew} value used during the test.

If it can be demonstrated by records of the calibration procedure under clause 8.1.8.6.2. of this Annex that the flowmeter calibration is stable over a longer period of time, the pre-test check may be omitted.

8.1.8.6.3.2. Determination of the transformation time

The system settings for the transformation time evaluation shall be the same as during measurement of the test run. The transformation time, defined in Figure A.5-1, shall be determined by the following method:

An independent reference flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system according to good engineering judgment. A step change shall be introduced to the exhaust flow (or air flow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90 per cent of full scale. The trigger for the step change shall be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50 per cent point of the flowmeter response. In a similar manner, the transformation times of the q_{mp} signal (i.e. sample flow of exhaust gas into partial flow dilution system) and of the $q_{mew,i}$ signal (i.e. the exhaust gas mass flow rate on wet basis supplied by the exhaust flowmeter) shall be determined. These signals are used in the regression checks performed after each test (see clause 8.2.1.2. of this Annex).

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 ms) of the reference flowmeter shall be subtracted from this value. Where look-ahead control is required, the look-ahead value of the partial flow dilution system shall be applied in accordance with clause 8.2.1.2. of this Annex.

8.1.8.7. Vacuum-side leak verification

8.1.8.7.1. Scope and frequency

Upon initial sampling system installation, after major maintenance such as pre-filter changes, and within 8 hours prior to each duty-cycle sequence, it shall be verified that there are no significant vacuum-side leaks using one of the leak tests described in this clause. This verification does not apply to any full-flow portion of a CVS dilution system.

8.1.8.7.2. Measurement principles

A leak may be detected either by measuring a small amount of flow when there shall be zero flow, by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system or by measuring the pressure increase of an evacuated system.

8.1.8.7.3. Low-flow leak test

A sampling system shall be tested for low-flow leaks as follows:

(a) The probe end of the system shall be sealed by taking one of the following steps:

(i) The end of the sample probe shall be capped or plugged;

(ii) The transfer line shall be disconnected at the probe and the transfer line capped or plugged;

(iii) A leak-tight valve in-line between a probe and transfer line shall be closed;

(b) All vacuum pumps shall be operated. After stabilizing, it shall be verified that the flow through the vacuum-side of the sampling system is less than 0.5 per cent of the system's normal in-use flow rate. Typical analyser and bypass flows may be estimated as an approximation of the system's normal in-use flow rate.

8.1.8.7.4. Dilution-of-span-gas leak test

Any gas analyser may be used for this test. If a FID is used for this test, any HC contamination in the sampling system shall be corrected according to Appendices A.1 and A.2 to Annex 5 on HC determination. Misleading results shall be avoided by using only analysers that have a repeatability of 0.5 per cent or better at the span gas concentration used for this test. The vacuum side leak check shall be performed as follows:

(a) A gas analyser shall be prepared as it would be for emission testing;

(b) Span gas shall be supplied to the analyser port and it shall be verified that the span gas concentration is measured within its expected measurement accuracy and repeatability;

(c) Overflow span gas shall be routed to one of the following locations in the sampling system:

(i) The end of the sample probe;

(ii) The transfer line shall be disconnected at the probe connection, and the span gas overflown at the open end of the transfer line;

(iii) A three-way valve installed in-line between a probe and its transfer line;

(d) It shall be verified that the measured overflow span gas concentration is within ±0.5 per cent of the span gas concentration. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyser itself. A measured value higher than expected does not indicate a leak.

8.1.8.7.5. Vacuum-decay leak test

To perform this test a vacuum shall be applied to the vacuum-side volume of the sampling system and the leak rate of the system shall be observed as a decay in the applied vacuum. To perform this test the vacuum-side volume of the sampling system shall be known to within ±10 per cent of its true volume. For this test measurement instruments that meet the specifications of clauses 8.1. and 9.4. shall also be used.

A vacuum-decay leak test shall be performed as follows:

(a) The probe end of the system shall be sealed as close to the probe opening as possible by taking one of the following steps:

(i) The end of the sample probe shall be capped or plugged;

(ii) The transfer line at the probe shall be disconnected and the transfer line capped or plugged;

(iii) A leak-tight valve in-line between a probe and transfer line shall be closed;

(b) All vacuum pumps shall be operated. A vacuum shall be drawn that is representative of normal operating conditions. In the case of sample bags, it is recommended that the normal sample bag pump-down procedure be repeated twice to minimise any trapped volumes;

(c) The sample pumps shall be turned off and the system sealed. The absolute pressure of the trapped gas and optionally the system absolute temperature shall be measured and recorded. Sufficient time shall be allowed for any transients to settle and long enough for a leak at 0.5 per cent to have caused a pressure change of at least 10 times the resolution of the pressure transducer. The pressure and optionally temperature shall be recorded once again;

(d) The leak flow rate based on an assumed value of zero for pumped-down bag volumes and based on known values for the sample system volume, the initial and final pressures, optional temperatures, and elapsed time shall be calculated. It shall be verified that the vacuum-decay leak flow rate is less than 0.5 per cent of the system's normal in-use flow rate by means of equation (A.4-22):

$$q_{V\,\mathrm{leak}} = \frac{V_{\mathrm{vac}}}{R} \frac{\left(\frac{p_2}{T_2} - \frac{p_1}{T_1} \right)}{\left(t_2 - t_1 \right)} \qquad \text{(A.4-22)}$$

Where:

$q_{V\mathrm{leak}}$ = vacuum-decay leak rate [mol/s]

V_{vac} = geometric volume of the vacuum-side of the sampling system [m^3]

R = molar gas constant [J/(mol·K)]

p_2 = vacuum-side absolute pressure at time t_2 [Pa]

T_2 = vacuum-side absolute temperature at time t_2 [K]

p_1 = vacuum-side absolute pressure at time t_1 [Pa]

T_1 = vacuum-side absolute temperature at time t_1 [K]

t_2 = time at completion of vacuum-decay leak verification test [s]

t_1 = time at start of vacuum-decay leak verification test [s]

8.1.9. CO and CO_2 measurements

8.1.9.1. H_2O interference verification for CO_2 NDIR analysers

8.1.9.1.1. Scope and frequency

If CO_2 is measured using an NDIR analyser, the amount of H_2O interference shall be verified after initial analyser installation and after major maintenance.

8.1.9.1.2. Measurement principles

H_2O can interfere with an NDIR analyser's response to CO_2. If the NDIR analyser uses compensation algorithms that use measurements of other gases to meet this interference verification, these other measurements shall be conducted simultaneously to test the compensation algorithms during the analyser interference verification.

8.1.9.1.3. System requirements

A CO_2 NDIR analyser shall have an H_2O interference that is within (0.0 ± 0.4) mmol/mol (of the expected mean CO_2 concentration).

8.1.9.1.4. Procedure

The interference verification shall be performed as follows:

(a) The CO_2 NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test;

(b) A humidified test gas shall be created by bubbling zero air that meets the specifications in clause 9.5.1 of this Annex through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O content in the test gas at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H2O content in the test gas at least as high as the maximum expected at the outlet of the dryer, according to the requirements in clause 9.3.2.3.1.1. of this Annex;

(c) The humidified test gas temperature shall be maintained at least 5 K (5 °C) above its dew point downstream of the vessel;

(d) The humidified test gas shall be introduced into the sampling system. The humidified test gas may be introduced downstream of any sample dryer, if one is used during testing;

(e) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O};

(f) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyser;

(g) Time shall be allowed for the analyser response to stabilise. Stabilization time shall include time to purge the transfer line and to account for analyser response;

(h) While the analyser measures the sample's concentration, 30 s of sampled data shall be recorded. The arithmetic mean of this data shall be calculated. The analyser meets the interference verification if this value is within (0.0 ± 0.4) mmol/mol

8.1.9.2. H_2O and CO_2 interference verification for CO NDIR analysers

8.1.9.2.1. Scope and frequency

If CO is measured using an NDIR analyser, the amount of H_2O and CO_2 interference shall be verified after initial analyser installation and after major maintenance.

8.1.9.2.2. Measurement principles

H_2O and CO_2 can positively interfere with an NDIR analyser by causing a response similar to CO. If the NDIR analyser uses compensation algorithms that use measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyser interference verification.

8.1.9.2.3. System requirements

A CO NDIR analyser shall have combined H_2O and CO_2 interference that is within ±2 per cent of the expected mean concentration of CO.

8.1.9.2.4. Procedure

The interference verification shall be performed as follows:

(a) The CO NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test;

(b) A humidified CO2 test gas shall be created by bubbling a CO2 span gas through distilled water in a sealed vessel. If the sample is not passed through a dryer, vessel temperature shall be controleed to generate an H_2O content in the test gas at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, vessel temperature shall be controleed to generate an H_2O content in the test gas at least as high as the maximum expected at the outlet of the dryer, according to the requirements in clause 9.3.2.3.1.1. of this Annex. A CO2 span gas concentration shall be used at least as high as the maximum expected during testing;

(c) The humidified CO_2 test gas shall be introduced into the sampling system. The humidified CO_2 test gas may be introduced downstream of any sample dryer, if one is used during testing;

(d) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example,

dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O};

(e) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyser;

(f) Time shall be allowed for the analyser response to stabilise;

(g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated;

(h) The analyser meets the interference verification if the result of sub-clause (g) of this clause meets the tolerance in clause 8.1.9.2.3. of this Annex;

(i) Interference procedures for CO_2 and H_2O may be also run separately. If the CO_2 and H_2O levels used are higher than the maximum levels expected during testing, each observed interference value shall be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference procedures concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the two scaled interference values shall meet the tolerance in clause 8.1.9.2.3. of this Annex.

8.1.10. Hydrocarbon measurements

8.1.10.1. FID optimisation and verification

8.1.10.1.1. Scope and frequency

For all FID analysers, the FID shall be calibrated upon initial installation. The calibration shall be repeated as needed using good engineering judgment. The following steps shall be performed for a FID that measures HC:

(a) A FID's response to various hydrocarbons shall be optimised after initial analyser installation and after major maintenance. FID response to propylene and toluene shall be between 0.9 and 1.1 relative to propane;

(b) A FID's methane (CH_4) response factor shall be determined after initial analyser installation and after major maintenance as described in clause 8.1.10.1.4. of this Annex;

(c) Methane (CH_4) response shall be verified within 185 days before testing.

8.1.10.1.2. Calibration

Good engineering judgment shall be used to develop a calibration procedure, such as one based on the FID-analyser manufacturer's instructions and recommended frequency for calibrating the FID. The FID shall be calibrated using C_3H_8 calibration gases that meet the specifications of clause 9.5.1. of this Annex. It shall be calibrated on a carbon number basis of one (C_1).

8.1.10.1.3. HC FID response optimisation

This procedure is only for FID analysers that measure HC.

(a) Instrument manufacturer requirements and good engineering judgment shall be used for initial instrument start-up and basic operating adjustment using FID fuel and zero air. Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimised to meet the requirement of the hydrocarbon response factors and the oxygen interference check according to sub-clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2. of this Annex at the most common analyser range expected during emission testing. Higher analyser range may be used according to the instrument manufacturer's recommendation and good engineering judgment in order to optimise FID accurately, if the common analyser range is lower than the minimum range for the optimisation specified by the instrument manufacturer;

(b) Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimised at the most common analyser range expected during emission testing. With the FID fuel and airflow rates set at the manufacturer's recommendations, a span gas shall be introduced to the analyser;

(c) The following step from (i) to (iv) or the procedure instructed by the instrument manufacturer shall be taken for optimisation. The procedures outlined in SAE paper No. 770141 may be optionally used for optimisation;

(i) The response at a given FID fuel flow shall be determined from the difference between the span gas response and the zero gas response;

(ii) The FID fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these FID fuel flows shall be recorded;

(iii) The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimisation depending on the results of the hydrocarbon response factors and the oxygen interference check according to sub- clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2. of this Annex;

(iv) If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating sub- clause (a) of clause 8.1.10.1.1. and clause 8.1.10.2. of this Annex for each flow;

(d) The optimum flow rates and/or pressures for FID fuel and burner air shall be determined, and they shall be sampled and recorded for future reference.

8.1.10.1.4. HC FID CH_4response factor determination

Since FID analysers generally have a different response to CH_4 versus C_3H_8, each HC FID analyser's CH_4 response factor, $RF_{CH4[THC\text{-}FID]}$ shall be determined, after FID optimisation. The most recent $RF_{CH4[THC\text{-}FID]}$ measured in accordance with this clause shall be used in the calculations for HC determination described in Annex 5, Appendix A.2 (molar based approach) or Annex 5, Appendix A.1 (mass based approach) to compensate for CH_4 response. $RF_{CH4[THC\text{-}FID]}$ shall be determined as follows:

(a) A C_3H_8 span gas concentration shall be selected to span the analyser before emission testing. Only span gases that meet the specifications of clause 9.5.1. of this Annex shall be selected and the C_3H_8 concentration of the gas shall be recorded;

(b) A CH_4 span gas that meets the specifications of clause 9.5.1. of this Annex shall be selected and the CH_4 concentration of the gas shall be recorded;

(c) The FID analyser shall be operated according to the manufacturer's instructions;

(d) It shall be confirmed that the FID analyser has been calibrated using C_3H_8. Calibration shall be performed on a carbon number basis of one (C_1);

(e) The FID shall be zeroed with a zero gas used for emission testing;

(f) The FID shall be spanned with the selected C_3H_8 span gas;

(g) The selected CH_4 span gas shall be introduced at the sample port of the FID analyser, the CH_4 span gas that has been selected under sub-clause (b) of this clause;

(h) The analyser response shall be stabilised. Stabilisation time may include time to purge the analyser and to account for its response;

(i) While the analyser measures the CH_4 concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these values shall be calculated;

(j) The mean measured concentration shall be divided by the recorded span concentration of the CH_4 calibration gas. The result is the FID analyser's response factor for CH_4, $RF_{CH4[THC\text{-}FID]}$.

8.1.10.1.5. HC FID methane (CH_4) response verification

If the value of $RF_{CH4[THC\text{-}FID]}$ obtained in accordance with clause 8.1.10.1.4. of this Annex is within ±5.0 per cent of its most recent previously determined value, the HC FID passes the methane response verification.

(a) It shall be first verified that the pressures and / or flow rates of FID fuel, burner air, and sample are each within ±0.5 per cent of their most recent previously recorded values, as described in clause 8.1.10.1.3. of this Annex. If these flow rates have to be adjusted, a new $RF_{CH4[THC\text{-}FID]}$ shall

be determined as described in clause 8.1.10.1.4. of this Annex. It should be verified that the value of $RF_{CH4[THC-FID]}$ determined is within the tolerance specified in this clause 8.1.10.1.5. of this Annex;

(b) If $RF_{CH4[THC-FID]}$ is not within the tolerance specified in this clause 8.1.10.1.5. of this Annex, the FID response shall be re-optimised as described in clause 8.1.10.1.3. of this Annex;

(c) A new $RF_{CH4[THC-FID]}$ shall be determined as described in clause 8.1.10.1.4. of this Annex. This new value of $RF_{CH4[THC-FID]}$ shall be used in the calculations for HC determination, as described in Annex 5, Appendix A.2 (molar based approach) or Annex 5, Appendix A.1 (mass based approach).

8.1.10.2. Non-stoichiometric raw exhaust gas FID O_2 interference verification

8.1.10.2.1. Scope and frequency

If FID analysers are used for raw exhaust measurements, the amount of FID O_2 interference shall be verified upon initial installation and after major maintenance.

8.1.10.2.2. Measurement principles

Changes in O_2 concentration in raw exhaust can affect FID response by changing FID flame temperature. FID fuel, burner air, and sample flow shall be optimised to meet this verification. FID performance shall be verified with the compensation algorithms for FID O_2 interference that is active during an emission test.

8.1.10.2.3. System requirements

Any FID analyser used during testing shall meet the FID O_2 interference verification according to the procedure in this clause.

8.1.10.2.4. Procedure

FID O_2 interference shall be determined as follows, noting that one or more gas dividers may be used to create reference gas concentrations that are required to perform this verification:

(a) Three span reference gases shall be selected that meet the specifications set out in clause 9.5.1 of this Annex. and contain C_3H_8 concentration used to span the analysers before emissions testing. The three balance gas concentrations shall be selected such that the concentrations of O_2 and N_2 represent the minimum and maximum and intermediate O_2 concentrations expected during testing. The requirement for using the average O_2 concentration can be removed if the FID is calibrated with span gas balanced with the average expected oxygen concentration;

(b) It shall be confirmed that the FID analyser meets all the specifications of clause 8.1.10.1. of this Annex;

(c) The FID analyser shall be started and operated as it would be before an emission test. Regardless of the FID burner's air source during testing, zero air shall be used as the FID burner's air source for this verification;

(d) The analyser shall be set at zero;

(e) The analyser shall be spanned using a span gas that is used during emissions testing;

(f) The zero response shall be checked by using the zero gas used during emission testing. It shall be proceeded to the next step if the mean zero response of 30 s of sampled data is within ±0.5 per cent of the span reference value used in sub- clause (e) of this clause, otherwise the procedure shall be restarted at sub- clause (d) of this clause;

(g) The analyser response shall be checked using the span gas that has the minimum concentration of O_2 expected during testing. The mean response of 30 s of stabilised sample data shall be recorded as $x_{O2minHC}$;

(h) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilised sample data is within ±0.5 per cent of the span reference value used in sub- clause (e) of this clause, otherwise the procedure shall be restarted at sub-clause (d) of this clause;

(i) The analyser response shall be checked using the span gas that has the average concentration of O_2 expected during testing. The mean response of 30 s of stabilised sample data shall be recorded as $x_{O2avgHC}$;

(j) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilised sample data is within ±0.5 per cent of the span reference value used in clause (e) of this clause, otherwise the procedure shall be restarted at clause (d) of this clause;

(k) The analyser response shall be checked using the span gas that has the maximum concentration of O_2 expected during testing. The mean response of 30 s of stabilised sample data shall be recorded as $x_{O2maxHC}$;

(l) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilised sample data is within ±0.5 per cent of the span reference value used in clause (e) of this clause, otherwise the procedure at clause (d) of this clause shall be restarted;

(m) The percent difference between $x_{O2maxHC}$ and its reference gas concentration shall be calculated. The percent difference between $x_{O2avgHC}$ and its reference gas concentration shall be calculated. The percent difference between $x_{O2minHC}$ and its reference gas concentration shall be calculated. The maximum percent difference of the three shall be determined. This is the O_2 interference;

(n) If the O_2 interference is within ±3 per cent, the FID passes the O_2 interference verification; otherwise one or more of the following need to be performed to address the deficiency:

(i) The verification shall be repeated to determine if a mistake was made during the procedure;

(ii) The zero and span gases for emission testing shall be selected that contain higher or lower O_2 concentrations and the verification shall be repeated;

(iii) The FID burner air, fuel, and sample flow rates shall be adjusted. Note that if these flow rates are adjusted on a HC FID to meet the O_2 interference verification, the RF_{CH4} shall be reset for the next RF_{CH4} verification. The O_2 interference verification shall be repeated after adjustment and RF_{CH4} shall be determined;

(iv) The FID shall be repaired or replaced and the O_2 interference verification shall be repeated.

8.1.11. NO_X measurements

8.1.11.1. CLD CO_2 and H_2O quench verification

8.1.11.1.1. Scope and frequency

If a CLD analyser is used to measure NO_X, the amount of H_2O and CO_2 quench shall be verified after installing the CLD analyser and after major maintenance.

8.1.11.1.2. Measurement principles

H_2O and CO_2 can negatively interfere with a CLD's NO_X response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD uses to detect NO_X. This procedure and the calculations in clause 8.1.11.2.3. of this Annex determine quench and scale the quench results to the maximum mole fraction of H_2O and the maximum CO_2 concentration expected during emission testing. If the CLD analyser uses quench compensation algorithms that use H_2O and/or CO_2 measurement instruments, quench shall be evaluated with these instruments active and with the compensation algorithms applied.

8.1.11.1.3. System requirements

For dilute measurement a CLD analyser shall not exceed a combined H_2O and CO_2 quench of ±2 per cent. For raw measurement a CLD analyser shall not exceed a combined H_2O and CO_2 quench of ±2.5 per cent. Combined quench is the sum of the CO_2 quench determined as described in clause 8.1.11.1.4. of this Annex and the H_2O quench as determined in clause 8.1.11.1.5. of this Annex. If these requirements are not met, corrective action shall be taken by repairing or replacing the analyser. Before running emission tests, it shall be verified that the corrective action have successfully restored the analyser to proper functioning.

8.1.11.1.4. CO_2quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine CO_2 quench by using a gas divider that blends binary span gases with zero gas as the diluent and meets the specifications in clause 9.4.5.6. of this Annex, or good engineering judgment shall be used to develop a different protocol:

(a) PTFE or stainless steel tubing shall be used to make necessary connections;

(b) The gas divider shall be configured such that nearly equal amounts of the span and diluent gases are blended with each other;

(c) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_X, the CLD analyser shall be operated in the NO-only operating mode;

(d) A CO_2 span gas that meets the specifications of clause 9.5.1. of this Annex and a concentration that is approximately twice the maximum CO_2 concentration expected during emission testing shall be used;

(e) An NO span gas that meets the specifications of clause 9.5.1. of this Annex and a concentration that is approximately twice the maximum NO concentration expected during emission testing shall be used. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(f) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from sub-clause (e) of this clause through the gas divider. The NO span gas shall be connected to the span port of the gas divider; a zero gas shall be connected to the diluent port of the gas divider; the same nominal blend ratio shall be used as selected in sub-clause (b) of this clause; and the gas divider's output concentration of NO shall be used to span the CLD analyser. Gas property corrections shall be applied as necessary to ensure accurate gas division;

(g) The CO_2 span gas shall be connected to the span port of the gas divider;

(h) The NO span gas shall be connected to the diluents port of the gas divider;

(i) While flowing NO and CO_2 through the gas divider, the output of the gas divider shall be stabilised. The CO_2 concentration from the gas divider output shall be determined, applying gas property correction as necessary to ensure accurate gas division. This concentration, x_{CO2act}, shall be recorded and it shall be used in the quench verification calculations in clause 8.1.11.2.3. of this Annex. As an alternative to using a gas divider, another simple gas blending device may be used. In this case an analyser shall be used to determine CO_2 concentration. If a NDIR is used together with a simple gas blending device, it shall meet the requirements of this clause and it shall be spanned with the CO_2span gas from sub-clause (d) of this clause. The linearity of the NDIR analyser has to be checked before over the whole range up to twice of the expected maximum CO_2 concentration expected during testing;

(j) The NO concentration shall be measured downstream of the gas divider with the CLD analyser. Time shall be allowed for the analyser response to stabilise. Stabilization time may include time to purge the transfer line and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 s. The arithmetic mean concentration shall be calculated from these data, x_{NOmeas}. x_{NOmeas} shall be recorded and it shall be used in the quench verification calculations in clause 8.1.11.2.3. of this Annex;

(k) The actual NO concentration shall be calculated at the gas divider's outlet, x_{NOact}, based on the span gas concentrations and x_{CO2act} according to equation (A.4-24). The calculated value shall be used in the quench verification calculations in equation (A.4-23);

(l) The values recorded according to clauses 8.1.11.1.4. and 8.1.11.1.5. of this Annex shall be used to calculate quench as described in clause 8.1.11.2.3. of this Annex.

8.1.11.1.5. H_2O quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine H_2O quench, or good engineering judgment shall be used to develop a different protocol:

(a) PTFE or stainless steel tubing shall be used to make necessary connections;

(b) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_X, the CLD analyser shall be operated in the NO-only operating mode;

(c) A NO span gas shall be used that meets the specifications of clause 9.5.1. of this Annex and a concentration that is near the maximum concentration expected during emission testing. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(d) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from clause (c) of this clause, the span gas concentration shall be recorded as x_{NOdry}, and it shall be used in the quench verification calculations in clause 8.1.11.2.3. of this Annex;

(e) The NO span gas shall be humidified by bubbling it through distilled water in a sealed vessel. If the humidified NO span gas sample does not pass through a sample dryer for this verification test, the vessel temperature shall be controlled to generate an H2O content in the test gas approximately equal to the maximum mole fraction of H2O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in clause 8.1.11.2.3. of this Annex scale the measured H2O quench to the highest mole fraction of H2O expected during emission

testing. If the humidified NO span gas sample passes through a dryer for this verification test, the vessel temperature shall be controlled to generate an H2O content in the test gas at least as high as the level the maximum expected at the outlet of the dryer, according to the requirements set out clause 9.3.2.3.1.1 of this Annex. For this case, the quench verification calculations in clause 8.1.11.2.3. of this Annex do not scale the measured H2O quench;

(f) The humidified NO test gas shall be introduced into the sample system. It may be introduced upstream or downstream of a sample dryer that is used during emission testing. Depending on the point of introduction, the respective calculation method of sub-clause (e) shall be selected. Note that the sample dryer shall meet the sample dryer verification check in clause 8.1.8.5.8. of this Annex;

(g) The mole fraction of H_2O in the humidified NO span gas shall bemeasured. In case a sample dryer is used, the mole fraction of H_2O in the humidified NO span gas shall be measured downstream of the sample dryer, $x_{H2Omeas}$. It is recommended to measure $x_{H2Omeas}$ as close as possible to the CLD analyser inlet. $x_{H2Omeas}$ may be calculated from measurements of dew point, T_{dew}, and absolute pressure, p_{total};

(h) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where $x_{H2Omeas}$ is measured to the analyser. It is recommended that the system is designed so the wall temperatures in the transfer lines, fittings, and valves from the point where $x_{H2Omeas}$ is measured to the analyser are at least 5 K (5 ºC) above the local sample gas dew point;

(i) The humidified NO span gas concentration shall be measured with the CLD analyser. Time shall be allowed for the analyser response to stabilise. Stabilization time may include time to purge the transfer line and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 seconds. The arithmetic mean shall be calculated of these data, x_{NOwet}. x_{NOwet} shall be recorded andused in the quench verification calculations in clause 8.1.11.2.3. of this Annex.

8.1.11.2. CLD quench verification calculations

CLD quench-check calculations shall be performed as described in this clause.

8.1.11.2.1. Amount of water expected during testing

The maximum expected mole fraction of water during emission testing, x_{H2Oexp} shall be estimated. This estimate shall be made where the humidified NO span gas was introduced in sub- clause (f) of clause 8.1.11.1.5. of this Annex. When estimating the maximum expected mole fraction of water, the maximum expected water content in combustion air, fuel combustion products, and dilution air (if applicable) shall be considered. If the humidified NO span gas is introduced into the sample system upstream of a sample dryer during the verification test, it is not needed to estimate the maximum expected mole fraction of water and x_{H2Oexp} shall be set equal to $x_{H2Omeas}$.

8.1.11.2.2. Amount of CO_2 expected during testing

The maximum expected CO_2 concentration during emission testing, x_{CO2exp} shall beestimated. This estimate shall be made at the sample system location where the blended NO and CO_2 span gases are introduced according to sub-clause (j) of clause 8.1.11.1.4. of this Annex. When estimating the maximum expected CO_2 concentration, the maximum expected CO_2 content in fuel combustion products and dilution air shall be considered.

8.1.11.2.3. Combined H_2O and CO_2 quench calculations

Combined H_2O and CO_2 quench shall be calculated by means of equation (A.4-23):

$$quench = \left[\left(\frac{\frac{x_{NOwet}}{1 - x_{H2Omeas}}}{x_{NOdry}} - 1 \right) \cdot \frac{x_{H20exp}}{x_{H2Omeas}} + \left(\frac{x_{NOmeas}}{x_{NOact}} - 1 \right) \cdot \frac{x_{CO2exp}}{x_{CO2act}} \right] \cdot 100\% \qquad \text{(A.4-23)}$$

Where:

quench = amount of CLD quench

x_{NOdry} = measured concentration of NO upstream of a bubbler, according to sub- clause (d) of clause 8.1.11.1.5. of this Annex.

x_{NOwet} = measured concentration of NO downstream of a bubbler, according to sub-clause (i) of clause 8.1.11.1.5. of this Annex.

x_{H2Oexp} = maximum expected mole fraction of water during emission testing according to clause 8.1.11.2.1. of this Annex.

$x_{H2Omeas}$ = measured mole fraction of water during the quench verification according to sub- clause (g) of clause 8.1.11.1.5. of this Annex.

x_{NOmeas} = measured concentration of NO when NO span gas is blended with CO_2 span gas, according to sub- clause (j) of clause 8.1.11.1.4. of this Annex.

x_{NOact} = actual concentration of NO when NO span gas is blended with CO_2 span gas, according to sub- clause (k) of clause 8.1.11.1.4. of this Annex and calculated according to equation (A.4-24)

x_{CO2exp} = maximum expected concentration of CO_2 during emission testing, according to clause 8.1.11.2.2. of this Annex.

x_{CO2act} = actual concentration of CO_2 when NO span gas is blended with CO_2 span gas, according to sub-clause (i) of clause 8.1.11.1.4. of this Annex.

$$x_{NOact} = \left(1 - \frac{x_{CO2act}}{x_{CO2span}} \right) \cdot x_{NOspan} \qquad \text{(A.4-24)}$$

Where:

x_{NOspan} = the NO span gas concentration input to the gas divider, according to sub- clause (e) of clause 8.1.11.1.4. of this Annex.

$x_{CO2span}$ = the CO_2 span gas concentration input to the gas divider, according to sub-clause (d) of clause 8.1.11.1.4. of this Annex.

8.1.11.3. NDUV analyser HC and H_2O interference verification

8.1.11.3.1. Scope and frequency

If NO_X is measured using an NDUV analyser, the amount of H_2O and hydrocarbon interference shall be verified after initial analyser installation and after major maintenance.

8.1.11.3.2. Measurement principles

Hydrocarbons and H_2O can positively interfere with a NDUV analyser by causing a response similar to NO_X. If the NDUV analyser uses compensation algorithms that use measurements of other gases to meet this interference verification, simultaneously such measurements shall be conducted to test the algorithms during the analyser interference verification.

8.1.11.3.3. System requirements

A NO_X NDUV analyser shall have combined H_2O and HC interference within ±2 per cent of the mean concentration of NO_X.

8.1.11.3.4. Procedure

The interference verification shall be performed as follows:

(a) The NO_X NDUV analyser shall be started, operated, zeroed, and spanned according to the instrument manufacturer's instructions;

(b) It is recommended to extract engine exhaust to perform this verification. A CLD shall be used that meets the specifications of clause 9.4 of this Annex. to quantify NO_X in the exhaust. The CLD response shall be used as the reference value. Also HC shall be measured in the exhaust with a FID analyser that meets the specifications of clause 9.4 of this Annex. The FID response shall be used as the reference hydrocarbon value;

(c) Upstream of any sample dryer, if one is used during testing, the engine exhaust shall be introduced into the NDUV analyser;

(d) Time shall be allowed for the analyser response to stabilise. Stabilization time may include time to purge the transfer line and to account for analyser response;

(e) While all analysers measure the sample's concentration, 30 s of sampled data shall be recorded, and the arithmetic means for the three analysers calculated;

(f) The CLD mean shall be subtracted from the NDUV mean;

(g) This difference shall be multiplied by the ratio of the expected mean HC concentration to the HC concentration measured during the verification. The analyser meets the interference verification of this clause if this result is within ±2 per cent of the NO_X concentration expected at the emission limit value, as set out in equation (A.4-25):

$$\left|\overline{x}_{\mathrm{NOx,CLD,meas}} - \overline{x}_{\mathrm{NOx,NDUV,meas}}\right| \cdot \left(\frac{\overline{x}_{\mathrm{HC,exp}}}{\overline{x}_{\mathrm{HC,meas}}}\right) \leq 2\% \cdot \left(\overline{x}_{\mathrm{NOx,exp}}\right) \qquad \text{(A.4-25)}$$

Where:

$\overline{x}_{\mathrm{NOx,CLD,meas}}$ = the mean concentration of NO_X measured by CLD [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{NOx,NDUV,meas}}$ = the mean concentration of NO_X measured by NDUV [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{HC,meas}}$ = the mean concentration of HC measured [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{HC,exp}}$ = the mean concentration of HC expected at the standard [µmol/mol] or [ppm]

$\overline{x}_{\mathrm{NOx,exp}}$ = the mean concentration of NO_X expected at the standard [µmol/mol] or [ppm]

8.1.11.4. Sample dryer NO_2 penetration

8.1.11.4.1. Scope and frequency

If a sample dryer is used to dry a sample upstream of a NO_X measurement instrument, but no NO_2-to-NO converter is used upstream of the sample dryer, this verification shall be performed for sample dryer NO_2 penetration. This verification shall be performed after initial installation and after major maintenance.

8.1.11.4.2. Measurement principles

A sample dryerremoves water, which can otherwise interfere with a NO_X measurement. However, liquid water remaining in an improperly designed sample dryercan remove NO_2 from the sample. If a sample dryeris used without an NO_2-to-NO converter upstream, it could therefore remove NO_2 from the sample prior NO_X measurement.

8.1.11.4.3. System requirements

The sample dryershall allow for measuring at least 95 per cent of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.4.4. Procedure

The following procedure shall be used to verify sample dryer performance:

(a) Instrument setup. The analyser and sample dryer manufacturers' start-up and operating instructions shall be followed. The analyser and sample dryer shall be adjusted as needed to optimise performance;

(b) Equipment setup and data collection.

(i) The total NO_X gas analyser(s) shall be zeroed and spanned as it would be before emission testing;

(ii) NO_2 calibration gas (balance gas of dry air) that has an NO_2 concentration that is near the maximum expected during testing shall be selected. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO_2 concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(iii) This calibration gas shall be overflowed at the gas sampling system's probe or overflow fitting. Time shall be allowed for stabilization of the total NO_X response, accounting only for transport delays and instrument response;

(iv) The mean of 30 s of recorded total NO_X data shall be calculated and this value recorded as x_{NOxref};

(v) The flowing the NO_2 calibration gas shall be stopped;

(vi) Next the sampling system shall be saturated by overflowing a dew point generator's output, set at a dew point of 323 K (50 °C), to the gas sampling system's probe or overflow fitting. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water;

(vii) It shall be immediately switched back to overflowing the NO_2 calibration gas used to establish x_{NOxref}. It shall be allowed for stabilization of the total NO_X response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO_X data shall be calculated and this value recorded as $x_{NOxmeas}$;

(viii) $x_{NOxmeas}$ shall be corrected to x_{NOxdry} based upon the residual water vapour that passed through the sample dryer at the sample dryer‘s outlet temperature and pressure;

(c) Performance evaluation.

If x_{NOxdry} is less than 95 per cent of x_{NOxref}, the sample dryer shall be repaired or replaced.

8.1.11.5. NO_2-to-NO converter conversion verification

8.1.11.5.1. Scope and frequency

If an analyser is used that measures only NO to determine NO_X, an NO_2-to-NO converter shall be used upstream of the analyser. This verification shall be performed after installing the converter, after major maintenance and within 35 days before an emission test. This verification shall be repeated at this frequency to verify that the catalytic activity of the NO_2-to-NO converter has not deteriorated.

8.1.11.5.2. Measurement principles

An NO_2-to-NO converter allows an analyser that measures only NO to determine total NO_X by converting the NO_2 in exhaust to NO.

8.1.11.5.3. System requirements

An NO_2-to-NO converter shall allow for measuring at least 95 per cent of the total NO_2 at the maximum expected concentration of NO_2.

8.1.11.5.4. Procedure

The following procedure shall be used to verify the performance of a NO_2-to-NO converter:

(a) For the instrument setup the analyser and NO_2-to-NO converter manufacturers' start-up and operating instructions shall be followed. The analyser and converter shall be adjusted as needed to optimise performance;

(b) An ozonator's inlet shall be connected to a zero-air or oxygen source and its outlet shall be connected to one port of a 3-way tee fitting. An NO span gas shall be connected to another port and the NO_2-to-NO converter inlet shall be connected to the last port;

(c) The following steps shall be taken when performing this check:

(i) The ozonator air shall be set off and the ozonator power shall be turned off and the NO_2-to-NO converter shall be set to the bypass mode (i.e., NO mode). Stabilization shall be allowed for, accounting only for transport delays and instrument response;

(ii) The NO and zero-gas flows shall be adjusted so the NO concentration at the analyser is near the peak total NO_X concentration expected during testing. The NO_2 content of the gas mixture shall be less than 5 per cent of the NO concentration. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOref}. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer;

(iii) The ozonator O_2 supply shall be turned on and the O_2 flow rate adjusted so that the NO indicated by the analyser is about 10 per cent less than x_{NOref}. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value recorded as $x_{NO+O2mix}$;

(iv) The ozonator shall be switched on and the ozone generation rate adjusted so that the NO measured by the analyser is approximately 20 per cent of x_{NOref}, while maintaining at least 10 per cent unreacted NO. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOmeas};

(v) The NO_X analyser shall be switched to NO_X mode and total NO_X measured. The concentration of NO_X shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as $x_{NOxmeas}$;

(vi) The ozonator shall be switched off but gas flow through the system shall be maintained. The NO_X analyser will indicate the NO_X in the NO + O_2 mixture. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as $x_{NOx+O2mix}$;

(vii) O_2 supply shall be turned off. The NO_X analyser will indicate the NO_X in the original NO-in-N_2 mixture. The concentration of NO_X shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOxref}. This value shall be no more than 5 per cent above the x_{NOref} value;

(d) Performance evaluation. The efficiency of the NO_X converter shall be calculated by substituting the concentrations obtained into equation (A.4-26):

$$Efficiency[\%] = \left(1 + \frac{x_{NOxmeas} - x_{NOx+O2mix}}{x_{NO+O2mix} - x_{NOmeas}}\right) \cdot 100 \qquad \text{(A.4-26)}$$

(e) If the result is less than 95 per cent, the NO_2-to-NO converter shall be repaired or replaced.

8.1.12. PM measurements

8.1.12.1. PM balance verifications and weighing process verification

8.1.12.1.1. Scope and frequency

This clause describes three verifications.

(a) Independent verification of PM balance performance within 370 days prior to weighing any filter;

(b) Zero and span of the balance within 12 h prior to weighing any filter;

(c) Verification that the mass determination of reference filters before and after a filter weighing session be less than a specified tolerance.

8.1.12.1.2. Independent verification

The balance manufacturer (or a representative approved by the balance manufacturer) shall verify the balance performance within 370 days of testing in accordance with internal audit procedures.

8.1.12.1.3. Zeroing and spanning

Balance performance shall be verified by zeroing and spanning it with at least one calibration weight, and any weights that are used shall meet the specifications in clause 9.5.2. of this Annex to perform this verification. A manual or automated procedure shall be used:

(a) A manual procedure requires that the balance shall be used in which the balance shall be zeroed and spanned with at least one calibration weight. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of PM measurements, the same process shall be used to verify balance performance;

(b) An automated procedure is carried out with internal calibration weights that are used automatically to verify balance performance. These internal calibration weights shall meet the specifications in clause 9.5.2. of this Annex to perform this verification.

8.1.12.1.4. Reference sample weighing

All mass readings during a weighing session shall be verified by weighing reference PM sample media (e.g. filters) before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre- and post-test mass readings. Successive mass determinations of each reference PM sample media shall return the same value within ±10 µg or ±10 per cent of the expected total PM mass, whichever is higher. Should successive PM sample filter weighing events fail this criterion, all individual test filter mass readings mass readings occurring between the successive reference filter mass determinations shall be invalidated. These filters may be re-weighed in another weighing session. Should a post-test filter be invalidated then the test interval is void. This verification shall be performed as follows:

(a) At least two samples of unused PM sample media shall be kept in the PM-stabilization environment. These shall be used as references. Unused filters of the same material and size shall be selected for use as references;

(b) References shall be stabilised in the PM stabilization environment. References shall be considered stabilised if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of clause 9.3.4.4. of this Annex for at least the preceding 60 min;

(c) The balance shall be exercised several times with a reference sample without recording the values;

(d) The balance shall be zeroed and spanned. A test mass shall be placed on the balance (e.g. calibration weight) and then removed ensuring that the balance returns to an acceptable zero reading within the normal stabilization time;

(e) Each of the reference media (e.g. filters) shall be weighed and their masses recorded. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of reference media (e.g. filters) masses, the same process shall be used to measure mean values of sample media (e.g. filters) masses;

(f) The balance environment dew point, ambient temperature, and atmospheric pressure shall be recorded;

(g) The recorded ambient conditions shall be used to correct results for buoyancy as described in clause 8.1.12.2. of this Annex. The buoyancy-corrected mass of each of the references shall be recorded;

(h) Each of the reference media's (e.g. filter's) buoyancy-corrected reference mass shall be subtracted from its previously measured and recorded buoyancy-corrected mass;

(i) If any of the reference filters' observed mass changes by more than that allowed under this clause, all PM mass determinations made since the last successful reference media (e.g. filter) mass validation shall be invalidated. Reference PM filters maybe discarded if only one of the filters mass has changed by more than the allowable amount and a special cause for that filter's mass change can be positively identified which would not have affected other in-process filters. Thus the validation can be considered a success. In this case, the contaminated reference media shall not be included when determining compliance with sub- clause (j) of this clause, but the affected reference filter shall be discarded and replaced;

(j) If any of the reference masses change by more than that allowed under this clause 8.1.12.1.4. of this Annex, all PM results that were determined between the two times that the reference masses were determined shall be invalidated. If reference PM sample media is discarded according to sub- clause (i) of this clause, at least one reference mass difference that meets the criteria in this clause 8.1.12.1.4. of this Annex shall be available. Otherwise, all PM results that were determined between the two times that the reference media (e.g. filters) masses were determined shall be invalidated.

8.1.12.2. PM sample filter buoyancy correction

8.1.12.2.1. General

PM sample filter shall be corrected for their buoyancy in air. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0.01 to 0.10) per cent of the total weight. A correction to this small fraction of mass would be at the most 0.010 per cent. The buoyancy-corrected values are the tare masses of the PM samples. These buoyancy-corrected values of the pre-test filter weighing are subsequently subtracted from the buoyancy-corrected values of the post-test weighing of the corresponding filter to determine the mass of PM emitted during the test.

8.1.12.2.2. PM sample filter density

Different PM sample filter have different densities. The known density of the sample media shall be used, or one of the densities for some common sampling media shall be used, as follows:

(a) For PTFE-coated borosilicate glass, a sample media density of 2,300 kg/m^3 shall be used;

(b) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95 per cent of the media mass, a sample media density of 920 kg/m^3 shall be used;

(c) For PTFE membrane (film) media with an integral support ring of PTFE, a sample media density of 2,144 kg/m^3 shall be used.

8.1.12.2.3. Air density

Because a PM balance environment shall be tightly controlled to an ambient temperature of 295 ± 1 K (22 ± 1 °C) and a dew point of 282.5 ± 1 K (9.5 ± 1 °C), air density is primarily function of atmospheric pressure. Therefore a buoyancy correction is specified that is only a function of atmospheric pressure.

8.1.12.2.4. Calibration weight density

The stated density of the material of the metal calibration weight shall be used.

8.1.12.2.5. Correction calculation

The PM sample filter shall be corrected for buoyancy by meas of equation (A.4-27):

$$m_{cor} = m_{uncor} \cdot \left(\frac{1 - \frac{\rho_{air}}{\rho_{weight}}}{1 - \frac{\rho_{air}}{\rho_{media}}} \right) \quad \text{(A.4-27)}$$

Where:

m_{cor} = PM sample filter mass corrected for buoyancy

m_{uncor} = PM sample filter mass uncorrected for buoyancy

ρ_{air} = density of air in balance environment

ρ_{weight} = density of calibration weight used to span balance

ρ_{media} = density of PM sample filter

with

$$\rho_{air} = \frac{p_{abs} \cdot M_{mix}}{R \cdot T_{amb}} \quad \text{(A.4-28)}$$

Where:

p_{abs} = absolute pressure in balance environment

M_{mix} = molar mass of air in balance environment

R = molar gas constant

T_{amb} = absolute ambient temperature of balance environment

8.2. Instrument validation for test

8.2.1. Validation of proportional flow control for batch sampling and minimum dilution ratio for PM batch sampling

8.2.1.1. Proportionality criteria for CVS

8.2.1.1.1. Proportional flows

For any pair of flowmeters, the recorded sample and total flow rates or their 1 Hz means shall be used with the statistical calculations in Appendix A.3 of Annex 5. The standard error of the estimate, SEE, of the sample flow rate versus the total flow rate shall be determined. For each test interval, it shall be demonstrated that SEE was less than or equal to 3.5 per cent of the mean sample flow rate.

8.2.1.1.2. Constant flows

For any pair of flowmeters, the recorded sample and total flow rates or their 1 Hz means shall be used to demonstrate that each flow rate was constant within ±2.5 per cent of its respective mean or target flow rate. The following options may be used instead of recording the respective flow rate of each type of meter:

(a) Critical-flow venturi option. For critical-flow venturis, the recorded venturi-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the venturi inlet was constant within ±2.5 per cent of the mean or target density over each test interval. For a CVS critical-flow venturi, this may be demonstrated by showing that the absolute temperature at the venturi inlet was constant within ±4 per cent of the mean or target absolute temperature over each test interval;

(b) Positive-displacement pump option. The recorded pump-inlet conditions or their 1 Hz means shall be used. It shall be demonstrated that the flow density at the pump inlet was constant within ±2.5 per cent of the mean or target density over each test interval. For a CVS pump, this may be demonstrated by showing that the absolute temperature at the pump inlet was constant within ±2 per cent of the mean or target absolute temperature over each test interval.

8.2.1.1.3. Demonstration of proportional sampling

For any proportional batch sample such as a bag or PM filter, it shall be demonstrated that proportional sampling was maintained using one of the following, noting that up to 5 per cent of the total number of data points may be omitted as outliers.

Using good engineering judgment, it shall be demonstrated with an engineering analysis that the proportional-flow control system inherently ensures proportional sampling under all circumstances expected during testing. For example, CFVs may be used for both sample flow and total flow if it is demonstrated that they always have the same inlet pressures and temperatures and that they always operate under critical-flow conditions.

Measured or calculated flows and/or tracer gas concentrations (e.g. CO_2) shall be used to determine the minimum dilution ratio for PM batch sampling over the test interval.

8.2.1.2. Partial flow dilution system validation

For the control of a partial flow dilution system to extract a proportional raw exhaust sample, a fast system response is required; this is identified by the promptness of the partial flow dilution system. The transformation time for the system shall be determined by the procedure in clause 8.1.8.6.3.2. The actual

control of the partial flow dilution system shall be based on the current measured conditions. If the combined transformation time of the exhaust flow measurement and the partial flow system is ≤ 0.3 s, online control shall be used. If the transformation time exceeds 0.3 s, look-ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$(sample flow of exhaust gas into partial flow dilution system), proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$versus $q_{mew,i}$ (exhaust gas mass flow rate on wet basis) shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

(a) The correlation coefficient r^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$shall not be less than 0.95;

(b) The standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 per cent of q_{mp} maximum;

(c) q_{mp} intercept of the regression line shall not exceed ±2 per cent of q_{mp} maximum.

Look-ahead control is required if the combined transformation times of the particulate system, $t_{50,P}$ and of the exhaust mass flow signal, $t_{50,F}$ are > 0.3 s. In this case, a pre-test shall be run and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pre-test, which controls q_{mp}, is shifted by a "look-ahead" time of $t_{50,P} + t_{50,F}$.

For establishing the correlation between $q_{mp,i}$ and $q_{mew,i}$ the data taken during the actual test shall be used, with $q_{mew,i}$ time aligned by $t_{50,F}$ relative to $q_{mp,i}$ (no contribution from $t_{50,P}$ to the time alignment). The time shift between q_{mew} and q_{mp} is the difference between their transformation times that were determined in clause 8.1.8.6.3.2. of this Annex.

8.2.2. Gas analyser range validation, drift validation and drift correction

8.2.2.1. Range validation

If an analyser operated above 100 per cent of its range at any time during the test, the following steps shall be performed:

8.2.2.1.1. Batch sampling

For batch sampling, the sample shall be re-analysed using the lowest analyser range that results in a maximum instrument response below 100 per cent. The result shall be reported from the lowest range from which the analyser operates below 100 per cent of its range for the entire test.

8.2.2.1.2. Continuous sampling

For continuous sampling, the entire test shall be repeated using the next higher analyser range. If the analyser again operates above 100 per cent of its range, the test shall be repeated using the next higher range. The test shall be continued to be repeated until the analyser always operates at less than 100 per cent of its range for the entire test.

8.2.2.2. Drift validation and drift correction

If the drift is within ±1 per cent, the data can be either accepted without any correction or accepted after correction. If the drift is greater than ±1 per cent, two sets of brake specific emission results shall be calculated for each pollutant, or the test shall be voided. One set shall be calculated using data before drift correction and another set of data calculated after correcting all the data for drift according to clause A.1.6. of Appendix A.1. and clause A.2.10. of Appendix A.2 to Annex 5. The comparison shall be made as a percentage of the uncorrected results. The difference between the uncorrected and the corrected brake-specific emission values shall be within ±4 per cent of the uncorrected brake-specific emission values. If not, the entire test is void.

8.2.3. PM sampling media (e.g. filters) preconditioning and tare weighing

Before an emission test, the following steps shall be taken to prepare PM sample filter media and equipment for PM measurements:

8.2.3.1. Periodic verifications

It shall be made sure that the balance and PM-stabilization environments meet the periodic verifications in clause 8.1.12. of this Annex. The reference filter shall be weighed just before weighing test filters to establish an appropriate reference point (see details of the procedure in clause 8.1.12.1. of this Annex). The verification of the stability of the reference filters shall occur after the post-test stabilization period, immediately before the post-test weighing.

8.2.3.2. Visual Inspection

The unused sample filter media shall be visually inspected for defects, defective filters shall be discarded.

8.2.3.3. Grounding

Electrically grounded tweezers or a grounding strap shall be used to handle PM filters as described in clause 9.3.4. of this Annex.

8.2.3.4. Unused sample media

Unused sample media shall be placed in one or more containers that are open to the PM-stabilization environment. If filters are used, they may be placed in the bottom half of a filter cassette.

8.2.3.5. Stabilisation

Sample media shall be stabilised in the PM-stabilization environment. An unused sample medium can be considered stabilised as long as it has been in the PM-stabilization environment for a minimum of 30 min, during which the PM-stabilization environment has been within the specifications of clause 9.3.4. of this Annex. However, if a PM mass of 400 µg or more is expected, then the sample media shall be stabilised for at least 60 min.

8.2.3.6. Weighing

The sample media shall be weighed automatically or manually, as follows:

(a) For automatic weighing, the automation system manufacturer's instructions shall be followed to prepare samples for weighing;

(b) For manual weighing, good engineering judgment shall be used;

(c) Optionally, substitution weighing is permitted (see clause 8.2.3.10. of this Annex);

(d) Once a filter is weighed it shall be returned to the Petri dish and covered.

8.2.3.7. Buoyancy correction

The measured weight shall be corrected for buoyancy as described in clause 8.1.12.2. of this Annex.

8.2.3.8. Repetition

The filter mass measurements may be repeated to determine the average mass of the filter using good engineering judgement and to exclude outliers from the calculation of the average.

8.2.3.9. Tare-weighing

Unused filters that have been tare-weighed shall be loaded into clean filter cassettes and the loaded cassettes shall be placed in a covered or sealed container before they are taken to the test cell for sampling.

8.2.3.10. Substitution weighing

Substitution weighing is an option and, if used, involves measurement of a reference weight before and after each weighing of a PM sampling medium (e.g. filter). While substitution weighing requires more measurements, it corrects for a balance's zero-drift and it relies on balance linearity only over a small range. This is most appropriate when quantifying total PM masses that are less than 0.1 per cent of the sample medium's mass. However, it may not be appropriate when total PM masses exceed 1 per cent of the sample medium's mass. If substitution weighing is used, it shall be used for both pre-test and post-test weighing. The same substitution weight shall be used for both pre-test and post-test weighing. The mass of the substitution weight shall be corrected for buoyancy if the density of the substitution weight is less than 2.0 g/cm^3. The following steps are an example of substitution weighing:

(a) Electrically grounded tweezers or a grounding strap shall be used, as described in clause 9.3.4.6. of this Annex;

(b) A static neutraliser shall be used as described in clause 9.3.4.6. of this Annex to minimise static electric charge on any object before it is placed on the balance pan;

(c) A substitution weight shall be selected that meets the specifications for calibration weights in clause 9.5.2. of this Annex. The substitution weight shall also have the same density as the weight that is used to span the microbalance, and shall be similar in mass to an unused sample medium (e.g. filter). If filters are used, the weight's mass should be about (80 to 100) mg for typical 47 mm diameter filters;

(d) The stable balance reading shall be recorded and then the calibration weight shall be removed;

(e) An unused sampling medium (e.g. a new filter) shall be weighed, the stable balance reading recorded and the balance environment's dew point, ambient temperature, and atmospheric pressure recorded;

(f) The calibration weight shall be reweighed and the stable balance reading recorded;

(g) The arithmetic mean of the two calibration-weight readings that were recorded immediately before and after weighing the unused sample shall be calculated. That mean value shall be subtracted from the unused sample reading, then the true mass of the calibration weight as stated on the calibration-weight certificate shall be added. This result shall be recorded. This is the unused sample's tare weight without correcting for buoyancy;

(h) These substitution-weighing steps shall be repeated for the remainder of the unused sample media;

(i) The instructions given in clauses 8.2.3.7. through 8.2.3.9. of this Annex shall be followed once weighing is completed.

8.2.4. Post-test PM sample conditioning and weighing

Used PM sample filters shall be placed into covered or sealed containers or the filter holders shall be closed, in order to protect the sample filters against ambient contamination. Thus protected, the loaded filters have to be returned to the PM-filter conditioning chamber or room. Then the PM sample filters shall be conditioned and weighted accordingly.

8.2.4.1. Periodic verification

It shall be assured that the weighing and PM-stabilization environments have met the periodic verifications in clause 8.1.12.1. of this Annex. After testing is complete, the filters shall be returned to the weighing and PM-stabilization environment. The weighing and PM-stabilization environment shall meet the ambient conditions requirements in clause 9.3.4.4. of this Annex, otherwise the test filters shall be left covered until proper conditions have been met.

8.2.4.2. Removal from sealed containers

In the PM-stabilization environment, the PM samples shall be removed from the sealed containers. Filters may be removed from their cassettes before or after stabilization. When a filter is removed from a cassette, the top half of the cassette shall be separated from the bottom half using a cassette separator designed for this purpose.

8.2.4.3. Electrical grounding

To handle PM samples, electrically grounded tweezers or a grounding strap shall be used, as described in clause 9.3.4.5. below.

8.2.4.4. Visual inspection

The collected PM samples and the associated filter media shall be inspected visually. If the conditions of either the filter or the collected PM sample appear to have been compromised, or if the particulate matter contacts any surface other than the filter, the sample may not be used to determine particulate emissions. In the case of contact with another surface; the affected surface shall be cleaned before proceeding.

8.2.4.5. Stabilization of PM samples

To stabilise PM samples, they shall be placed in one or more containers that are open to the PM-stabilization environment, which is described in clause 9.3.4.3. of this Annex. A PM sample is stabilised as long as it has been in the PM-stabilization environment for one of the following durations, during which the stabilization environment has been within the specifications of clause 9.3.4.3. below:

(a) If it is expected that a filter's total surface concentration of PM will be greater than 0.353 µg/mm^2, assuming a 400 µg PM loading on a 38 mm diameter filter stain area, the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing;

(b) If it is expected that a filter's total surface concentration of PM will be less than 0.353 µg/mm^2, the filter shall be exposed to the stabilization environment for at least 30 minutes before weighing;

(c) If a filter's total surface concentration of PM to be expected during the test is unknown, the filter shall be exposed to the stabilization environment for at least 60 minutes before weighing.

8.2.4.6. Determination of post-test filter mass

The procedures in clause 8.2.3. shall be repeated (clauses 8.2.3.6. through 8.2.3.9. of this Annex) to determine the post-test filter mass.

8.2.4.7. Total mass

Each buoyancy-corrected filter tare mass shall be subtracted from its respective buoyancy-corrected post-test filter mass. The result is the total mass, m_{total}, which shall be used in emission calculations in Annex 5.

9. MEASUREMENT EQUIPMENT

9.1. Engine dynamometer specification

9.1.1. Shaft work

An engine dynamometer shall be used that has adequate characteristics to perform the applicable duty cycle including the ability to meet appropriate cycle validation criteria. The following dynamometers may be used:

(a) Eddy-current or water-brake dynamometers;

(b) Alternating-current or direct-current motoring dynamometers;

(c) One or more dynamometers.

9.1.2. Transient (NRTC and LSI-NRTC) cycle

Load cell or in-line torque meter may be used for torque measurements.

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

9.1.3. Engine accessories

The work of engine accessories required to fuel, lubricate, or heat the engine, circulate liquid coolant to the engine, or to operate after-treatment devices shall be accounted for and they shall be installed in accordance with clause 6.3.

9.1.4. Engine fixture and power transmission shaft system (category NRSh)

Where necessary for the proper testing of an engine of category NRSh, the engine fixture for the test bench and power transmission shaft system for connection to the dynamometer rotating system specified by the manufacturer shall be used.

9.2. Dilution procedure (if applicable)

9.2.1. Diluent conditions and background concentrations

Gaseous constituents may be measured raw or dilute whereas PM measurement generally requires dilution. Dilution may be accomplished by a full flow or partial flow dilution system. When dilution is applied then the exhaust may be diluted with ambient air, synthetic air, or nitrogen. For gaseous emissions measurement the diluent shall be at least 288 K (15 °C). For PM sampling the temperature of the diluent is specified in clauses 9.2.2. for CVS and 9.2.3. for PFD of this Annex with varying dilution ratio. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. The dilution tunnel walls may be heated or insulated as well as the bulk stream tubing downstream of the tunnel to prevent the precipitation of water-containing constituents from a gas phase to a liquid phase (‘aqueous condensation’).

Before a diluent is mixed with exhaust, it may be preconditioned by increasing or decreasing its temperature or humidity. Constituents may be removed from the diluent to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

(a) Constituent concentrations in the diluent may be measured and compensated for background effects on test results. See Annex 5 for calculations that compensate for background concentrations;

(b) The following changes to the requirements of clauses 7.2, 9.3. and 9.4 of this Annex are permitted for measuring background gaseous or particulate pollutants:

(i) It shall not be required to use proportional sampling;

(ii) Unheated sampling systems may be used;

(iii) Continuous sampling may be used irrespective of the use of batch sampling for diluted emissions;

(iv) Batch sampling may be used irrespective of the use of continuous sampling for diluted emissions.

(c) To account for background PM the following options are available:

(i) For removing background PM, the diluent shall be filtered with high-efficiency particulate air (HEPA) filters that have an initial

minimum collection efficiency specification of 99.97 per cent (see clause 2.1.38. of this Part for procedures related to HEPA filtration efficiencies);

(ii) For correcting for background PM without HEPA filtration, the background PM shall not contribute more than 50 per cent of the net PM collected on the sample filter;

(iii) Background correction of net PM with HEPA filtration is permitted without pressure restriction.

9.2.2. Full flow system

Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flowmeter within the limits. For non constant flow the flow shall be measured directly to allow for proportional sampling. The system shall be designed as follows (see Figure A.4-5):

(a) A tunnel with inside surfaces of stainless steel shall be used. The entire dilution tunnel shall be electrically grounded; Alternatively non-conductive materials may be used for engine categories neither subject to PM nor PN limits;

(b) The exhaust system backpressure shall not be artificially lowered by the dilution air inlet system. The static pressure at the location where raw exhaust is introduced into the tunnel shall be maintained within ±1.2 kPa of atmospheric pressure;

(c) To support mixing the raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. A fraction of dilution air maybe introduced radially from the tunnel's inner surface to minimise exhaust interaction with the tunnel walls;

(d) For PM sampling the temperature of the diluents (ambient air, synthetic air, or nitrogen as quoted in clause 9.2.1. of this Annex) shall be maintained between 293 and 325 K (20 to 52°C) in close proximity to the entrance into the dilution tunnel.

(e) The Reynolds number, *Re*, shall be at least 4,000 for the diluted exhaust stream, where *Re* is based on the inside diameter of the dilution tunnel. *Re* is defined in Annex 5. Verification of adequate mixing shall be performed while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyser response indicates any deviation exceeding ±2 per cent of the mean measured concentration, the CVS shall be operated at a higher flow rate or a mixing plate or orifice shall be installed to improve mixing;

(f) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:

(i) Flow straighteners, pulsation dampeners, or both of these maybe used;

(ii) A filter maybe used;

(iii) A heat exchanger maybe used to control the temperature upstream of any flowmeter but steps shall be taken to prevent aqueous condensation;

(g) Aqueous condensation.

Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulphuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition — including the amount of hydrogen and sulphur in the fuel.

To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flowmeter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flowmeter inlet measured. The dilution tunnel walls or bulk stream tubing downstream of the tunnel may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel. Certain exhaust components can be diluted or eliminated by the presence of moisture;

For PM sampling, the already proportional flow coming from CVS goes through secondary dilution (one or more) to achieve the requested overall dilution ratio as shown in Figure A.4-6 and mentioned in clause 9.2.3.2. of this Annex;

(h) The minimum overall dilution ratio shall be within the range of 5:1 to 7:1 and at least 2:1 for the primary dilution stage based on the maximum engine exhaust flow rate during the test cycle or test interval;

(i) The overall residence time in the system shall be between 0.5 and 5 s, as measured from the point of diluent introduction to the filter holder(s);

(j) The residence time in the secondary dilution system, if present, shall be at least 0.5 s, as measured from the point of secondary diluent introduction to the filter holder(s).

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a gravimetric balance, and a temperature and humidity controlled weighing chamber, are required.

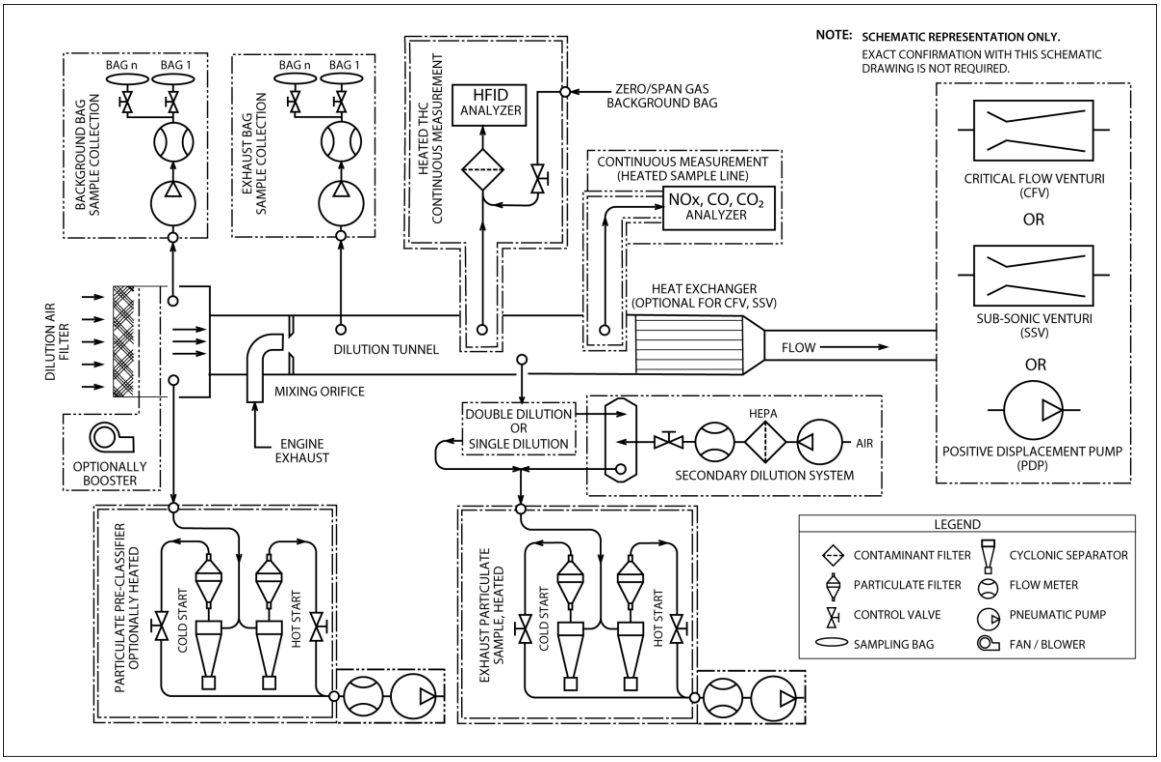


Figure A.4-5

Examples of Full-Flow Dilution Sampling Configurations

9.2.3. Partial flow dilution (PFD) system

9.2.3.1. Description of partial flow system

A schematic of a PFD system is shown in Figure A.4-6. It is a general schematic showing principles of sample extraction, dilution and PM sampling. It is not meant to indicate that all the components described in the figure are necessary for other possible sampling systems that satisfy the intent of sample collection. Other configurations which do not match these schematics are allowed under the condition that they serve the same purpose of sample collection, dilution, and PM sampling. These need to satisfy other criteria such as in clauses 8.1.8.6. (periodic calibration) and 8.2.1.2. (validation) for varying dilution PFD, and clause 8.1.4.5. as well as Table A.4-5 (linearity verification) and clause 8.1.8.5.7. (verification) for constant dilution PFD of this Annex.

As shown in Figure A.4-6, the raw exhaust gas or the primary diluted flow is transferred from the exhaust pipe EP or from CVS respectively to the dilution tunnel DT through the sampling probe SP and the transfer line TL. The total flow through the tunnel is adjusted with a flow controller and the sampling pump P of the particulate sampling system (PSS). For proportional raw exhaust sampling, the dilution air flow is controlled by the flow controller FC1, which may use q_{mew} (exhaust gas mass flow rate on wet basis) or q_{maw} (intake air mass flow rate on wet basis) and q_{mf} (fuel mass flow rate) as command signals, for

the desired exhaust split. The sample flow into the dilution tunnel DT is the difference of the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device of the particulate sampling system. The dilution ratio is calculated from these two flow rates. For sampling with a constant dilution ratio of raw or diluted exhaust versus exhaust flow (e.g.: secondary dilution for PM sampling), the dilution air flow rate is usually constant and controlled by the flow controller FC1 or dilution air pump.

The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency PM air (HEPA) filter.

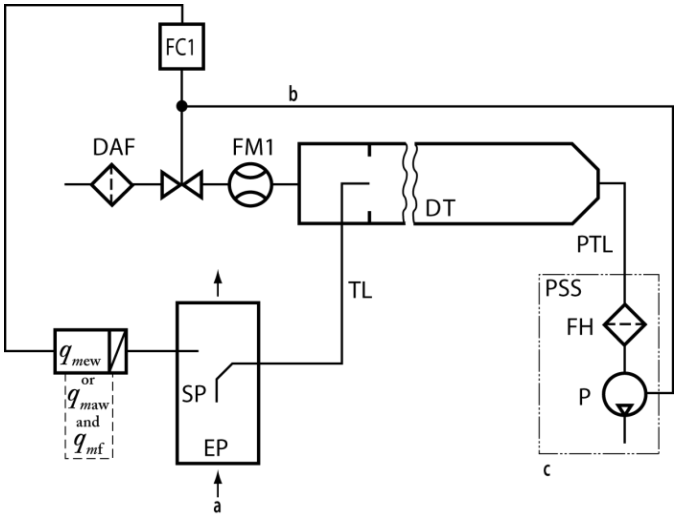


Figure A.4-6
Schematic of Partial Flow Dilution System
(Total Sampling Type)

a = engine exhaust or primary diluted flow

b = optional c = PM sampling

Components of Figure A.4-6:

DAF = Dilution air filter – The dilution air (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency PM air (HEPA) filter.

DT = Dilution tunnel or secondary dilution system

EP = Exhaust pipe or primary dilution system

FC1 = Flow controller

FH = Filter holder

FM1 = Flow measurement device measuring the dilution air flow rate

P = Sampling pump

PSS = PM sampling system

PTL = PM transfer line

SP = Raw or dilute exhaust gas sampling probe

TL = Transfer line

Mass flow rates applicable only for proportional raw exhaust sampling PFD:

q_{mew} = Exhaust gas mass gas flow rate on wet basis

q_{maw} = Intake air mass flow rate on wet basis

q_{mf} = Fuel mass flow rate

9.2.3.2. Dilution

The temperature of the diluents (ambient air, synthetic air, or nitrogen as quoted in clause 9.2.1.) shall be maintained between 293 and 325 K (20 to 52 °C) in close proximity to the entrance into the dilution tunnel.

De-humidifying the dilution air before entering the dilution system is permitted. The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature at the test filter as prescribed by clause 9.3.3.4.3. of this Annex. For this it is essential that the dilution ratio be determined such that the accuracy requirements of clause 8.1.8.6.1. of this Annex are fulfilled.

To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flowmeter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flowmeter inlet measured. The PFD system may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel.

The minimum dilution ratio shall be within the range of 5:1 to 7:1 based on the maximum engine exhaust flow rate during the test cycle or test interval.

The residence time in the system shall be between 0.5 and 5 s, as measured from the point of diluent introduction to the filter holder(s).

To determine the mass of the particulates, a particulate sampling system, a particulate sampling filter, a gravimetric balance, and a temperature and humidity controlled weighing chamber, are required.

9.2.3.3. Applicability

PFD may be used to extract a proportional raw exhaust sample for any batch or continuous PM and gaseous emission sampling over any transient (NRTC and LSI-NRTC) duty cycle, any discrete-mode NRSC or any RMC duty cycle..

The system may be used also for a previously diluted exhaust where, via a constant dilution-ratio, an already proportional flow is diluted (see Figure A.4-

6). This is the way of performing secondary dilution from a CVS tunnel to achieve the necessary overall dilution ratio for PM sampling.

9.2.3.4. Calibration

The calibration of the PFD to extract a proportional raw exhaust sample is considered in clause 8.1.8.6. of this Annex.

9.3. Sampling procedures

9.3.1 General sampling requirements

9.3.1.1. Probe design and construction

A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that it's inside and outside surfaces are in contact with the exhaust. A sample is transported out of a probe into a transfer line.

Sample probes shall be made with inside surfaces of stainless steel or, for raw exhaust sampling, with any non-reactive material capable of withstanding raw exhaust temperatures. Sample probes shall be located where constituents are mixed to their mean sample concentration and where interference with other probes is minimised. It is recommended that all probes remain free from influences of boundary layers, wakes, and eddies – especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Purging or back-flushing of a probe shall not influence another probe during testing. A single probe to extract a sample of more than one constituent may be used as long as the probe meets all the specifications for each constituent.

9.3.1.1.1. Mixing chamber (category NRSh)

Where permitted by the manufacturer, a mixing chamber may be used when testing engines of category NRSh. The mixing chamber is an optional component of a raw gas sampling system and is located in the exhaust system between the silencer and the sample probe. The shape and dimensions of the mixing chamber and tubing before and after shall be such that it provides a well-mixed, homogenous sample at the sample probe location and so that strong pulsations or resonances of the chamber influencing the emissions results are avoided.

9.3.1.2. Transfer lines

Transfer lines that transport an extracted sample from a probe to an analyser, storage medium, or dilution system shall be minimised in length by locating analysers, storage media, and dilution systems as close to the probes as practical. The number of bends in transfer lines shall be minimised and that the radius of any unavoidable bend shall be maximized.

9.3.1.3. Sampling methods

For continuous and batch sampling, introduced in clause 7.2. of this Annex, the following conditions apply:

(a) When extracting from a constant flow rate, the sample shall also be carried out at a constant flow rate;

(b) When extracting from a varying flow rate, the sample flow rate shall be varied in proportion to the varying flow rate;

(c) Proportional sampling shall be validated as described in clause 8.2.1. of this Annex.

9.3.2. Gas sampling

9.3.2.1. Sampling probes

Either single-port or multi-port probes are used for sampling gaseous emissions. The probes may be oriented in any direction relative to the raw or diluted exhaust flow. For some probes, the sample temperatures shall be controlled, as follows:

(a) For probes that extract NO_X from diluted exhaust, the probe's wall temperature shall be controlled to prevent aqueous condensation;

(b) For probes that extract hydrocarbons from the diluted exhaust, a probe wall temperature is recommended to be controlled approximately 464 K (191 ºC) to minimise contamination.

9.3.2.1.1. Mixing chamber (Category NRSh)

When used in accordance with clause 9.3.1.1.1. of this Annex, the internal volume of the mixing chamber shall not be less than ten times the individual cylinder swept volume of the engine under test. The mixing chamber shall be coupled as closely as possible to the engine silencer and shall have a minimum inner surface temperature of 452 K (179 °C). The manufacturer may specify the design of the mixing chamber.

9.3.2.2. Transfer lines

Transfer lines with inside surfaces of stainless steel, PTFE, Viton^{TM}, or any other material that has better properties for emission sampling shall be used. A non-reactive material capable of withstanding exhaust temperatures shall be used. In-line filters may be used if the filter and its housing meet the same temperature requirements as the transfer lines, as follows:

(a) For NO_X transfer lines upstream of either an NO_2-to-NO converter that meets the specifications of clause 8.1.11.5. of this Annex or a chiller that meets the specifications of clause 8.1.11.4. of this Annex a sample temperature that prevents aqueous condensation shall be maintained;

(b) For THC transfer lines a wall temperature tolerance throughout the entire line of 464 ± 11 K (191 ± 11 °C) shall be maintained. If sampled from raw exhaust, an unheated, insulated transfer line may be connected directly to a probe. The length and insulation of the transfer line shall be designed to cool the highest expected raw exhaust temperature to no lower than 464 K (191 °C), as measured at the transfer line outlet. For dilute sampling a transition zone between the probe and transfer line of up to 0.92 m in length is allowed to transition the wall temperature to 464 ± 11 K (191 ± 11 °C).

9.3.2.3. Sample-conditioning components

9.3.2.3.1. Sample dryers

9.3.2.3.1.1. Requirements

Sample dryers may be used for removing moisture from the sample in order to decrease the effect of water on gaseous emissions measurement. Sample dryers shall meet the requirements set out in clause 9.3.2.3.1.1. and in clause 9.3.2.3.1.2. of this Annex. The moisture content of 0.8 volume per cent H_2O is used in equation (A.5-13).

For the highest expected water vapour concentration H_m, the water removal technique shall maintain humidity at ≤ 5 g water/kg dry air (or about 0.8 volume per cent H_2O), which is 100 per cent relative humidity at 277.1 K (3.9 °C) and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 298 K (25 °C) and 101.3 kPa. This may be demonstrated by either:

(a) measuring the temperature at the outlet of the sample dryer; or,

(b) measuring humidity at a point just upstream of the CLD; or,

(c) performing the verification procedure in clause 8.1.8.5.8. of this Annex.

9.3.2.3.1.2. Type of sample dryers allowed and procedure to estimate moisture content after the dryer

Either type of sample dryer described in this clause to decrease the effects of water on gaseous emission measurements may be used.

(a) If an osmotic-membrane dryer upstream of any gaseous analyser or storage medium is used, it shall meet the temperature specifications in clause 9.3.2.2. of this Annex. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer shall be monitored. The amount of water shall be calculated as specified in Annex 5 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the dryer's lowest absolute pressure expected during testing;

(b) A thermal chiller upstream of a THC measurement system for compression-ignition engines may not be used. If a thermal chiller upstream of an NO_2-to-NO converter or in a sampling system without an NO_2-to-NO converter is used, the chiller shall meet the NO_2 loss-performance check specified in clause 8.1.11.4. of this Annex. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller shall be monitored. The amount of water shall be calculated as specified in Annex 5 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the thermal chiller's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, T_{dew} based on the known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$ may be calculated. If values of $T_{chiller}$ are not continuously recorded, its peak value observed during a test, or its alarm setpoint, may be used as a constant value to determine a constant amount of water according to Annex 5. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, $T_{chiller}$ may be used in lieu of T_{dew} according to Annex

5. If it is valid to assume a constant temperature offset between $T_{chiller}$ and T_{dew}, due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, this assumed temperature offset value may be factored in into emission calculations. The validity of any assumptions allowed by this clause shall be shown by engineering analysis or by data.

9.3.2.3.2. Sample pumps

Sample pumps upstream of an analyser or storage medium for any gas shall be used. Sample pumps with inside surfaces of stainless steel, PTFE, or any other material having better properties for emission sampling shall be used. For some sample pumps, temperatures shall be controlled, as follows:

(a) If a NO_X sample pump upstream of either a NO_2-to-NO converter that meets the requirements set out in clause 8.1.11.5. or a chiller that meets the requirements set out in clause 8.1.11.4. of this Annex is used, it shall be heated to prevent aqueous condensation;

(b) If a THC sample pump upstream of a THC analyser or storage medium is used, its inner surfaces shall be heated to a tolerance of 464 ± 11 K (191 ± 11 °C).

9.3.2.3.3. Ammonia scrubbers

Ammonia scrubbers may be used for any or all gaseous sampling systems to prevent NH_3 interference, poisoning of NO_2-to-NO converter, and deposits in the sampling system or analysers. Installation of the ammonia scrubber shall follow the manufacturer's recommendations.

9.3.2.4. Sample storage media

In the case of bag sampling, gas volumes shall be stored in sufficiently clean containers that minimally off-gas or allow permeation of gases. Good engineering judgment shall be used to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, it may be repeatedly purged and evacuated and may be heated. A flexible container (such as a bag) within a temperature-controlled environment, or a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement, shall be used. Containers meeting the specifications in the following Table A.4-6 shall be used.

Table A.4-6

Gaseous Batch Sampling Container Materials

CO, CO_2, O_2, CH_4, C_2H_6, C_3H_8, NO, NO_2[1]	polyvinyl fluoride (PVF)[2] for example Tedlar™, polyvinylidene fluoride[2] for example Kynar™, polytetrafluoroethylene[3] for example Teflon™, or stainless steel[3]
HC	polytetrafluoroethylene[4] or stainless steel[4]

[1] As long as aqueous condensation in storage container is prevented.

[2] Up to 313 K (40 °C).

[3] Up to 475 K (202 °C).

[4] At 464 ± 11 K (191 ± 11 °C).

9.3.3. PM sampling

9.3.3.1. Sampling probes

PM probes with a single opening at the end shall be used. PM probes shall be oriented to face directly upstream.

The PM probe may be shielded with a hat that conforms with the requirements in Figure A.4-7. In this case the pre-classifier described in clause 9.3.3.3. of this Annex shall not be used.

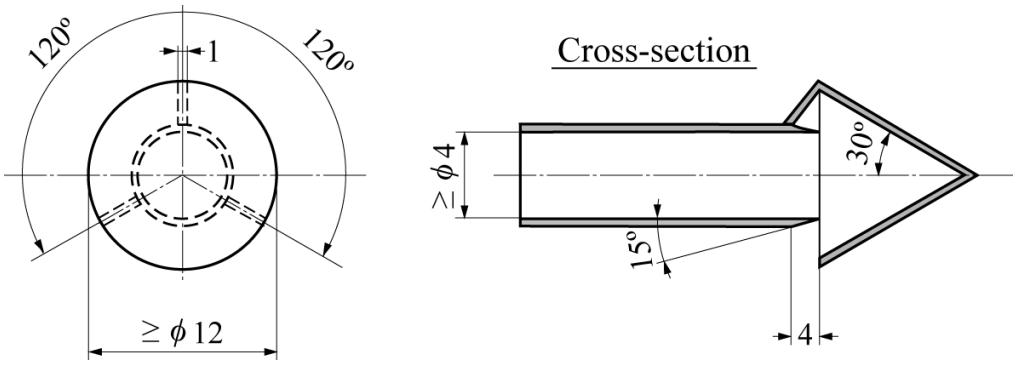


Figure A.4-7

Scheme of a Sampling Probe with a Hat-Shaped Pre-Classifier

9.3.3.2. Transfer lines

Insulated or heated transfer lines or a heated enclosure are recommended to minimise temperature differences between transfer lines and exhaust constituents. Transfer lines that are inert with respect to PM and are electrically

conductive on the inside surfaces shall be used. It is recommended using PM transfer lines made of stainless steel; any material other than stainless steel will be required to meet the same sampling performance as stainless steel. The inside surface of PM transfer lines shall be electrically grounded.

9.3.3.3. Pre-classifier

The use of a PM pre-classifier to remove large-diameter particles is permitted that is installed in the dilution system directly before the filter holder. Only one pre-classifier is permitted. If a hat shaped probe is used (see FigureA.4-7), the use of a pre-classifier is prohibited.

The PM pre-classifier may be either an inertial impactor or a cyclonic separator. It shall be constructed of stainless steel. The pre-classifier shall be rated to remove at least 50 per cent of PM at an aerodynamic diameter of 10 µm and no more than 1 per cent of PM at an aerodynamic diameter of 1 µm over the range of flow rates for which it is used. The pre-classifier outlet shall be configured with a means of bypassing any PM sample filter so that the pre-classifier flow can be stabilised before starting a test. PM sample filter shall be located within 75 cm downstream of the pre-classifier's exit.

9.3.3.4. Sample filter

The diluted exhaust shall be sampled by a filter that meets the requirements set out in clauses 9.3.3.4.1. to 9.3.3.4.4. of this Annex during the test sequence.

9.3.3.4.1. Filter specification

All filter types shall have a collection efficiency of at least 99.7 per cent. The sample filter manufacturer's measurements reflected in their product ratings may be used to show this requirement. The filter material shall be either:

(a) Fluorocarbon (PTFE) coated glass fibre; or

(b) Fluorocarbon (PTFE) membrane.

If the expected net PM mass on the filter exceeds 400 µg, a filter with a minimum initial collection efficiency of 98 per cent may be used.

9.3.3.4.2. Filter size

The nominal filter size shall be 46.50 mm ± 0.6 mm diameter (at least 37 mm stain diameter). Larger diameter filters may be used with prior agreement of the Test Agency. Proportionality between filter and stain area is recommended.

9.3.3.4.3. Dilution and temperature control of PM samples

PM samples shall be diluted at least once upstream of transfer lines in case of a CVS system and downstream in case of PFD system (see clause 9.3.3.2. of this Annex relating to transfer lines). Sample temperature shall be controlled to a 320 ± 5 K (47 ± 5 °C) tolerance, as measured anywhere within 200 mm upstream or 200 mm downstream of the PM filter media. The PM sample is intended to be heated or cooled primarily by dilution conditions as specified in sub-clause (a) of clause 9.2.1. of this Annex.

9.3.3.4.4. Filter face velocity

A filter face velocity shall be between 0.90 and 1.00 m/s with less than 5 per cent of the recorded flow values exceeding this range. If the total PM mass exceeds 400 µg, the filter face velocity may be reduced. The face velocity shall be measured as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter face, divided by the filter's exposed area. The exhaust system stack or CVS tunnel pressure shall be used for the upstream pressure if the pressure drop through the PM sampler up to the filter is less than 2 kPa.

9.3.3.4.5 Filter holder

To minimise turbulent deposition and to deposit PM evenly on a filter, a 12.5° (from centre) divergent cone angle to transition from the transfer-line inside diameter to the exposed diameter of the filter face shall be used. Stainless steel for this transition shall be used.

9.3.4. PM-stabilisation and weighing environments for gravimetric analysis

9.3.4.1. Environment for gravimetric analysis

This clause describes the two environments required to stabilise and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space.

Both the stabilization and the weighing environments shall be kept free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples.

9.3.4.2. Cleanliness

The cleanliness of the PM-stabilization environment using reference filters shall be verified, as described in clause 8.1.12.1.4. of this Annex.

9.3.4.3. Temperature of the chamber

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295± 1 K (22 ± 1 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 282.5 ± 1 K (9.5 ± 1 °C) and a relative humidity of 45 per cent ± 8 per cent. If the stabilization and weighing environments are separate, the stabilization environment shall be maintained at a tolerance of 295± 3 K (22 ± 3 °C).

9.3.4.4. Verification of ambient conditions

When using measurement instruments that meet the specifications in clause 9.4 the following ambient conditions shall be verified:

(a) Dew point and ambient temperature shall be recorded. These values shall be used to determine if the stabilization and weighing environments have remained within the tolerances specified in clause 9.3.4.3. of this Annex for at least 60 min before weighing filters;

(b) Atmospheric pressure shall be continuously recorded within the weighing environment. An acceptable alternative is to use a barometer that measures atmospheric pressure outside the weighing environment,

as long as it can be ensured that the atmospheric pressure at the balance is always at the balance within ±100 Pa of the shared atmospheric pressure. A means to record the most recent atmospheric pressure shall be provided when each PM sample is weighed. This value shall be used to calculate the PM buoyancy correction in clause 8.1.12.2. of this Annex.

9.3.4.5. Installation of balance

The balance shall be installed as follows:

(a) Installed on a vibration-isolation platform to isolate it from external noise and vibration;

(b) Shielded from convective airflow with a static-dissipating draft shield that is electrically grounded.

9.3.4.6. Static electric charge

Static electric charge shall be minimised in the balance environment, as follows:

(a) The balance is electrically grounded;

(b) Stainless steel tweezers shall be used if PM samples shall be handled manually;

(c) Tweezers shall be grounded with a grounding strap, or a grounding strap shall be provided for the operator such that the grounding strap shares a common ground with the balance;

(d) A static-electricity neutraliser shall be provided that is electrically grounded in common with the balance to remove static charge from PM samples.

9.4. Measurement instruments

9.4.1. Introduction

9.4.1.1. Scope

This clause specifies measurement instruments and associated system requirements related to emission testing. This includes laboratory instruments for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations (raw or diluted).

9.4.1.2. Instrument types

Any instrument mentioned in this annex shall be used as described in the annex itself (see Table A.4-5 for measurement quantities provided by these instruments). Whenever an instrument mentioned in this annex is used in a way that is not specified, or another instrument is used in its place, the requirements for equivalency provisions shall apply as specified in clause 5.1.3. of this Annex. Where more than one instrument for a particular measurement is specified, one of them will be identified by Test Agency upon application as the reference for showing that an alternative procedure is equivalent to the specified procedure.

9.4.1.3. Redundant systems

Data from multiple instruments to calculate test results for a single test may be used for all measurement instruments described in this clause, with prior approval of the Test Agency. Results from all measurements shall be recorded and the raw data shall be retained. This requirement applies whether or not the measurements are actually used in the calculations.

9.4.2. Data recording and control

The test system shall be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Data acquisition and control systems shall be used that can record at the specified minimum frequencies, as shown in Table A.4-7 (this table does not apply to discrete mode NRSC testing).

Table A.4-7

Data Recording and Control Minimum Frequencies

Applicable test protocol clause	Measured values	Minimum command and control frequency	Minimum recording frequency
7.6.	Speed and torque during an engine step-map	1 Hz	1 mean value per step
7.6.	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
7.8.3.	Transient (NRTC and LSI-NRTC) duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
7.8.2.	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
7.3.	Continuous concentrations of raw analysers	N/A	1 Hz
7.3.	Continuous concentrations of dilute analysers	N/A	1 Hz
7.3.	Batch concentrations of raw or dilute analysers	N/A	1 mean value per test interval
7.6.8.2.1.	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
7.6.8.2.1.	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
7.6.8.2.1.	Intake-air or exhaust flow rate (for raw transient measurement)	N/A	1 Hz means
7.6.8.2.1.	Dilution air if actively controlled	5 Hz	1 Hz means
7.6.8.2.1.	Sample flow from a CVS with a heat exchanger	1 Hz	1 Hz
7.6.8.2.1.	Sample flow from a CVS without a heat exchanger	5 Hz	1 Hz mean

9.4.3. Performance specifications for measurement instruments

9.4.3.1. Overview

The test system as a whole shall meet all the applicable calibrations, verifications, and test-validation criteria specified in clause 8.1. of this Annex, including the requirements of the linearity check of clauses 8.1.4. and 8.2. of this Annex. Instruments shall meet the specifications in Table A.4-7 for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in Table A.4-7 shall be kept.

9.4.3.2. Component requirements

Table A.4-8 shows the specifications of transducers of torque, speed, and pressure, sensors of temperature and dew point, and other instruments. The overall system for measuring the given physical and/or chemical quantity shall meet the linearity verification in clause 8.1.4. of this Annex. For gaseous emissions measurements, analysers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the fuel properties for the specific engine test. Any compensation algorithm shall only provide offset compensation without affecting any gain (that is no bias).

Table A.4-8

Recommended Performance Specifications for Measurement Instruments

Measurement instrument	*Measured quantity symbol*	*Complete systemrise time*	*Recordingupdate frequency*	*Accuracy*[a]	*Repeatability*[a]
Engine speed transducer	n	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max	1.0 % of pt. or 0.25 % of max
Engine torque transducer	T	1 s	1 Hz means	2.0 % of pt. or 1.0 % of max	1.0 % of pt. or 0.5 % of max
Fuel flowmeter (Fuel totalizer)		5 s (N/A)	1 Hz (N/A)	2.0 % of pt. or 1.5 % of max	1.0 % of pt. or 0.75 % of max
Total diluted exhaust meter (CVS) (With heat exchanger before meter)		1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max	1.0 % of pt. or 0.75 % of max
Dilution air, inlet air, exhaust, and sample flowmeters		1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max	1.25 % of pt. or 0.75 % of max
Continuous gas analyser raw	x	5 s	2 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Continuous gas analyser dilute	x	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.

Continuous gas analyser	x	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Batch gas analyser	x	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Gravimetric PM balance	m_{PM}	N/A	N/A	See 9.4.11.	0.5 µg
Inertial PM balance	m_{PM}	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.

[a] Accuracy and repeatability are all determined with the same collected data, as described in pargraph 9.4.3. of this Annex, and based on absolute values. "pt." refers to the overall mean value expected at the emission limit; "max." refers to the peak value expected at the emission limit over the duty cycle , not the maximum of the instrument's range; "meas." refers to the actual mean measured over the duty cycle.

9.4.4. Measurement of engine parameters and ambient conditions

9.4.4.1. Speed and torque sensors

9.4.4.1.1. Application

Measurement instruments for work inputs and outputs during engine operation shall meet the specifications in this clause. Sensors, transducers, and meters meeting the specifications in Table A.4-8 are recommended. Overall systems for measuring work inputs and outputs shall meet the linearity verifications in clause 8.1.4. of this Annex.

9.4.4.1.2. Shaft work

Work and power shall be calculated from outputs of speed and torque transducers according to clause 9.4.4.1. of this Annex. Overall systems for measuring speed and torque shall meet the calibration and verifications in clauses 8.1.7. and 8.1.4. of this Annex.

Torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for as needed, based on good engineering judgment.

9.4.4.2. Pressure transducers, temperature sensors, and dew point sensors

Overall systems for measuring pressure, temperature, and dew point shall meet the calibration in clause 8.1.7. of this Annex.

Pressure transducers shall be located in a temperature-controlled environment, or they shall compensate for temperature changes over their expected operating range. Transducer materials shall be compatible with the fluid being measured.

9.4.5. Flow-related measurements

For any type of flowmeter (of fuel, intake-air, raw exhaust, diluted exhaust, sample), the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins,

orifice plates (or pneumatic pulsation dampeners for the fuel flowmeter) to establish a steady and predictable velocity profile upstream of the meter.

9.4.5.1. Fuel flowmeter

Overall system for measuring fuel flow shall meet the calibration in clause 8.1.8.1. of this Annex. In any fuel flow measurement it shall be accounted for any fuel that bypasses the engine or returns from the engine to the fuel storage tank.

9.4.5.2. Intake-air flowmeter

Overall system for measuring intake-air flow shall meet the calibration in clause 8.1.8.2. of this Annex.

9.4.5.3. Raw exhaust flowmeter

9.4.5.3.1. Component requirements

The overall system for measuring raw exhaust flow shall meet the linearity requirements in clause 8.1.4. of this Annex. Any raw-exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust gas' thermodynamic, fluid, and compositional states.

9.4.5.3.2. Flowmeter response time

For the purpose of controlling of a partial flow dilution system to extract a proportional raw exhaust sample, a flowmeter response time faster than indicated in Table A.4-8 is required. For partial flow dilution systems with online control, the flowmeter response time shall meet the specifications of clause 8.2.1.2. of this Annex.

9.4.5.3.3. Exhaust cooling

This clause does not apply to cooling of the exhaust gas due to the design of the engine, including, but not limited to, water-cooled exhaust manifolds or turbochargers.

Exhaust cooling upstream of the flowmeter is permitted with the following restrictions:

(a) PM shall not be sampled downstream of the cooling;

(b) If cooling causes exhaust temperatures above 475 K (202 °C) to decrease to below 453 K (180 °C), HC shall not be sampled downstream of the cooling;

(c) If cooling causes aqueous condensation, NO_X shall not be sampled downstream of the cooling unless the cooler meets the performance verification in clause 8.1.11.4. of this Annex;

(d) If cooling causes aqueous condensation before the flow reaches a flowmeter, dew point, T_{dew} and pressure p_{total} shall be measured at the flowmeter inlet. These values shall be used in emission calculations according to Annex 5 .

9.4.5.4. Dilution air and diluted exhaust flowmeters

9.4.5.4.1. Application

Instantaneous diluted exhaust gas flow rates or total diluted exhaust gas flow over a test interval shall be determined by using a diluted exhaust flowmeter. Raw exhaust gas flow rates or total raw exhaust gas flow over a test interval may be calculated from the difference between a diluted exhaust gas flowmeter and a dilution air meter.

9.4.5.4.2. Component requirements

The overall system for measuring diluted exhaust flow shall meet the calibration and verifications in clauses 8.1.8.4. and 8.1.8.5. of this Annex. The following meters may be used:

(a) For constant-volume sampling (CVS) of the total flow of diluted exhaust gas, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flowmeter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller by keeping the diluted exhaust gas temperature constant in a CVS system;

(b) For the Partial Flow Dilution (PFD) system the combination of any flowmeter with any active flow control system to maintain proportional sampling of exhaust gas constituents may be used. The total flow of diluted exhaust gas, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

For any other dilution system, a laminar flow element, an ultrasonic flowmeter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer may be used.

9.4.5.4.3. Exhaust gas cooling

Diluted exhaust gas upstream of a dilute flowmeter may be cooled, as long as all the following provisions are observed:

(a) PM shall not be sampled downstream of the cooling;

(b) If cooling causes exhaust temperatures above 475 K (202 °C) to decrease to below 453 K (180 °C), HC shall not be sampled downstream of the cooling;

(c) If cooling causes aqueous condensation, NO_X shall not be sampled downstream of the cooling unless the cooler meets the performance verification in clause 8.1.11.4. of this Annex;

(d) If cooling causes aqueous condensation before the flow reaches a flowmeter, dew point, T_{dew} and pressure p_{total} shall be measured at the flowmeter inlet. These values shall be used in emission calculations according Annex 5 .

9.4.5.5. Sample flowmeter for batch sampling

A sample flowmeter shall be used to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. The difference between two flowmeters may be used to calculate sample flow into a dilution

tunnel e.g. for partial flow dilution PM measurement and secondary dilution flow PM measurement. Specifications for differential flow measurement to extract a proportional raw exhaust sample is given in clause 8.1.8.6.1. and the calibration of differential flow measurement is given in clause 8.1.8.6.2. of this Annex.

Overall system for the sample flowmeter shall meet the calibration in clause 8.1.8. of this Annex.

9.4.5.6. Gas divider

A gas divider may be used to blend calibration gases.

A gas divider shall be used that blends gases to the specifications of clause 9.5.1. of this Annex and to the concentrations expected during testing. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division. The gas-divider system shall meet the linearity verification in clause 8.1.4.5. of this Annex. Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings used and the nominal value shall be compared to the measured concentration of the instrument.

9.4.6. CO and CO_2 measurements

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO_2 concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system shall meet the calibration and verifications set out in clause 8.1.9.1. or 8.1.9.2. of this Annex, as applicable.

9.4.7. Hydrocarbon measurements

9.4.7.1. Flame-ionization detector

9.4.7.1.1. Application

A heated flame-ionization detector (HFID) analyser shall be used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Hydrocarbon concentrations shall be determined on a carbon number basis of one, C_1. Heated FID analysers shall maintain all surfaces that are exposed to emissions at a temperature of 464 ± 11 K (191 ± 11 °C). Optionally, for NG and LPG fuelled and SI engines, the hydrocarbon analyser may be of the non-heated flame ionisation detector (FID) type.

9.4.7.1.2. Component requirements

The FID-based system for measuring THC shall meet all of the verifications for hydrocarbon measurement in clause 8.1.10. of this Annex.

9.4.7.1.3. FID fuel and burner air

FID fuel and burner air shall meet the specifications of clause 9.5.1. of this Annex. The FID fuel and burner air shall not mix before entering the FID

analyser to ensure that the FID analyser operates with a diffusion flame and not a premixed flame.

9.4.7.1.4. Reserved

9.4.7.1.5. Reserved

9.4.7.2. Reserved

9.4.7.2.1.

9.4.8. NO_X measurements

Two measurement instruments are specified for NO_X measurement and either instrument may be used provided it meets the criteria specified in clause 9.4.8.1. or 9.4.8.2. of this Annex, respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure under clause 5.1.3. of this Annex.

9.4.8.1. Chemiluminescent detector

9.4.8.1.1. Application

A chemiluminescent detector (CLD) coupled with an NO_2-to-NO converter is used to measure NO_X concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.1.2. Component requirements

The CLD-based system shall meet the quench verification in clause 8.1.11.1. of this Annex. A heated or unheated CLD may be used, and a CLD that operates at atmospheric pressure or under a vacuum may be used.

9.4.8.1.3. NO_2-to-NO converter

An internal or external NO_2-to-NO converter that meets the verification in clause 8.1.11.5. of this Annex shall be placed upstream of the CLD, while the converter shall be configured with a bypass to facilitate this verification.

9.4.8.1.4. Humidity effects

All CLD temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, one of the following configurations shall be used:

(a) A CLD connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in clause 8.1.11.5. of this Annex;

(b) A CLD connected downstream of any dryer or thermal chiller that meets the verification in clause 8.1.11.4. of this Annex.

9.4.8.1.5. Response time

A heated CLD may be used to improve CLD response time.

9.4.8.2. Non-dispersive ultraviolet analyser

9.4.8.2.1. Application

A non-dispersive ultraviolet (NDUV) analyser is used to measure NO_X concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.8.2.2. Component requirements

The NDUV-based system shall meet the verifications in clause 8.1.11.3. of this Annex.

9.4.8.2.3. NO_2-to-NO converter

If the NDUV analyser measures only NO, an internal or external NO_2-to-NO converter that meets the verification in clause 8.1.11.5. of this Annex shall be placed upstream of the NDUV analyser. The converter shall be configured with a bypass to facilitate this verification.

9.4.8.2.4. Humidity effects

The NDUV temperature shall be maintained to prevent aqueous condensation, unless one of the following configurations is used:

(a) An NDUV shall be connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in clause 8.1.11.5. of this Annex;

(b) An NDUV shall be connected downstream of any dryer or thermal chiller that meets the verification in clause 8.1.11.4. of this Annex.

9.4.9. O_2 measurements

A paramagnetic detection (PMD) or magneto pneumatic detection (MPD) analyser shall be used to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling.

9.4.10. Air-to-fuel ratio measurements

A Zirconia (ZrO_2) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O_2 measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to Annex 5.

9.4.11. PM measurements with gravimetric balance

A balance shall be used to weigh net PM collected on sample filter media.

The minimum requirement on the balance resolution shall be equal or lower than the repeatability of 0.5 microgram recommended in Table A.4-8. If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights shall meet the specifications in clause 9.5.2. of this Annex.

The balance shall be configured for optimum settling time and stability at its location.

9.4.12. Ammonia (NH_3) measurements

A FTIR (Fourier transform infrared) analyser, NDUV or laser infrared analyser may be used in accordance with Appendix A.4.

9.5. Analytical gases and mass standards

9.5.1. Analytical gases

Analytical gases shall meet the accuracy and purity specifications of this clause.

9.5.1.1. Gas specifications

The following gas specifications shall be considered:

(a) Purified gases shall be used to blend with calibration gases and to adjust measurement instruments so as to obtain a zero response to a zero calibration standard. Gases with contamination no higher than the highest of the following values in the gas cylinder or at the outlet of a zero-gas generator shall be used:

(i) 2 per cent contamination, measured relative to the mean concentration expected at the emission limit value. For example, if a CO concentration of 100.0 µmol/mol is expected, then it would be allowed to use a zero gas with CO contamination less than or equal to 2.000 µmol/mol;

(ii) Contamination as specified in Table A.4-9, applicable for raw or dilute measurements;

(iii) Contamination as specified in Table A.4-10, applicable for raw measurements.

Table A.4-9

Contamination Limits, Applicable for Raw or Dilute Measurements [µmol/mol = ppm (3.2.)]

Constituent	*Purified synthetic air*[a]	*Purified N_2*[a]
THC (C_1 equivalent)	≤ 0.05 µmol/mol	≤ 0.05 µmol/mol
CO	≤ 1 µmol/mol	≤ 1 µmol/mol
CO_2	≤ 10 µmol/mol	≤ 10 µmol/mol
O_2	0.205 to 0.215 mol/mol	≤ 2 µmol/mol
NO_X	≤ 0.02 µmol/mol	≤ 0.02 µmol/mol
[a] It is not required that these levels of purity are international and/or national recognized standards-traceable.		

Table A.4-10

Contamination Limits, Applicable for Raw Measurements [µmol/mol = ppm (3.2.)]

Constituent	*Purified synthetic air*[a]	*Purified N_2*[a]
THC (C_1 equivalent)	≤ 1 µmol/mol	≤ 1 µmol/mol
CO	≤ 1 µmol/mol	≤ 1 µmol/mol
CO_2	≤ 400 µmol/mol	≤ 400 µmol/mol
O_2	0.18 to 0.21 mol/mol	-
NO_X	≤ 0.1 µmol/mol	≤ 0.1 µmol/mol
[a]It is not required that these levels of purity are international and/or national recognized standards-traceable.		

(b) The following gases shall be used with a FID analyser:

(i) FID fuel shall be used with an H_2 concentration of (0.39 to 0.41) mol/mol, balance He or N_2. The mixture shall not contain more than 0.05 µmol/mol THC;

(ii) FID burner air shall be used that meets the specifications of purified air in clause (a) of this clause;

(iii) FID zero gas.Flame-ionization detectors shall be zeroed with purified gas that meets the specifications in clause (a) of this clause, except that the purified gas O_2 concentration may be any value;

(iv) FID propane span gas. The THC FID shall be spanned and calibrated with span concentrations of propane, C_3H_8. It shall be calibrated on a carbon number basis of one (C_1);

(c) The following gas mixtures shall be used, with gases traceable within ±1.0 per cent of the international and/or national recognized standards true value or of other gas standards that are approved:

(i) CH_4, balance purified synthetic air and/or N_2 (as applicable);

(ii) Reserved;

(iii) C_3H_8, balance purified synthetic air and/or N_2 (as applicable);

(iv) CO, balance purified N_2;

(v) CO_2, balance purified N_2;

(vi) NO, balance purified N_2;

(vii) NO_2, balance purified synthetic air;

(viii) O_2, balance purified N_2;

(ix) C_3H_8, CO, CO_2, NO, balance purified N_2;

(x) C_3H_8, CH_4, CO, CO_2, NO, balance purified N_2.

(d) Gases for species other than those listed in sub- clause (c) of this clause may be used (such as methanol in air, which may be used to determine response factors), as long as they are traceable to within ±3.0 per cent of the international and/or national recognized standards true value, and meet the stability requirements of clause 9.5.1.2. of this Annex;

(e) Own calibration gases may be generated using a precision blending device, such as a gas divider, to dilute gases with purified N_2 or purified synthetic air. If the gas dividers meet the specifications in clause 9.4.5.6. of this Annex, and the gases being blended meet the requirements of sub-clauses (a) and (c) of this clause, the resulting blends are considered to meet the requirements of this clause 9.5.1.1. of this Annex.

9.5.1.2. Concentration and expiration date

The concentration of any calibration gas standard and its expiration date specified by the gas supplier shall be recorded.

(a) No calibration gas standard may be used after its expiration date, except as allowed by sub-clause (b) of this clause.

(b) Calibration gases may be relabelled and used after their expiration date if it is approved in advance by Test Agency.

9.5.1.3. Gas transfer

Gases shall be transferred from their source to analysers using components that are dedicated to controlling and transferring only those gases.

9.5.2. Mass standards

PM balance calibration weights that are certified as international and/or national recognized standards-traceable within 0.1 per cent uncertainty shall be used. Calibration weights may be certified by any calibration lab that maintains international and/or national recognized standards-traceability. It shall be made sure that the lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium. The calibration report shall also state the density of the weights.

ANNEX 4 - APPENDIX A.1.

PARTICLE NUMBER EMISSIONS MEASUREMENT EQUIPMENT

A.1.1. MEASUREMENT TEST PROCEDURE

A.1.1.1. Sampling

Particle number emissions shall be measured by continuous sampling from either a partial flow dilution system, as described in clause 9.2.3 of this Annex or a full flow dilution system as described in clause 9.2.2 of this Annex.

A.1.1.1.1. Diluent filtration

Diluent used for both the primary and, where applicable, secondary dilution of the exhaust gas in the dilution system shall be passed through filters meeting the High-Efficiency Particulate Air (HEPA) filter requirements defined in clause 2.1.38. of this Part. The diluent may optionally be charcoal scrubbed before being passed to the HEPA filter to reduce and stabilise the hydrocarbon concentrations in the diluent. It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal scrubber, if used.

A.1.1.2. Compensating for particle number sample flow — full flow dilution systems

To compensate for the mass flow extracted from the dilution system for particle number sampling the extracted mass flow (filtered) shall be returned to the dilution system. Alternatively, the total mass flow in the dilution system may be mathematically corrected for the particle number sample flow extracted. Where the total mass flow extracted from the dilution system for the sum of particle number sampling and particulate mass sampling is less than 0.5 per cent of the total diluted exhaust gas flow in the dilution tunnel (med) this correction, or flow return, may be neglected.

A.1.1.3. Compensating for particle number sample flow — partial flow dilution systems

A.1.1.3.1. For partial flow dilution systems the mass flow extracted from the dilution system for particle number sampling shall be accounted for in controlling the proportionality of sampling. This shall be achieved either by feeding the particle number sample flow back into the dilution system upstream of the flow measuring device or by mathematical correction as outlined in clause A.1.1.3.2. In the case of total sampling type partial flow dilution systems, the mass flow extracted for particle number sampling shall also be corrected for in the particulate mass calculation as outlined in clause A.1.1.3.3.

A.1.1.3.2. The instantaneous exhaust gas flow rate into the dilution system (q_{mp}), used for controlling the proportionality of sampling, shall be corrected according to one of the following methods:

(a) In the case where the extracted particle number sample flow is discarded, equation (A.4-20) in clause 8.1.8.6.1 of this Annex shall be replaced by equation (A.4-29):

$$q_{mp} = q_{mdew} - q_{mdw} + q_{ex} \quad \text{(A.4-29)}$$

Where:

q_{mdew} is the diluted exhaust mass flow rate, kg/s,

q_{mdw} is the dilution air mass flow rate, kg/s,

q_{ex} is the particle number sample mass flow rate, kg/s.

The q_{ex} signal sent to the partial flow system controller shall be accurate to within ± 0.1 per cent of q_{mdew} at all times and should be sent with frequency of at least 1 Hz.

(b) In the case where the extracted particle number sample flow is fully or partially discarded, but an equivalent flow is fed back to the dilution system upstream of the flow measurement device, equation (A.4-20) in clause 8.1.8.6.1. of this Annex shall be replaced by equation (A.4-30):

$$q_{mp} = q_{mdew} - q_{mdw} + q_{ex} - q_{sw} \quad \text{(A.4-30)}$$

Where:

q_{mdew} is the diluted exhaust mass flow rate, kg/s,

q_{mdw} is the dilution air mass flow rate, kg/s,

q_{ex} is the particle number sample mass flow rate, kg/s,

q_{sw} is the mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction, kg/s.

The difference between q_{ex} and q_{sw} sent to the partial flow system controller shall be accurate to within ± 0.1 per cent of q_{mdew} at all times. The signal (or signals) should be sent with frequency of at least 1 Hz.

A.1.1.3.3. Correction of PM measurement

When a particle number sample flow is extracted from a total sampling partial flow dilution system, the mass of particulates (m_{PM}) calculated in clause A.1.2.3.1.1. of Appendix A.1 to Annex 5. shall be corrected as follows to account for the flow extracted. This correction is required even where filtered extracted flow is fed back into the partial flow dilution systems, as set out in equation (A.4-31):

$$m_{PM,corr} = m_{PM} \times \frac{m_{sed}}{(m_{sed} - m_{ex})} \quad \text{(A.4-31)}$$

Where:

m_{PM} is the mass of particulates determined in accordance with clause A.1.2.3.1.1. of Appendix A.1 to Annex 5., g/test,

m_{sed} is the total mass of diluted exhaust gas passing through the dilution tunnel, kg,

m_{ex} is the total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg.

A.1.1.3.4. Proportionality of partial flow dilution sampling

For particle number measurement, exhaust mass flow rate, determined according to any of the methods described in clause A.1.1.6.1. to A.1.1.6.4. of Appendix A.1 to Annex 5, is used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with clause 8.2.1.2. of this Annex.

A.1.1.3.5. Particle number calculation

Determination and calculation of PN are laid down in Appendix A.6 of Annex 5.

A.1.2. MEASUREMENT EQUIPMENT

A.1.2.1. Specification

A.1.2.1.1. System overview

A.1.2.1.1.1. The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system as described in clause 9.2.2. or 9.2.3.of this Annex, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer line.

A.1.2.1.1.2. It is recommended that a particle size pre-classifier (e.g. cyclone, impactor, etc.) be located prior to the inlet of the VPR. However, a sample probe acting as an appropriate size-classification device, such as shown in Figure A.4-7, is an acceptable alternative to the use of a particle size pre-classifier. In the case of partial flow dilution systems it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

A.1.2.1.2. General requirements

A.1.2.1.2.1. The particle sampling point shall be located within a dilution system.

The sampling probe tip or particle sampling point and particle transfer line (PTL) together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance of the VPR. The PTS shall meet the following conditions:

(a) In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in clause 9.2.3. of this Annex) the sampling probe shall be installed near the tunnel centre line, 10 to 20 tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel. The sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.

(b) In the case of partial flow dilution systems of the total sampling type (as described in clause 9.2.3.of this Annex) the particle sampling point or sampling probe shall be located in the particulate transfer line, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the

sample is taken from a homogeneous diluent/exhaust mixture. The dimensions of the particle sampling probe should be sized not to interfere with the operation of the partial flow dilution system.

Sample gas drawn through the PTS shall meet the following conditions:

(a) In the case of full flow dilution systems, it shall have a flow Reynolds number (Re) of < 1,700;

(b) In the case of partial flow dilution systems, it shall have a flow Reynolds number (Re) of < 1,700 in the PTT i.e. downstream of the sampling probe or point;

(c) It shall have a residence time in the PTS of ≤ 3 seconds.

(d) Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

(e) The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:

(f) It shall have an internal diameter of ≥ 4 mm;

(g) Sample Gas flow through the OT shall have a residence time of ≤ 0.8 second.

(h) Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

A.1.2.1.2.2. The VPR shall include devices for sample dilution and for volatile particle removal.

A.1.2.1.2.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be designed to minimise deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

A.1.2.1.2.4. The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in cross-section, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Gradual changes in the cross-section are permissible.

A.1.2.1.3. Specific requirements

A.1.2.1.3.1. The particle sample shall not pass through a pump before passing through the PNC.

A.1.2.1.3.2. A sample pre-classifier is recommended.

A.1.2.1.3.3. The sample preconditioning unit shall:

A.1.2.1.3.3.1. Be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC and a gas temperature below 308 K (35 °C) at the inlet to the PNC;

A.1.2.1.3.3.2. Include an initial heated dilution stage which outputs a sample at a temperature of ≥ 423 K (150 °C) and ≤ 673 K (400 °C), and dilutes by a factor of at least 10;

A.1.2.1.3.3.3. Control heated stages to constant nominal operating temperatures, within the range specified in clause A.1.2.1.3.3.2., to a tolerance of ± 10 K (± 10 °C). Provide an indication of whether or not heated stages are at their correct operating temperatures;

A.1.2.1.3.3.4. Achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in clause A.1.2.2.2.2., for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent

lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;

A.1.2.1.3.3.5. Also achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane.

A.1.2.1.3.4. The PNC shall:

A.1.2.1.3.4.1. Operate under full flow operating conditions;

A.1.2.1.3.4.2. Have a counting accuracy of ± 10 per cent across the range 1 cm^{-3} to the upper threshold of the single particle count mode of the PNC against a traceable standard. At concentrations below 100 cm^{-3} measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;

A.1.2.1.3.4.3. Have a readability of at least 0.1 particle cm^{-3} at concentrations below 100 cm^{-3};

A.1.2.1.3.4.4. Have a linear response to particle concentrations over the full measurement range in single particle count mode;

A.1.2.1.3.4.5. Have a data reporting frequency equal to or greater than 0.5 Hz;

A.1.2.1.3.4.6. Have a response time over the measured concentration range of less than 5 s;

A.1.2.1.3.4.7. Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an internal calibration factor as determined in clause A.1.2.2.1.3., but shall not make use of any other algorithm to correct for or define the counting efficiency;

A.1.2.1.3.4.8. Have counting efficiencies at particle sizes of 23 nm (± 1 nm) and 41 nm (± 1 nm) electrical mobility diameter of 50 per cent (± 12 per cent) and > 90 per cent respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means;

A.1.2.1.3.4.9. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

A.1.2.1.3.5. Where they are not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at inlet to the PNC shall be measured and reported for the purposes of correcting particle concentration measurements to standard conditions.

A.1.2.1.3.6. The sum of the residence time of the PTS, VPR and OT plus the response time of the PNC shall be no greater than 20 s.

A.1.2.1.3.7. The transformation time of the entire particle number sampling system (PTS, VPR, OT and PNC) shall be determined by aerosol switching directly at the inlet of the PTS. The aerosol switching shall be done in less than 0.1 s. The aerosol used for the test shall cause a concentration change of at least 60 per cent full scale (FS).

The concentration trace shall be recorded. For time alignment of the particle number concentration and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

A.1.2.1.4. Recommended system description

This clause contains the recommended practice for measurement of particle number. However, any system meeting the performance specifications in clauses A.1.2.1.2. and A.1.2.1.3. is acceptable.

Figures A.4-8 and A.4-9 are schematic drawings of the recommended particle sampling system configures for partial and full flow dilution systems respectively.

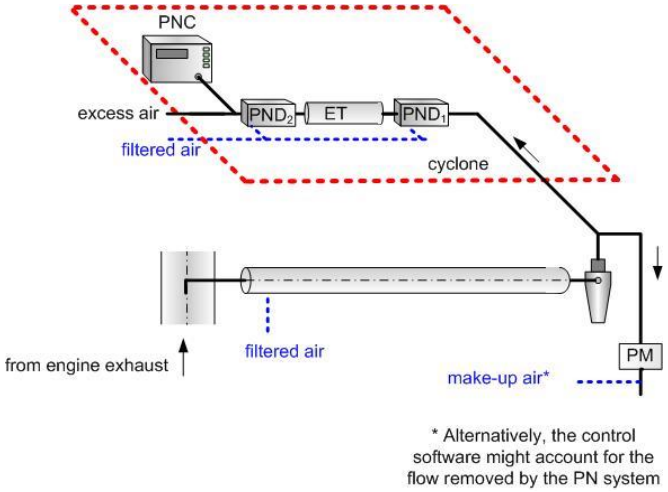


Figure A.4-8.

Schematic of recommended Particle Sampling System – Partial Flow Sampling

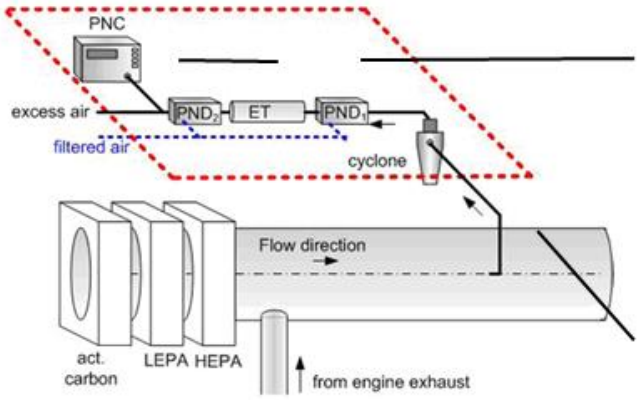


Figure A.4-9.

Schematic of recommended Particle Sampling System – Full Flow Sampling

A.1.2.1.4.1. Sampling system description

The particle sampling system shall consist of a sampling probe tip or particle sampling point in the dilution system, a particle transfer line (PTL), a particle pre-classifier (PCF) and a volatile particle remover (VPR) upstream of the particle number concentration measurement (PNC) unit. The VPR shall include devices for sample dilution (particle number diluters: PND_1 and PND_2) and particle evaporation (Evaporation tube, ET). The sampling probe or sampling point for the test gas flow shall be so arranged within the dilution tract that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture. The sum of the residence time of the system plus the response time of the PNC shall be no greater than 20 s.

A.1.2.1.4.2. Particle transfer system

The sampling probe tip or particle sampling point and Particle Transfer line (PTL) together comprise the Particle Transfer System (PTS). The PTS conducts the sample from the dilution tunnel to the entrance to the first particle number diluter. The PTS shall meet the following conditions:

In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in clause 9.2.3. of this Annex) the sampling probe shall be installed near the tunnel centre line, 10 to 20 tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel. The sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.

In the case of partial flow dilution systems of the total sampling type (as described in clause 9.2.3. of this Annex) the particle sampling point shall be located in the particulate transfer line, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture.

Sample gas drawn through the PTS shall meet the following conditions:

It shall have a flow Reynolds number (Re) of $< 1,700$;

It shall have a residence time in the PTS of ≤ 3 seconds.

Any other sampling configuration for the PTS for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable.

The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:

It shall have an internal diameter of ≥ 4 mm;

Sample gas flow through the POT shall have a residence time of ≤ 0.8 second.

Any other sampling configuration for the OT for which equivalent particle penetration for particles of 30 nm electrical mobility diameter can be demonstrated will be considered acceptable.

A.1.2.1.4.3. Particle pre-classifier

The recommended particle pre-classifier shall be located upstream of the VPR. The pre-classifier 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling particle number emissions. The

pre-classifier shall allow at least 99 per cent of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling particle number emissions. In the case of partial flow dilution systems, it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

A.1.2.1.4.4. Volatile particle remover (VPR)

The VPR shall comprise one particle number diluter (PND_1), an evaporation tube and a second diluter (PND_2) in series. This dilution function is to reduce the number concentration of the sample entering the particle concentration measurement unit to less than the upper threshold of the single particle count mode of the PNC and to suppress nucleation within the sample. The VPR shall provide an indication of whether or not PND_1 and the evaporation tube are at their correct operating temperatures.

The VPR shall achieve > 99.0 per cent vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor (f_r) for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 per cent and 20 per cent respectively higher, and no more than per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole.

A.1.2.1.4.4.1. First particle number dilution device (PND_1)

The first particle number dilution device shall be specifically designed to dilute particle number concentration and operate at a (wall) temperature of 423 K to 673 K (150 °C to 400 °C). The wall temperature setpoint should be held at a constant nominal operating temperature, within this range, to a tolerance of ±10 °C and not exceed the wall temperature of the ET (clause A.1.2.1.4.4.2.). The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution factor of 10 to 200 times.

A.1.2.1.4.4.2. Evaporation Tube (ET)

The entire length of the ET shall be controlled to a wall temperature greater than or equal to that of the first particle number dilution device and the wall temperature held at a fixed nominal operating temperature between 573 K (300 °C) and 673 K (400 °C), to a tolerance of ± 10 K.

A.1.2.1.4.4.3. Second particle number dilution device (PND_2)

PND_2 shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of maintaining a single dilution factor within a range of 10 to 30 times. The dilution factor of PND_2 shall be selected in the range between 10 and 15 such that particle number concentration downstream of the second diluter is less than the upper threshold of the single particle count mode of the PNC and the gas temperature prior to entry to the PNC is < 308 K (35 °C).

A.1.2.1.4.5. Particle number counter (PNC)

The PNC shall meet the requirements of clause A.1.2.1.3.4..

A.1.2.2. Calibration/Validation of the particle sampling system[1]

[1]Example calibration/validation methods are available at:

A.1.2.2.1. Calibration of the particle number counter

A.1.2.2.1.1 The Test Agency shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 12-month period prior to the emissions test.

A.1.2.2.1.2. The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

A.1.2.2.1.3. Calibration shall be traceable to a standard calibration method:

(a) By comparison of the response of the PNC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles; or

(b) By comparison of the response of the PNC under calibration with that of a second PNC which has been directly calibrated by the above method.

In the electrometer case, calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ± 10 per cent of the standard concentration for each concentration used, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).

In the reference PNC case, calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1,000 cm^{-3}, the remaining concentrations shall be linearly spaced between 1,000 cm^{-3} and the maximum of the PNC's range in single particle count mode. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ± 10 per cent of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).

A.1.2.2.1.4. Calibration shall also include a check, against the requirements in clause A.1.2.1.3.4.8., on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.

A.1.2.2.2. Calibration/Validation of the volatile particle remover

www.unece.org/es/trans/main/wp29/wp29wgs/wp29grpe/pmpfcp

A.1.2.2.2.1. Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on diesel particulate filter equipped construction equipment vehicle, agricultural tractors or combine harvester. The Test Agency shall ensure the existence of a calibration or validation certificate for the volatile particle remover within a 6-month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12 month validation interval shall be permissible.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors ($f_r(d)$) for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 per cent of the mean particle concentration reduction factor ($\overline{f_r}$) determined during the primary calibration of the VPR.

A.1.2.2.2.2. The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles cm^{-3} at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor at each particle size ($f_r(d_i)$) shall be calculated by means of equation (A.4-32):

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)} \qquad \text{(A.4-32)}$$

Where:

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i

d_i is the particle electrical mobility diameter (30, 50 or 100 nm)

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The mean particle concentration reduction ($\overline{f_r}$) at a given dilution setting shall be calculated by means of equation (A.4-33):

$$\overline{f_r} = \frac{f_r(30nm) + f_r(50nm) + f_r(100nm)}{3} \qquad \text{(A.4-33)}$$

It is recommended that the VPR is calibrated and validated as a complete unit.

A.1.2.2.2.3. The Test Agency shall ensure the existence of a validation certificate for the VPR demonstrating effective volatile particle removal efficiency within a 6 month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12 month validation interval shall be permissible. The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration of ≥

10,000 cm^{-3} when operated at its minimum dilution setting and manufacturers recommended operating temperature.

A.1.2.2.3. Particle number system check procedures

A.1.2.2.3.1. Prior to each test, the particle counter shall report a measured concentration of less than 0.5 particles cm^{-3} when a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, is attached to the inlet of the entire particle sampling system (VPR and PNC).

A.1.2.2.3.2. On a monthly basis, the flow into the particle counter shall report a measured value within 5 per cent of the particle counter nominal flow rate when checked with a calibrated flowmeter.

A.1.2.2.3.3. Each day, following the application of a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of the particle counter, the particle counter shall report a concentration of ≤ 0.2 cm^{-3}. Upon removal of this filter, the particle counter shall show an increase in measured concentration to at least 100 particles cm^{-3} when challenged with ambient air and a return to ≤ 0.2 cm^{-3} on replacement of the HEPA filter.

A.1.2.2.3.4. Prior to the start of each test it shall be confirmed that the measurement system indicates that the evaporation tube, where featured in the system, has reached its correct operating temperature.

A.1.2.2.3.5. Prior to the start of each test it shall be confirmed that the measurement system indicates that the diluter PND_1 has reached its correct operating temperature.

ANNEX 4 - APPENDIX A.2

INSTALLATION REQUIREMENTS FOR EQUIPMENT AND AUXILIARIES

Number	Equipment and auxiliaries	Fitted for emission test
1	Inlet system	
	Inlet manifold	Yes
	Crankcase emission control system	Yes
	Air flowmeter	Yes
	Air filter	Yes[(a)]
	Inlet silencer	Yes[(a)]
2	Exhaust system	
	Exhaust after-treatment	Yes
	Exhaust manifold	Yes
	Connecting pipes	Yes[(b)]
	Silencer	Yes[(b)]
	Tail pipe	Yes[(b)]
	Exhaust brake	No[(c)]
	Pressure charging device	Yes
3	Fuel supply pump	Yes[(d)]
4	Fuel injection equipment	
	Prefilter	Yes
	Filter	Yes
	Pump	Yes
5	High-pressure pipe	Yes
	Injector	Yes

Number	Equipment and auxiliaries	Fitted for emission test
	Electronic control unit, sensors, etc.	Yes
	Governor/control system	Yes
	Automatic full-load stop for the control rack depending on atmospheric conditions	Yes
6	Liquid-cooling equipment	
	Radiator	No
	Fan	No
	Fan cowl	No
	Water pump	Yes[(e)]
	Thermostat	Yes[(f)]
7	Air cooling	
	Cowl	No[(g)]
	Fan or Blower	No[(g)]
	Temperature-regulating device	No
8	Pressure charging equipment	
	Compressor driven either directly by the engine and/or by the exhaust gases	Yes
	Charge air cooler	Yes[(g)(h)]
	Coolant pump or fan (engine-driven)	No[(g)]
	Coolant flow control device	Yes
9	Auxiliary test-bed fan	Yes, if necessary
10	Anti-pollution device	Yes
11	Starting equipment	Yes or test bed equipment(i)
12	Lubricating oil pump	Yes

Number	Equipment and auxiliaries	Fitted for emission test
13	Certain auxiliaries whose definition is linked with the operation of the agricultural tractor, construction equipment vehicle or combine harvester and which may be mounted on the engine shall be removed for the test. The following non-exhaustive list is given as an example: (i) air compressor for brakes (ii) power steering compressor (iii) suspension compressor (iv) air-conditioning system.	No

(a) The complete inlet system shall be fitted as provided for the intended application:

(i) where there is a risk of an appreciable effect on the engine power;

(ii) when the manufacturer requests that this should be done.

In other cases, an equivalent system may be used and a check should be made to ascertain that the intake pressure does not differ by more than 100 Pa from the upper limit specified by the manufacturer for a clean air filter.

(b) The complete exhaust system shall be fitted as provided for the intended application:

(i) where there is a risk of an appreciable effect on the engine power;

(ii) when the manufacturer requests that this should be done.

In other cases, an equivalent system may be installed provided the pressure measured does not differ by more than 1,000 Pa from the upper limit specified by the manufacturer.

(c) If an exhaust brake is incorporated in the engine, the throttle valve shall be fixed in the fully open position.

(d) The fuel feed pressure may be adjusted, if necessary, to reproduce the pressure existing in the particular engine application (particularly when a "fuel return" system is used).

(e) The cooling-liquid circulation shall be operated by the engine water pump only. Cooling of the liquid may be produced by an external circuit, such that the pressure loss of this circuit and the pressure at the pump inlet remain substantially the same as those of the engine cooling system.

(f) The thermostat may be fixed in the fully open position.

(g) When the cooling fan or blower is fitted for the test, the power absorbed shall be added to the results, except for cooling fans of air cooled engines directly fitted on the crankshaft. The fan or blower power shall be determined at the speeds used for the test either by calculation from standard characteristics or by practical tests.

Number	Equipment and auxiliaries	Fitted for emission test
(h)	Charge air-cooled engines shall be tested with charge air cooling, whether liquid - or air-cooled, but if the manufacturer prefers, a test bench system may replace the air cooler. In either case, the measurement of power at each speed shall be made with the maximum pressure drop and the minimum temperature drop of the engine air across the charge air cooler on the test bench system as those specified by the manufacturer.	
(i)	The power for electrical or other starting systems shall be provided from the test bed.	

ANNEX 4 - APPENDIX A.3

VERIFICATION OF TORQUE SIGNAL BROADCAST BY ELECTRONIC CONTROL UNIT

A.3.1. INTRODUCTION

To conduct in-service monitoring tests, this Appendix sets out the requirements for torque verification should the manufacturer intend to use the torque signal broadcast by the electronic control unit (ECU), of engines so equipped.

The basis for the gross torque shall be uncorrected gross torque delivered by the engine inclusive of the equipment and auxiliaries to be included for an emissions test according to Appendix A.2.

A.3.2. BROADCAST TORQUE

With the engine installed on the test bench for conducting the mapping procedure, means shall be provided to read the torque signal broadcast by the ECU.

A.3.3. VERIFICATION PROCEDURE

When conducting the mapping procedure according to clause 7.6.2. of this Annex readings of the torque measured by the dynamometer and torque broadcast by the ECU shall be taken simultaneously at a minimum of three points on the torque curve. At least one of the readings shall be taken at a point on the curve where the torque is no less than 98 per cent of the maximum value.

The torque broadcast by the ECU shall be accepted without correction if, at each point where measurements were taken, the factor calculated from dividing the torque value from the dynamometer by the torque value from the ECU is not less than 0.93 (i.e a maximum difference of 7 per cent). In this case it shall be recorded in the communication that the torque broadcast by the ECU has been verified without correction. Where the factor at one or more test points is less than 0.93 the average correction factor shall be determined from all the points where readings were taken and recorded in the communication. Where a factor is recorded in the communication it shall be applied to the torque broadcast by the ECU when conducting in-service monitoring tests.

ANNEX 4 - APPENDIX A.4

PROCEDURES FOR THE MEASUREMENT OF AMMONIA

A.4.1. This appendix describes the procedure for measurement of ammonia (NH_3). For non-linear analysers, the use of linearising circuits shall be permitted.

A.4.2. Three measurement principles are specified for NH_3 measurement and either principle may be used provided it meets the criteria specified in clauses A.4.2.1., A.4.2.2. or A.4.2.3., respectively. Gas dryers shall not be permitted for NH_3 measurement.

A.4.2.1. Fourier Transform Infrared (hereinafter "FTIR") analyser

A.4.2.1.1. Measurement principle

The FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose standardised spectra are available in the instrument. The absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

A.4.2.1.2. Installation and sampling

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. The NH_3 wavelength shall be selected for evaluation. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to set points between 383 K (110 °C) and 464 K (191 °C) in order to minimise NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

A.4.2.1.3. Cross interference

The spectral resolution of the NH_3 wavelength shall be within 0.5 cm^{-1} in order to minimise cross interference from other gases present in the exhaust gas.

A.4.2.2. Non Dispersive Ultra Violet Resonance Absorption analyser (hereinafter "NDUV")

A.4.2.2.1. Measurement Principle

The NDUV is based on a purely physical principle, no auxiliary gases or equipment is necessary. The main element of the photometer is an electrode-less discharge lamp. It produces a sharply structured radiation in the ultraviolet range, enabling the measurement of several components such as NH_3.

The photometric system has a dual beam in time design set up to produce a measuring and a reference beam by filter correlation technique.

In order to achieve a high stability of the measuring signal the dual beam in time design is combined with a dual beam in space design. The detector signals processing fosters an almost negligible amount of zero point drift rate.

In the calibration mode of the analyser a sealed-off quartz cell is tilted into the beam path to obtain an exact calibration value, since any reflection and absorption losses of the cell windows are cancelled out. Since the gas filling of the cell is very stable, this calibration method leads to a very stable long term stability of the photometer.

A.4.2.2.2. Installation

The analyser shall be installed within an analyser cabinet using extractive sampling in accordance with the instrument manufacturer's instructions. The analiser location shall be capable of supporting the weight specified by the manufacturer.

The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to set points between 383 K (110 °C) and 464 K (191 °C).

In addition, the sampling line shall be as short as possible. Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimised.

The gas analiser shall be protected from cold, heat, temperature variations, and strong air currents, accumulation of dust, corrosive atmosphere and vibrations. Adequate air circulation shall be provided to avoid heat build-up. The complete surface shall be used to dissipate the heat losses.

A.4.2.2.3. Cross Sensitivity

An appropriate spectral range shall be chosen in order to minimise cross interferences of accompanying gases. Typical components causing cross sensitivities on the NH_3 measurement are SO_2, NO_2 and NO.

Additionally, further methods can be applied to reduce the cross sensitivities.

(a) Usage of interference filters;

(b) Cross sensitivity compensation by measuring cross sensitivity components and using the measurement signal for compensation.

A.4.2.3. Laser Infrared analyser

A.4.2.3.1. Measurement principle

An infrared laser such as a tunable diode laser (TDL) or a quantum cascade laser (QCL) can emit coherent light in the near-infrared region or in mid-infrared region respectively where nitrogen compounds including NH_3 have strong absorption. This laser optics can give a pulsed-mode high resolution narrow band near-infarred or mid-infrared spectrum. Therefore, laser infrared analisers can reduce interference caused by the spectral overlap of co-existing gases in engine exhaust.

A.4.2.3.2. Installation

The analyser shall be installed either directly in the exhaust pipe (in-situ) or within an analyser cabinet using extractive sampling in accordance with the instrument manufacturers instructions. If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to set points between 383 K (110 °C) and 464 K (191 °C) in order to minimise NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimised, or compensation techniques be used.

If applicable, sheath air used in conjunction with in-situ measurement for protection of the instrument, shall not affect the concentration of any exhaust component

measured downstream of the device, or sampling of other exhaust components shall be made upstream of the device.

A.4.2.3.3. Interference verification for NH_3 laser infrared analisers (cross interference)

A.4.2.3.3.1. Scope and frequency

If NH_3 is measured using laser infrared analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance.

A.4.2.3.3.2. Measurement principles for interference verification

Interference gasses can positively interfere with certain laser infrared analiser by causing a response similar to NH_3. If the analiser uses compensation algorithms that use measurements of other gases to meet this interference verification, these other measurements shall be simultaneously conducted to test the compensation algorithms during the analiser interference verification.

Good engineering judgment shall be used to determine interference gases for laser infrared analiser. Note that interference species, with the exception of H_2O, are dependent on the NH_3 infrared absorption band chosen by the instrument manufacturer. For each analiser the NH_3 infrared absorption band shall be determined. For each NH_3 infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

A.4.3. EMISSIONS TEST PROCEDURE

A.4.3.1. Checking the analysers

Prior to the emissions test, the analyser range shall be selected. Emission analysers with automatic or manual range switching shall be permitted. During the test cycle, the range of the analysers shall not be switched.

Zero and span response shall be determined, if the provisions set out in clause A.4.3.4.2. do not apply for the instrument. For the span response, a NH_3 gas that meets the specifications set out in clause A.4.4.2.7., shall be used. The use of reference cells that contain NH_3 span gas is permitted.

A.4.3.2. Collection of emission relevant data

At the start of the test sequence, the NH_3 data collection shall be started, simultaneously. The NH_3 concentration shall be measured continuously and stored with at least 1 Hz on a computer system.

A.4.3.3. Operations after test

At the completion of the test, sampling shall continue until system response times have elapsed. Determination of analyser's drift in accordance with clause A.4.3.4.1. shall only be required if the information required in clause A.4.3.4.2. is not available.

A.4.3.4. Analyser drift

A.4.3.4.1. As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the analyser shall be determined. The difference between the pre-test and post-test results shall be less than 2 per cent of full scale.

A.4.3.4.2. Determination of analyser drift is not required in the following situations:

(a) If the zero and span drift specified by the instrument manufacturer in clause A.4.4.2.3. and A.4.4.2.4. meets the requirements of clause A.4.3.4.1.;

(b) The time interval for zero and span drift specified by the instrument manufacturer in clause A.4.4.2.3. and A.4.4.2.4. exceeds the duration of the test.

A.4.4. ANALYSER SPECIFICATION AND VERIFICATION

A.4.4.1. Linearity requirements

The analyser shall comply with the linearity requirements specified in Table A.4-8 of this Annex. The linearity verification in accordance with clause 8.1.4. of this Annex shall be performed at least at the minimum frequency set out in Table A.4-5. of this Annex. With the prior approval of the Test Agency, less than 10 reference points are permitted, if an equivalent accuracy can be demonstrated.

For the linearity verification, a NH_3 gas that meets the specifications set out in clause A.4.4.2.7. shall be used. The use of reference cells that contain NH_3 span gas shall be permitted.

Instruments, whose signals are used for compensation algorithms, shall meet the linearity requirements specified in Table 5. of this Annex. Linearity verification shall be done as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

A.4.4.2. Analyser specifications

The analyser shall have a measuring range and response time appropriate for the accuracy required to measure the concentration of NH_3 under transient and steady state conditions.

A.4.4.2.1. Minimum detection limit

The analyser shall have a minimum detection limit of < 2 ppm under all conditions of testing.

A.4.4.2.2. Accuracy

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed ± 3 per cent of the reading or ± 2 ppm, whichever is larger.

A.4.4.2.3. Zero drift

The drift of the zero response and the related time interval shall be specified by the instrument manufacturer.

A.4.4.2.4. Span drift

The drift of the span response and the related time interval shall be specified by the instrument manufacturer.

A.4.4.2.5. System response time

The system response time shall be ≤ 20 s.

A.4.4.2.6. Rise time

The rise time of the analyser shall be ≤ 5 s.

A.4.4.2.7. NH_3 calibration gas

A gas mixture with the following chemical composition shall be available.

NH_3 and purified nitrogen.

The true concentration of the calibration gas shall be within ± 3 per cent of the nominal value. The concentration of NH_3 shall be given on a volume basis (volume per cent or volume ppm).

The expiration date of the calibration gases shall be recorded.

A.4.4.2.8. Interference verification procedure

The interference verification shall be performed as follows:

(a) The NH_3 analiser shall be started, operated, zeroed, and spanned as it would be before an emission test;

(b) A humidified interference test gas shall be created by bubbling a multi component span gas through distilled H_2O in a sealed vessel. If the sample is not passed through a sample dryer, the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during emission testing. Interference span gas concentrations shall be used at least as high as the maximum expected during testing;

(c) The humidified interference test gas shall be introduced into the sample system.

(d) The water mole fraction, x_{H2O}, of the humidified interference test gas shall be measured, as close as possible to the inlet of the analiser. For example, dew point, T_{dew}, and absolute pressure, p_{total}, shall be measured to calculate x_{H2O};

(e) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analiser;

(f) Time shall be allowed for the analyser response to stabilise;

(g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated;

(h) The analiser meets the interference verification if the result of sub-clause (g) of this clause meets the tolerance in sub- clause (j).

(i) Interference procedures for individual interference gases may also run separately. If the interference gas levels used are higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference concentrations of H_2O (down to 0.025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values must meet the tolerance for combined interference as specified in sub- clause (j) of this clause.

(j) Analiser shall have combined interference within ± 0.2 ppm NH_3.

A.4.5. ALTERNATIVE SYSTEMS

Other systems or analysers may be approved by the Test Agency, if it is found that they yield equivalent results in accordance with clause 5.1.3. of this Annex. In this case, "Results" in that clause shall refer to mean NH_3 concentration calculated for the applicable cycle.

ANNEX 4 - APPENDIX A.5

DESCRIPTION OF SYSTEM RESPONSES

This appendix describes the times used to express the response of analytical systems and other measurement systems to an input signal.

A.5.1. The following times apply, as shown in figure A.4-10:

A.5.1.1. Delay time is the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point.

A.5.1.2. Response time is the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point.

A.5.1.3. Rise time is the difference in time the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$)

A.5.1.4. Transformation time is the difference in time between the change of the component to be measured at the reference point and a system response of 50 per cent of the final reading (t_{50}) with the sampling probe being defined as the reference point.

A.5.1.5 Step input time is the time at which there is a change in the parameter being measured.

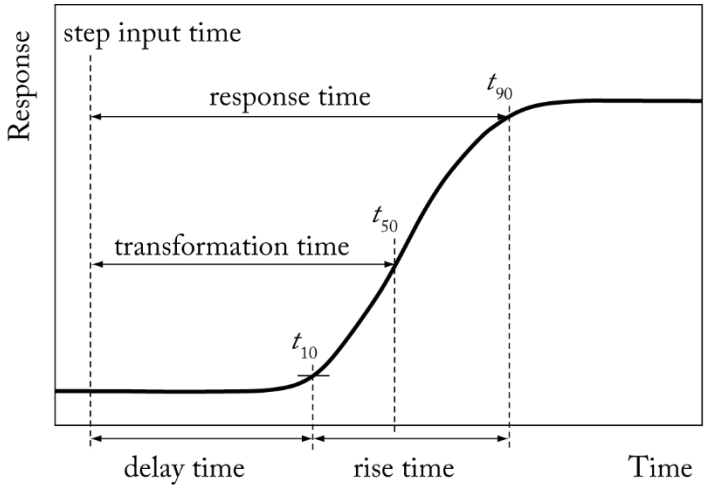


Figure A.4-10

Illustration of System Responses

ANNEX 4 - APPENDIX A.6

CHARACTERISTICS OF THE STEADY-STATE AND TRANSIENT TEST CYCLES

A.6.1. Test cycles applicable to engine categories and sub-categories are set out in table A.4-11 and table A.4-17.

Table A.4-11

NRSC Test Cycles for Engines of Category NRE

Category	Speed operation	Purpose	Sub-category	NRSC
NRE	variable	Variable speed engine having a reference power less than 19 kW	NRE-v-1 NRE-v-2	G2 or C1
		Variable speed engine having a reference power greater than or equal to 19 kW but not more than 560 kW	NRE-v-3 NRE-v-4 NRE-v-5 NRE-v-6	C1
		Variable speed engine having a reference power greater than 560 kW	NRE-v-7	C1
	constant	Constant speed engine	NRE-c-1 NRE-c-2 NRE-c-3 NRE-c-4 NRE-c-5 NRE-c-6 NRE-c-7	D2

Tables A.4-12 to 16 : Reserved

Table A.4-17

Non-road Transient Test Cycle for Engines of Category NRE

Category	Speed operation	Purpose	Sub-category	
NRE	variable	Variable speed engine having reference power greater than or equal to 19 kW but not more than 560 kW	NRE-v-3 NRE-v-4 NRE-v-5 NRE-v-6	NRTC

Tables A.4-18 : Reserved

A.6.2. Steady-state discrete-mode cycles

The detailed description of the test modes and weighting factors for the steady-state discrete-mode test cycles are set out in tables A.4-19, 21 and 22

Table A.4-19

Cycle C1 Test Modes and Weighting Factors

Mode number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Speed(a)	100%				Intermediate			Idle
Torque(b) (%)	100	75	50	10	100	75	50	0
Weighting factor	0.15	0.15	0.15	0.1	0.1	0.1	0.1	0.15

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) The per cent torque is relative to the maximum torque at the commanded engine speed.

Tables A.4-20 : Reserved

Table A.4-21

Cycle D2 Test Modes and Weighting Factors

Mode number (cycle D2)	**1**	**2**	**3**	**4**	**5**
Speed(a)	100%				
Torque(b) (%)	100	75	50	25	10
Weighting factor	0.05	0.25	0.3	0.3	0.1

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) per cent torque is relative to the torque corresponding to the rated gross power declared by the manufacturer.

Table A.4-22

Cycles Type G Test Modes and Weighting Factors

Mode number (cycle G1)						**1**	**2**	**3**	**4**	**5**	**6**
Speed(a)	100%					Intermediate					Idle
Torque(b) %						100	75	50	25	10	0
Weighting factor						0.09	0.20	0.29	0.30	0.07	0.05

Mode number (cycle G2)	**1**	**2**	**3**	**4**	**5**						**6**
Speed(a)	100%										Idle
Torque(b) %	100	75	50	25	10						0
Weighting factor	0.09	0.20	0.29	0.30	0.07						0.05
Mode number (cycle G3)	**1**										**2**
Speed(a)	100%					Intermediate					Idle
Torque(b) %	100										0
Weighting factor	0.85										0.15

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) The per cent torque is relative to the maximum torque at the commanded engine speed.

Tables A.4-23 : Reserved

A.6.3. Steady-state ramped modal cycles (RMC)

The detailed description of the test modes and time in mode for the steady-state ramped modal cycles are set out in tables A.4-24,26,27 and 28.

Table A.4-24

RMC-C1 Test Modes

RMC Mode Number	**Time in mode [s]**	**Engine speed** (a)(c)	**Torque [%]** (b)(c)
1a Steady-state	126	Idle	0
1b Transition	20	Linear transition	Linear transition
2a Steady-state	159	Intermediate	100
2b Transition	20	Intermediate	Linear transition
3a Steady-state	160	Intermediate	50
3b Transition	20	Intermediate	Linear transition
4a Steady-state	162	Intermediate	75

4b Transition	20	Linear transition	Linear transition
5a Steady-state	246	100 %	100
5b Transition	20	100 %	Linear transition
6a Steady-state	164	100 %	10
6b Transition	20	100 %	Linear transition
7a Steady-state	248	100 %	75
7b Transition	20	100 %	Linear transition
8a Steady-state	247	100 %	50
8b Transition	20	Linear transition	Linear transition
9 Steady-state	128	Idle	0

a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) per cent torque is relative to the maximum torque at the commanded engine speed.

(c) Advance from one mode to the next within a 20-second transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode, and simultaneously command a similar linear progression for engine speed if there is a change in speed setting.

Table A.4-25 : Reserved

Table A.4-26

RMC-D2 Test Modes

RMC Mode Number	Time in mode [s]	Engine speed [%] [(a)]	Torque [%] [(b)(c)]
1a Steady State	53	100	100
1b Transition	20	100	Linear transition
2a Steady-state	101	100	10
2b Transition	20	100	Linear transition
3a Steady-state	277	100	75
3b Transition	20	100	Linear transition
4a Steady-state	339	100	25
4b Transition	20	100	Linear transition
5 Steady-state	350	100	50

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) per cent torque is relative to the torque corresponding to the rated gross power declared by the manufacturer.

(c) Advance from one mode to the next within a 20-second transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode.

Table A.4-27

RMC-G1 Test Modes

RMC Mode Number	Time in mode [s]	Engine speed[(a)(c)]	Torque [%][(b)(c)]
1a Steady-state	41	Idle	0
1b Transition	20	Linear transition	Linear transition
2a Steady-state	135	Intermediate	100
2b Transition	20	Intermediate	Linear transition
3a Steady-state	112	Intermediate	10
3b Transition	20	Intermediate	Linear transition
4a Steady-state	337	Intermediate	75
4b Transition	20	Intermediate	Linear transition
5a Steady-state	518	Intermediate	25
5b Transition	20	Intermediate	Linear transition
6a Steady-state	494	Intermediate	50
6b Transition	20	Linear transition	Linear transition
7 Steady-state	43	Idle	0

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) The per cent torque is relative to the maximum torque at the commanded engine speed.

(c) Advance from one mode to the next within a 20-second transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode and simultaneously command a similar linear progression for engine speed if there is a change in speed setting.

Table A.4-28

RMC-G2 Test Modes

RMC Mode Number	**Time in mode [s]**	**Engine speed[(a)(c)]**	**Torque [%][(b)(c)]**
1a Steady-state	41	Idle	0
1b Transition	20	Linear transition	Linear transition
2a Steady-state	135	100 %	100
2b Transition	20	100 %	Linear transition
3a Steady-state	112	100 %	10
3b Transition	20	100 %	Linear transition
4a Steady-state	337	100 %	75
4b Transition	20	100 %	Linear transition
5a Steady-state	518	100 %	25
5b Transition	20	100 %	Linear transition
6a Steady-state	494	100 %	50
6b Transition	20	Linear transition	Linear transition
7 Steady-state	43	Idle	0

(a) See clauses 5.2.5., 7.6. and 7.7. of Annex 4 for determination of required test speeds.

(b) The per cent torque is relative to the maximum torque at the commanded engine speed.

(c) Advance from one mode to the next within a 20-second transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode and simultaneously command a similar linear progression for engine speed if there is a change in speed setting.

Table A.4-29 : Reserved

A.6.4. TRANSIENT TEST CYCLES

The second-by-second normalised engine speed and torque for the transient test cycles are set out in tables A.4-30 and A.4-31.

Table A.4-30

NRTC Engine Dynamometer Schedule

Time (s)	Normalised speed (%)	Normalised torque (%)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	1	3
25	1	3
26	1	3
27	1	3
28	1	3
29	1	3
30	1	6
31	1	6
32	2	1
33	4	13
34	7	18
35	9	21
36	17	20
37	33	42
38	57	46
39	44	33
40	31	0
41	22	27
42	33	43
43	80	49
44	105	47
45	98	70
46	104	36
47	104	65
48	96	71
49	101	62
50	102	51
51	102	50
52	102	46
53	102	41
54	102	31
55	89	2
56	82	0
57	47	1
58	23	1
59	1	3
60	1	8
61	1	3
62	1	5
63	1	6
64	1	4
65	1	4
66	0	6
67	1	4
68	9	21
69	25	56

Time (s)	Normalised speed (%)	Normalised torque (%)
70	64	26
71	60	31
72	63	20
73	62	24
74	64	8
75	58	44
76	65	10
77	65	12
78	68	23
79	69	30
80	71	30
81	74	15
82	71	23
83	73	20
84	73	21
85	73	19
86	70	33
87	70	34
88	65	47
89	66	47
90	64	53
91	65	45
92	66	38
93	67	49
94	69	39
95	69	39

Time (s)	Normalised speed (%)	Normalised torque (%)
96	66	42
97	71	29
98	75	29
99	72	23
100	74	22
101	75	24
102	73	30
103	74	24
104	77	6
105	76	12
106	74	39
107	72	30
108	75	22
109	78	64
110	102	34
111	103	28
112	103	28
113	103	19
114	103	32
115	104	25
116	103	38
117	103	39
118	103	34
119	102	44
120	103	38
121	102	43

Time (s)	Normalised speed (%)	Normalised torque (%)
122	103	34
123	102	41
124	103	44
125	103	37
126	103	27
127	104	13
128	104	30
129	104	19
130	103	28
131	104	40
132	104	32
133	101	63
134	102	54
135	102	52
136	102	51
137	103	40
138	104	34
139	102	36
140	104	44
141	103	44
142	104	33
143	102	27
144	103	26
145	79	53
146	51	37
147	24	23

Time (s)	Normalised speed (%)	Normalised torque (%)
148	13	33
149	19	55
150	45	30
151	34	7
152	14	4
153	8	16
154	15	6
155	39	47
156	39	4
157	35	26
158	27	38
159	43	40
160	14	23
161	10	10
162	15	33
163	35	72
164	60	39
165	55	31
166	47	30
167	16	7
168	0	6
169	0	8
170	0	8
171	0	2
172	2	17
173	10	28
174	28	31
175	33	30
176	36	0
177	19	10
178	1	18
179	0	16
180	1	3
181	1	4
182	1	5
183	1	6
184	1	5
185	1	3
186	1	4
187	1	4
188	1	6
189	8	18
190	20	51
191	49	19
192	41	13
193	31	16
194	28	21
195	21	17
196	31	21
197	21	8
198	0	14
199	0	12
200	3	8
201	3	22
202	12	20
203	14	20
204	16	17
205	20	18
206	27	34
207	32	33
208	41	31
209	43	31
210	37	33
211	26	18
212	18	29
213	14	51
214	13	11
215	12	9
216	15	33
217	20	25
218	25	17
219	31	29
220	36	66
221	66	40
222	50	13
223	16	24
224	26	50
225	64	23

Time (s)	Normalised speed (%)	Normalised torque (%)
226	81	20
227	83	11
228	79	23
229	76	31
230	68	24
231	59	33
232	59	3
233	25	7
234	21	10
235	20	19
236	4	10
237	5	7
238	4	5
239	4	6
240	4	6
241	4	5
242	7	5
243	16	28
244	28	25
245	52	53
246	50	8
247	26	40
248	48	29
249	54	39
250	60	42
251	48	18

Time (s)	Normalised speed (%)	Normalised torque (%)
252	54	51
253	88	90
254	103	84
255	103	85
256	102	84
257	58	66
258	64	97
259	56	80
260	51	67
261	52	96
262	63	62
263	71	6
264	33	16
265	47	45
266	43	56
267	42	27
268	42	64
269	75	74
270	68	96
271	86	61
272	66	0
273	37	0
274	45	37
275	68	96
276	80	97
277	92	96

Time (s)	Normalised speed (%)	Normalised torque (%)
278	90	97
279	82	96
280	94	81
281	90	85
282	96	65
283	70	96
284	55	95
285	70	96
286	79	96
287	81	71
288	71	60
289	92	65
290	82	63
291	61	47
292	52	37
293	24	0
294	20	7
295	39	48
296	39	54
297	63	58
298	53	31
299	51	24
300	48	40
301	39	0
302	35	18
303	36	16

Time (s)	Normalised speed (%)	Normalised torque (%)
304	29	17
305	28	21
306	31	15
307	31	10
308	43	19
309	49	63
310	78	61
311	78	46
312	66	65
313	78	97
314	84	63
315	57	26
316	36	22
317	20	34
318	19	8
319	9	10
320	5	5
321	7	11
322	15	15
323	12	9
324	13	27
325	15	28
326	16	28
327	16	31
328	15	20
329	17	0
330	20	34
331	21	25
332	20	0
333	23	25
334	30	58
335	63	96
336	83	60
337	61	0
338	26	0
339	29	44
340	68	97
341	80	97
342	88	97
343	99	88
344	102	86
345	100	82
346	74	79
347	57	79
348	76	97
349	84	97
350	86	97
351	81	98
352	83	83
353	65	96
354	93	72
355	63	60
356	72	49
357	56	27
358	29	0
359	18	13
360	25	11
361	28	24
362	34	53
363	65	83
364	80	44
365	77	46
366	76	50
367	45	52
368	61	98
369	61	69
370	63	49
371	32	0
372	10	8
373	17	7
374	16	13
375	11	6
376	9	5
377	9	12
378	12	46
379	15	30
380	26	28
381	13	9

Time (s)	Normalised speed (%)	Normalised torque (%)
382	16	21
383	24	4
384	36	43
385	65	85
386	78	66
387	63	39
388	32	34
389	46	55
390	47	42
391	42	39
392	27	0
393	14	5
394	14	14
395	24	54
396	60	90
397	53	66
398	70	48
399	77	93
400	79	67
401	46	65
402	69	98
403	80	97
404	74	97
405	75	98
406	56	61
407	42	0

Time (s)	Normalised speed (%)	Normalised torque (%)
408	36	32
409	34	43
410	68	83
411	102	48
412	62	0
413	41	39
414	71	86
415	91	52
416	89	55
417	89	56
418	88	58
419	78	69
420	98	39
421	64	61
422	90	34
423	88	38
424	97	62
425	100	53
426	81	58
427	74	51
428	76	57
429	76	72
430	85	72
431	84	60
432	83	72
433	83	72

Time (s)	Normalised speed (%)	Normalised torque (%)
434	86	72
435	89	72
436	86	72
437	87	72
438	88	72
439	88	71
440	87	72
441	85	71
442	88	72
443	88	72
444	84	72
445	83	73
446	77	73
447	74	73
448	76	72
449	46	77
450	78	62
451	79	35
452	82	38
453	81	41
454	79	37
455	78	35
456	78	38
457	78	46
458	75	49
459	73	50

Time (s)	Normalised speed (%)	Normalised torque (%)
460	79	58
461	79	71
462	83	44
463	53	48
464	40	48
465	51	75
466	75	72
467	89	67
468	93	60
469	89	73
470	86	73
471	81	73
472	78	73
473	78	73
474	76	73
475	79	73
476	82	73
477	86	73
478	88	72
479	92	71
480	97	54
481	73	43
482	36	64
483	63	31
484	78	1
485	69	27
486	67	28
487	72	9
488	71	9
489	78	36
490	81	56
491	75	53
492	60	45
493	50	37
494	66	41
495	51	61
496	68	47
497	29	42
498	24	73
499	64	71
500	90	71
501	100	61
502	94	73
503	84	73
504	79	73
505	75	72
506	78	73
507	80	73
508	81	73
509	81	73
510	83	73
511	85	73
512	84	73
513	85	73
514	86	73
515	85	73
516	85	73
517	85	72
518	85	73
519	83	73
520	79	73
521	78	73
522	81	73
523	82	72
524	94	56
525	66	48
526	35	71
527	51	44
528	60	23
529	64	10
530	63	14
531	70	37
532	76	45
533	78	18
534	76	51
535	75	33
536	81	17
537	76	45

Time (s)	Normalised speed (%)	Normalised torque (%)
538	76	30
539	80	14
540	71	18
541	71	14
542	71	11
543	65	2
544	31	26
545	24	72
546	64	70
547	77	62
548	80	68
549	83	53
550	83	50
551	83	50
552	85	43
553	86	45
554	89	35
555	82	61
556	87	50
557	85	55
558	89	49
559	87	70
560	91	39
561	72	3
562	43	25
563	30	60

Time (s)	Normalised speed (%)	Normalised torque (%)
564	40	45
565	37	32
566	37	32
567	43	70
568	70	54
569	77	47
570	79	66
571	85	53
572	83	57
573	86	52
574	85	51
575	70	39
576	50	5
577	38	36
578	30	71
579	75	53
580	84	40
581	85	42
582	86	49
583	86	57
584	89	68
585	99	61
586	77	29
587	81	72
588	89	69
589	49	56

Time (s)	Normalised speed (%)	Normalised torque (%)
590	79	70
591	104	59
592	103	54
593	102	56
594	102	56
595	103	61
596	102	64
597	103	60
598	93	72
599	86	73
600	76	73
601	59	49
602	46	22
603	40	65
604	72	31
605	72	27
606	67	44
607	68	37
608	67	42
609	68	50
610	77	43
611	58	4
612	22	37
613	57	69
614	68	38
615	73	2

Time (s)	Normalised speed (%)	Normalised torque (%)
616	40	14
617	42	38
618	64	69
619	64	74
620	67	73
621	65	73
622	68	73
623	65	49
624	81	0
625	37	25
626	24	69
627	68	71
628	70	71
629	76	70
630	71	72
631	73	69
632	76	70
633	77	72
634	77	72
635	77	72
636	77	70
637	76	71
638	76	71
639	77	71
640	77	71
641	78	70

Time (s)	Normalised speed (%)	Normalised torque (%)
642	77	70
643	77	71
644	79	72
645	78	70
646	80	70
647	82	71
648	84	71
649	83	71
650	83	73
651	81	70
652	80	71
653	78	71
654	76	70
655	76	70
656	76	71
657	79	71
658	78	71
659	81	70
660	83	72
661	84	71
662	86	71
663	87	71
664	92	72
665	91	72
666	90	71
667	90	71

Time (s)	Normalised speed (%)	Normalised torque (%)
668	91	71
669	90	70
670	90	72
671	91	71
672	90	71
673	90	71
674	92	72
675	93	69
676	90	70
677	93	72
678	91	70
679	89	71
680	91	71
681	90	71
682	90	71
683	92	71
684	91	71
685	93	71
686	93	68
687	98	68
688	98	67
689	100	69
690	99	68
691	100	71
692	99	68
693	100	69

Time (s)	Normalised speed (%)	Normalised torque (%)
694	102	72
695	101	69
696	100	69
697	102	71
698	102	71
699	102	69
700	102	71
701	102	68
702	100	69
703	102	70
704	102	68
705	102	70
706	102	72
707	102	68
708	102	69
709	100	68
710	102	71
711	101	64
712	102	69
713	102	69
714	101	69
715	102	64
716	102	69
717	102	68
718	102	70
719	102	69

Time (s)	Normalised speed (%)	Normalised torque (%)
720	102	70
721	102	70
722	102	62
723	104	38
724	104	15
725	102	24
726	102	45
727	102	47
728	104	40
729	101	52
730	103	32
731	102	50
732	103	30
733	103	44
734	102	40
735	103	43
736	103	41
737	102	46
738	103	39
739	102	41
740	103	41
741	102	38
742	103	39
743	102	46
744	104	46
745	103	49

Time (s)	Normalised speed (%)	Normalised torque (%)
746	102	45
747	103	42
748	103	46
749	103	38
750	102	48
751	103	35
752	102	48
753	103	49
754	102	48
755	102	46
756	103	47
757	102	49
758	102	42
759	102	52
760	102	57
761	102	55
762	102	61
763	102	61
764	102	58
765	103	58
766	102	59
767	102	54
768	102	63
769	102	61
770	103	55
771	102	60

Time (s)	Normalised speed (%)	Normalised torque (%)
772	102	72
773	103	56
774	102	55
775	102	67
776	103	56
777	84	42
778	48	7
779	48	6
780	48	6
781	48	7
782	48	6
783	48	7
784	67	21
785	105	59
786	105	96
787	105	74
788	105	66
789	105	62
790	105	66
791	89	41
792	52	5
793	48	5
794	48	7
795	48	5
796	48	6
797	48	4

Time (s)	Normalised speed (%)	Normalised torque (%)
798	52	6
799	51	5
800	51	6
801	51	6
802	52	5
803	52	5
804	57	44
805	98	90
806	105	94
807	105	100
808	105	98
809	105	95
810	105	96
811	105	92
812	104	97
813	100	85
814	94	74
815	87	62
816	81	50
817	81	46
818	80	39
819	80	32
820	81	28
821	80	26
822	80	23
823	80	23

Time (s)	Normalised speed (%)	Normalised torque (%)
824	80	20
825	81	19
826	80	18
827	81	17
828	80	20
829	81	24
830	81	21
831	80	26
832	80	24
833	80	23
834	80	22
835	81	21
836	81	24
837	81	24
838	81	22
839	81	22
840	81	21
841	81	31
842	81	27
843	80	26
844	80	26
845	81	25
846	80	21
847	81	20
848	83	21
849	83	15

Time (s)	Normalised speed (%)	Normalised torque (%)
850	83	12
851	83	9
852	83	8
853	83	7
854	83	6
855	83	6
856	83	6
857	83	6
858	83	6
859	76	5
860	49	8
861	51	7
862	51	20
863	78	52
864	80	38
865	81	33
866	83	29
867	83	22
868	83	16
869	83	12
870	83	9
871	83	8
872	83	7
873	83	6
874	83	6
875	83	6

Time (s)	Normalised speed (%)	Normalised torque (%)
876	83	6
877	83	6
878	59	4
879	50	5
880	51	5
881	51	5
882	51	5
883	50	5
884	50	5
885	50	5
886	50	5
887	50	5
888	51	5
889	51	5
890	51	5
891	63	50
892	81	34
893	81	25
894	81	29
895	81	23
896	80	24
897	81	24
898	81	28
899	81	27
900	81	22
901	81	19

Time (s)	Normalised speed (%)	Normalised torque (%)
902	81	17
903	81	17
904	81	17
905	81	15
906	80	15
907	80	28
908	81	22
909	81	24
910	81	19
911	81	21
912	81	20
913	83	26
914	80	63
915	80	59
916	83	100
917	81	73
918	83	53
919	80	76
920	81	61
921	80	50
922	81	37
923	82	49
924	83	37
925	83	25
926	83	17
927	83	13

Time (s)	Normalised speed (%)	Normalised torque (%)
928	83	10
929	83	8
930	83	7
931	83	7
932	83	6
933	83	6
934	83	6
935	71	5
936	49	24
937	69	64
938	81	50
939	81	43
940	81	42
941	81	31
942	81	30
943	81	35
944	81	28
945	81	27
946	80	27
947	81	31
948	81	41
949	81	41
950	81	37
951	81	43
952	81	34
953	81	31

Time (s)	Normalised speed (%)	Normalised torque (%)
954	81	26
955	81	23
956	81	27
957	81	38
958	81	40
959	81	39
960	81	27
961	81	33
962	80	28
963	81	34
964	83	72
965	81	49
966	81	51
967	80	55
968	81	48
969	81	36
970	81	39
971	81	38
972	80	41
973	81	30
974	81	23
975	81	19
976	81	25
977	81	29
978	83	47
979	81	90

Time (s)	Normalised speed (%)	Normalised torque (%)
980	81	75
981	80	60
982	81	48
983	81	41
984	81	30
985	80	24
986	81	20
987	81	21
988	81	29
989	81	29
990	81	27
991	81	23
992	81	25
993	81	26
994	81	22
995	81	20
996	81	17
997	81	23
998	83	65
999	81	54
1000	81	50
1001	81	41
1002	81	35
1003	81	37
1004	81	29
1005	81	28

Time (s)	Normalised speed (%)	Normalised torque (%)
1006	81	24
1007	81	19
1008	81	16
1009	80	16
1010	83	23
1011	83	17
1012	83	13
1013	83	27
1014	81	58
1015	81	60
1016	81	46
1017	80	41
1018	80	36
1019	81	26
1020	86	18
1021	82	35
1022	79	53
1023	82	30
1024	83	29
1025	83	32
1026	83	28
1027	76	60
1028	79	51
1029	86	26
1030	82	34
1031	84	25

Time (s)	Normalised speed (%)	Normalised torque (%)
1032	86	23
1033	85	22
1034	83	26
1035	83	25
1036	83	37
1037	84	14
1038	83	39
1039	76	70
1040	78	81
1041	75	71
1042	86	47
1043	83	35
1044	81	43
1045	81	41
1046	79	46
1047	80	44
1048	84	20
1049	79	31
1050	87	29
1051	82	49
1052	84	21
1053	82	56
1054	81	30
1055	85	21
1056	86	16
1057	79	52

Time (s)	Normalised speed (%)	Normalised torque (%)
1058	78	60
1059	74	55
1060	78	84
1061	80	54
1062	80	35
1063	82	24
1064	83	43
1065	79	49
1066	83	50
1067	86	12
1068	64	14
1069	24	14
1070	49	21
1071	77	48
1072	103	11
1073	98	48
1074	101	34
1075	99	39
1076	103	11
1077	103	19
1078	103	7
1079	103	13
1080	103	10
1081	102	13
1082	101	29
1083	102	25

Time (s)	Normalised speed (%)	Normalised torque (%)
1084	102	20
1085	96	60
1086	99	38
1087	102	24
1088	100	31
1089	100	28
1090	98	3
1091	102	26
1092	95	64
1093	102	23
1094	102	25
1095	98	42
1096	93	68
1097	101	25
1098	95	64
1099	101	35
1100	94	59
1101	97	37
1102	97	60
1103	93	98
1104	98	53
1105	103	13
1106	103	11
1107	103	11
1108	103	13
1109	103	10
1110	103	10
1111	103	11
1112	103	10
1113	103	10
1114	102	18
1115	102	31
1116	101	24
1117	102	19
1118	103	10
1119	102	12
1120	99	56
1121	96	59
1122	74	28
1123	66	62
1124	74	29
1125	64	74
1126	69	40
1127	76	2
1128	72	29
1129	66	65
1130	54	69
1131	69	56
1132	69	40
1133	73	54
1134	63	92
1135	61	67
1136	72	42
1137	78	2
1138	76	34
1139	67	80
1140	70	67
1141	53	70
1142	72	65
1143	60	57
1144	74	29
1145	69	31
1146	76	1
1147	74	22
1148	72	52
1149	62	96
1150	54	72
1151	72	28
1152	72	35
1153	64	68
1154	74	27
1155	76	14
1156	69	38
1157	66	59
1158	64	99
1159	51	86
1160	70	53
1161	72	36

Time (s)	Normalised speed (%)	Normalised torque (%)
1162	71	47
1163	70	42
1164	67	34
1165	74	2
1166	75	21
1167	74	15
1168	75	13
1169	76	10
1170	75	13
1171	75	10
1172	75	7
1173	75	13
1174	76	8
1175	76	7
1176	67	45
1177	75	13
1178	75	12
1179	73	21
1180	68	46
1181	74	8
1182	76	11
1183	76	14
1184	74	11
1185	74	18
1186	73	22
1187	74	20

Time (s)	Normalised speed (%)	Normalised torque (%)
1188	74	19
1189	70	22
1190	71	23
1191	73	19
1192	73	19
1193	72	20
1194	64	60
1195	70	39
1196	66	56
1197	68	64
1198	30	68
1199	70	38
1200	66	47
1201	76	14
1202	74	18
1203	69	46
1204	68	62
1205	68	62
1206	68	62
1207	68	62
1208	68	62
1209	68	62
1210	54	50
1211	41	37
1212	27	25
1213	14	12

Time (s)	Normalised speed (%)	Normalised torque (%)
1214	0	0
1215	0	0
1216	0	0
1217	0	0
1218	0	0
1219	0	0
1220	0	0
1221	0	0
1222	0	0
1223	0	0
1224	0	0
1225	0	0
1226	0	0
1227	0	0
1228	0	0
1229	0	0
1230	0	0
1231	0	0
1232	0	0
1233	0	0
1234	0	0
1235	0	0
1236	0	0
1237	0	0
1238	0	0

A graphical display of the NRTC dynamometer schedule is shown below

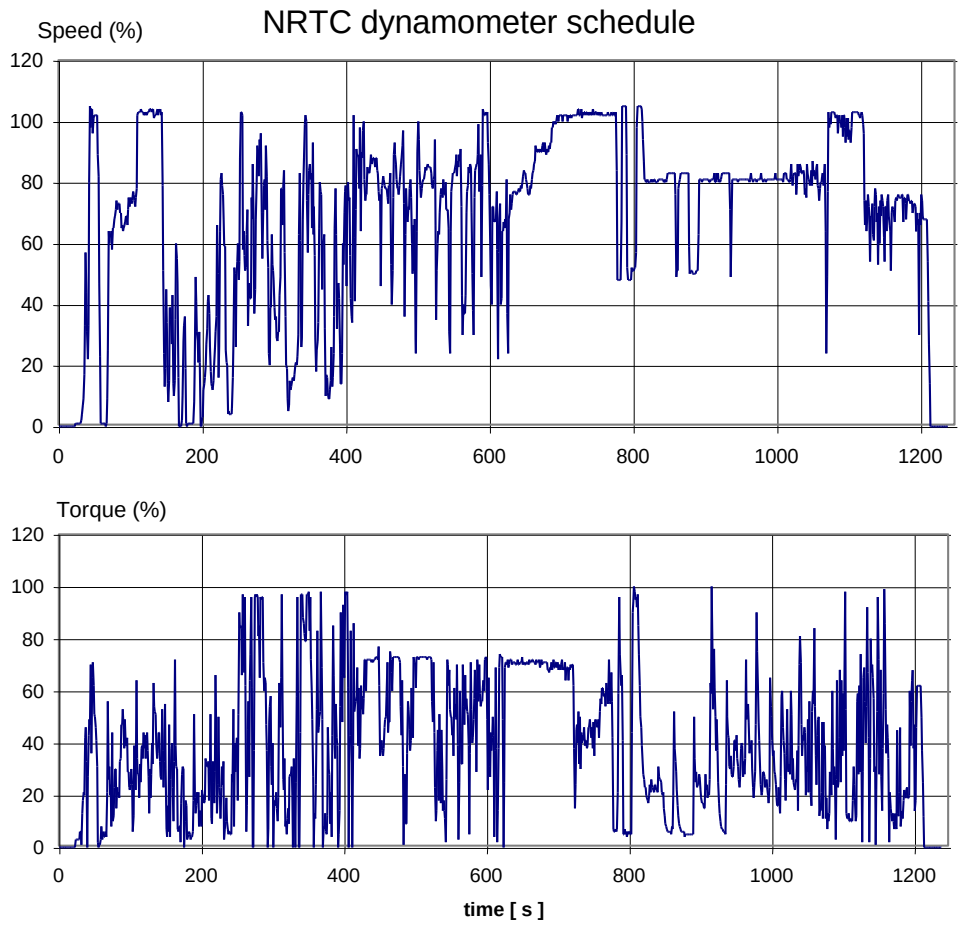


Table A.4-31

LSI-NRTC Engine Dynamometer Schedule

Time (s)	Normalised speed (%)	Normalised torque (%)
0	0	0
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	1	8
10	6	54
11	8	61
12	34	59
13	22	46
14	5	51
15	18	51
16	31	50
17	30	56
18	31	49
19	25	66
20	58	55
21	43	31
22	16	45
23	24	38
24	24	27
25	30	33
26	45	65
27	50	49
28	23	42
29	13	42
30	9	45
31	23	30
32	37	45
33	44	50
34	49	52
35	55	49
36	61	46
37	66	38
38	42	33
39	17	41
40	17	37
41	7	50
42	20	32
43	5	55
44	30	42
45	44	53
46	45	56
47	41	52
48	24	41
49	15	40
50	11	44
51	32	31
52	38	54
53	38	47
54	9	55
55	10	50
56	33	55
57	48	56
58	49	47
59	33	44
60	52	43
61	55	43
62	59	38
63	44	28
64	24	37
65	12	44
66	9	47
67	12	52
68	34	21
69	29	44
70	44	54
71	54	62

Time (s)	Normalised speed (%)	Normalised torque (%)
72	62	57
73	72	56
74	88	71
75	100	69
76	100	34
77	100	42
78	100	54
79	100	58
80	100	38
81	83	17
82	61	15
83	43	22
84	24	35
85	16	39
86	15	45
87	32	34
88	14	42
89	8	48
90	5	51
91	10	41
92	12	37
93	4	47
94	3	49
95	3	50
96	4	49
97	4	48

Time (s)	Normalised speed (%)	Normalised torque (%)
98	8	43
99	2	51
100	5	46
101	8	41
102	4	47
103	3	49
104	6	45
105	3	48
106	10	42
107	18	27
108	3	50
109	11	41
110	34	29
111	51	57
112	67	63
113	61	32
114	44	31
115	48	54
116	69	65
117	85	65
118	81	29
119	74	21
120	62	23
121	76	58
122	96	75
123	100	77

Time (s)	Normalised speed (%)	Normalised torque (%)
124	100	27
125	100	79
126	100	79
127	100	81
128	100	57
129	99	52
130	81	35
131	69	29
132	47	22
133	34	28
134	27	37
135	83	60
136	100	74
137	100	7
138	100	2
139	70	18
140	23	39
141	5	54
142	11	40
143	11	34
144	11	41
145	19	25
146	16	32
147	20	31
148	21	38
149	21	42

Time (s)	Normalised speed (%)	Normalised torque (%)
150	9	51
151	4	49
152	2	51
153	1	58
154	21	57
155	29	47
156	33	45
157	16	49
158	38	45
159	37	43
160	35	42
161	39	43
162	51	49
163	59	55
164	65	54
165	76	62
166	84	59
167	83	29
168	67	35
169	84	54
170	90	58
171	93	43
172	90	29
173	66	19
174	52	16
175	49	17

Time (s)	Normalised speed (%)	Normalised torque (%)
176	56	38
177	73	71
178	86	80
179	96	75
180	89	27
181	66	17
182	50	18
183	36	25
184	36	24
185	38	40
186	40	50
187	27	48
188	19	48
189	23	50
190	19	45
191	6	51
192	24	48
193	49	67
194	47	49
195	22	44
196	25	40
197	38	54
198	43	55
199	40	52
200	14	49
201	11	45

Time (s)	Normalised speed (%)	Normalised torque (%)
202	7	48
203	26	41
204	41	59
205	53	60
206	44	54
207	22	40
208	24	41
209	32	53
210	44	74
211	57	25
212	22	49
213	29	45
214	19	37
215	14	43
216	36	40
217	43	63
218	42	49
219	15	50
220	19	44
221	47	59
222	67	80
223	76	74
224	87	66
225	98	61
226	100	38
227	97	27

Time (s)	Normalised speed (%)	Normalised torque (%)
228	100	53
229	100	72
230	100	49
231	100	4
232	100	13
233	87	15
234	53	26
235	33	27
236	39	19
237	51	33
238	67	54
239	83	60
240	95	52
241	100	50
242	100	36
243	100	25
244	85	16
245	62	16
246	40	26
247	56	39
248	81	75
249	98	86
250	100	76
251	100	51
252	100	78
253	100	83

Time (s)	Normalised speed (%)	Normalised torque (%)
254	100	100
255	100	66
256	100	85
257	100	72
258	100	45
259	98	58
260	60	30
261	43	32
262	71	36
263	44	32
264	24	38
265	42	17
266	22	51
267	13	53
268	23	45
269	29	50
270	28	42
271	21	55
272	34	57
273	44	47
274	19	46
275	13	44
276	25	36
277	43	51
278	55	73
279	68	72

Time (s)	Normalised speed (%)	Normalised torque (%)
280	76	63
281	80	45
282	83	40
283	78	26
284	60	20
285	47	19
286	52	25
287	36	30
288	40	26
289	45	34
290	47	35
291	42	28
292	46	38
293	48	44
294	68	61
295	70	47
296	48	28
297	42	22
298	31	29
299	22	35
300	28	28
301	46	46
302	62	69
303	76	81
304	88	85
305	98	81

Time (s)	Normalised speed (%)	Normalised torque (%)
306	100	74
307	100	13
308	100	11
309	100	17
310	99	3
311	80	7
312	62	11
313	63	11
314	64	16
315	69	43
316	81	67
317	93	74
318	100	72
319	94	27
320	73	15
321	40	33
322	40	52
323	50	50
324	11	53
325	12	45
326	5	50
327	1	55
328	7	55
329	62	60
330	80	28
331	23	37

Time (s)	Normalised speed (%)	Normalised torque (%)
332	39	58
333	47	24
334	59	51
335	58	68
336	36	52
337	18	42
338	36	52
339	59	73
340	72	85
341	85	92
342	99	90
343	100	72
344	100	18
345	100	76
346	100	64
347	100	87
348	100	97
349	100	84
350	100	100
351	100	91
352	100	83
353	100	93
354	100	100
355	94	43
356	72	10
357	77	3

Time (s)	Normalised speed (%)	Normalised torque (%)
358	48	2
359	29	5
360	59	19
361	63	5
362	35	2
363	24	3
364	28	2
365	36	16
366	54	23
367	60	10
368	33	1
369	23	0
370	16	0
371	11	0
372	20	0
373	25	2
374	40	3
375	33	4
376	34	5
377	46	7
378	57	10
379	66	11
380	75	14
381	79	11
382	80	16
383	92	21

Time (s)	Normalised speed (%)	Normalised torque (%)
384	99	16
385	83	2
386	71	2
387	69	4
388	67	4
389	74	16
390	86	25
391	97	28
392	100	15
393	83	2
394	62	4
395	40	6
396	49	10
397	36	5
398	27	4
399	29	3
400	22	2
401	13	3
402	37	36
403	90	26
404	41	2
405	25	2
406	29	2
407	38	7
408	50	13
409	55	10

Time (s)	Normalised speed (%)	Normalised torque (%)
410	29	3
411	24	7
412	51	16
413	62	15
414	72	35
415	91	74
416	100	73
417	100	8
418	98	11
419	100	59
420	100	98
421	100	99
422	100	75
423	100	95
424	100	100
425	100	97
426	100	90
427	100	86
428	100	82
429	97	43
430	70	16
431	50	20
432	42	33
433	89	64
434	89	77
435	99	95

Time (s)	Normalised speed (%)	Normalised torque (%)
436	100	41
437	77	12
438	29	37
439	16	41
440	16	38
441	15	36
442	18	44
443	4	55
444	24	26
445	26	35
446	15	45
447	21	39
448	29	52
449	26	46
450	27	50
451	13	43
452	25	36
453	37	57
454	29	46
455	17	39
456	13	41
457	19	38
458	28	35
459	8	51
460	14	36
461	17	47

Time (s)	Normalised speed (%)	Normalised torque (%)
462	34	39
463	34	57
464	11	70
465	13	51
466	13	68
467	38	44
468	53	67
469	29	69
470	19	65
471	52	45
472	61	79
473	29	70
474	15	53
475	15	60
476	52	40
477	50	61
478	13	74
479	46	51
480	60	73
481	33	84
482	31	63
483	41	42
484	26	69
485	23	65
486	48	49
487	28	57

Time (s)	Normalised speed (%)	Normalised torque (%)
488	16	67
489	39	48
490	47	73
491	35	87
492	26	73
493	30	61
494	34	49
495	35	66
496	56	47
497	49	64
498	59	64
499	42	69
500	6	77
501	5	59
502	17	59
503	45	53
504	21	62
505	31	60
506	53	68
507	48	79
508	45	61
509	51	47
510	41	48
511	26	58
512	21	62
513	50	52

Time (s)	Normalised speed (%)	Normalised torque (%)
514	39	65
515	23	65
516	42	62
517	57	80
518	66	81
519	64	62
520	45	42
521	33	42
522	27	57
523	31	59
524	41	53
525	45	72
526	48	73
527	46	90
528	56	76
529	64	76
530	69	64
531	72	59
532	73	58
533	71	56
534	66	48
535	61	50
536	55	56
537	52	52
538	54	49
539	61	50

Time (s)	Normalised speed (%)	Normalised torque (%)
540	64	54
541	67	54
542	68	52
543	60	53
544	52	50
545	45	49
546	38	45
547	32	45
548	26	53
549	23	56
550	30	49
551	33	55
552	35	59
553	33	65
554	30	67
555	28	59
556	25	58
557	23	56
558	22	57
559	19	63
560	14	63
561	31	61
562	35	62
563	21	80
564	28	65
565	7	74

Time (s)	Normalised speed (%)	Normalised torque (%)
566	23	54
567	38	54
568	14	78
569	38	58
570	52	75
571	59	81
572	66	69
573	54	44
574	48	34
575	44	33
576	40	40
577	28	58
578	27	63
579	35	45
580	20	66
581	15	60
582	10	52
583	22	56
584	30	62
585	21	67
586	29	53
587	41	56
588	15	67
589	24	56
590	42	69
591	39	83

Time (s)	Normalised speed (%)	Normalised torque (%)
592	40	73
593	35	67
594	32	61
595	30	65
596	30	72
597	48	51
598	66	58
599	62	71
600	36	63
601	17	59
602	16	50
603	16	62
604	34	48
605	51	66
606	35	74
607	15	56
608	19	54
609	43	65
610	52	80
611	52	83
612	49	57
613	48	46
614	37	36
615	25	44
616	14	53
617	13	64

Time (s)	Normalised speed (%)	Normalised torque (%)
618	23	56
619	21	63
620	18	67
621	20	54
622	16	67
623	26	56
624	41	65
625	28	62
626	19	60
627	33	56
628	37	70
629	24	79
630	28	57
631	40	57
632	40	58
633	28	44
634	25	41
635	29	53
636	31	55
637	26	64
638	20	50
639	16	53
640	11	54
641	13	53
642	23	50
643	32	59

Time (s)	Normalised speed (%)	Normalised torque (%)
644	36	63
645	33	59
646	24	52
647	20	52
648	22	55
649	30	53
650	37	59
651	41	58
652	36	54
653	29	49
654	24	53
655	14	57
656	10	54
657	9	55
658	10	57
659	13	55
660	15	64
661	31	57
662	19	69
663	14	59
664	33	57
665	41	65
666	39	64
667	39	59
668	39	51
669	28	41

Time (s)	Normalised speed (%)	Normalised torque (%)
670	19	49
671	27	54
672	37	63
673	32	74
674	16	70
675	12	67
676	13	60
677	17	56
678	15	62
679	25	47
680	27	64
681	14	71
682	5	65
683	6	57
684	6	57
685	15	52
686	22	61
687	14	77
688	12	67
689	12	62
690	14	59
691	15	58
692	18	55
693	22	53
694	19	69
695	14	67

Time (s)	Normalised speed (%)	Normalised torque (%)
696	9	63
697	8	56
698	17	49
699	25	55
700	14	70
701	12	60
702	22	57
703	27	67
704	29	68
705	34	62
706	35	61
707	28	78
708	11	71
709	4	58
710	5	58
711	10	56
712	20	63
713	13	76
714	11	65
715	9	60
716	7	55
717	8	53
718	10	60
719	28	53
720	12	73
721	4	64

Time (s)	Normalised speed (%)	Normalised torque (%)
722	4	61
723	4	61
724	10	56
725	8	61
726	20	56
727	32	62
728	33	66
729	34	73
730	31	61
731	33	55
732	33	60
733	31	59
734	29	58
735	31	53
736	33	51
737	33	48
738	27	44
739	21	52
740	13	57
741	12	56
742	10	64
743	22	47
744	15	74
745	8	66
746	34	47
747	18	71

Time (s)	Normalised speed (%)	Normalised torque (%)
748	9	57
749	11	55
750	12	57
751	10	61
752	16	53
753	12	75
754	6	70
755	12	55
756	24	50
757	28	60
758	28	64
759	23	60
760	20	56
761	26	50
762	28	55
763	18	56
764	15	52
765	11	59
766	16	59
767	34	54
768	16	82
769	15	64
770	36	53
771	45	64
772	41	59
773	34	50

Time (s)	Normalised speed (%)	Normalised torque (%)
774	27	45
775	22	52
776	18	55
777	26	54
778	39	62
779	37	71
780	32	58
781	24	48
782	14	59
783	7	59
784	7	55
785	18	49
786	40	62
787	44	73
788	41	68
789	35	48
790	29	54
791	22	69
792	46	53
793	59	71
794	69	68
795	75	47
796	62	32
797	48	35
798	27	59
799	13	58

Time (s)	Normalised speed (%)	Normalised torque (%)
800	14	54
801	21	53
802	23	56
803	23	57
804	23	65
805	13	65
806	9	64
807	27	56
808	26	78
809	40	61
810	35	76
811	28	66
812	23	57
813	16	50
814	11	53
815	9	57
816	9	62
817	27	57
818	42	69
819	47	75
820	53	67
821	61	62
822	63	53
823	60	54
824	56	44
825	49	39

Time (s)	Normalised speed (%)	Normalised torque (%)
826	39	35
827	30	34
828	33	46
829	44	56
830	50	56
831	44	52
832	38	46
833	33	44
834	29	45
835	24	46
836	18	52
837	9	55
838	10	54
839	20	53
840	27	58
841	29	59
842	30	62
843	30	65
844	27	66
845	32	58
846	40	56
847	41	57
848	18	73
849	15	55
850	18	50
851	17	52

Time (s)	Normalised speed (%)	Normalised torque (%)
852	20	49
853	16	62
854	4	67
855	2	64
856	7	54
857	10	50
858	9	57
859	5	62
860	12	51
861	14	65
862	9	64
863	31	50
864	30	78
865	21	65
866	14	51
867	10	55
868	6	59
869	7	59
870	19	54
871	23	61
872	24	62
873	34	61
874	51	67
875	60	66
876	58	55
877	60	52

Time (s)	Normalised speed (%)	Normalised torque (%)
878	64	55
879	68	51
880	63	54
881	64	50
882	68	58
883	73	47
884	63	40
885	50	38
886	29	61
887	14	61
888	14	53
889	42	6
890	58	6
891	58	6
892	77	39
893	93	56
894	93	44
895	93	37
896	93	31
897	93	25
898	93	26
899	93	27
900	93	25
901	93	21
902	93	22
903	93	24

Time (s)	Normalised speed (%)	Normalised torque (%)
904	93	23
905	93	27
906	93	34
907	93	32
908	93	26
909	93	31
910	93	34
911	93	31
912	93	33
913	93	36
914	93	37
915	93	34
916	93	30
917	93	32
918	93	35
919	93	35
920	93	32
921	93	28
922	93	23
923	94	18
924	95	18
925	96	17
926	95	13
927	96	10
928	95	9
929	95	7

Time (s)	Normalised speed (%)	Normalised torque (%)
930	95	7
931	96	7
932	96	6
933	96	6
934	95	6
935	90	6
936	69	43
937	76	62
938	93	47
939	93	39
940	93	35
941	93	34
942	93	36
943	93	39
944	93	34
945	93	26
946	93	23
947	93	24
948	93	24
949	93	22
950	93	19
951	93	17
952	93	19
953	93	22
954	93	24
955	93	23

Time (s)	Normalised speed (%)	Normalised torque (%)
956	93	20
957	93	20
958	94	19
959	95	19
960	95	17
961	96	13
962	95	10
963	96	9
964	95	7
965	95	7
966	95	7
967	95	6
968	96	6
969	96	6
970	89	6
971	68	6
972	57	6
973	66	32
974	84	52
975	93	46
976	93	42
977	93	36
978	93	28
979	93	23
980	93	19
981	93	16

Time (s)	Normalised speed (%)	Normalised torque (%)
982	93	15
983	93	16
984	93	15
985	93	14
986	93	15
987	93	16
988	94	15
989	93	32
990	93	45
991	93	43
992	93	37
993	93	29
994	93	23
995	93	20
996	93	18
997	93	16
998	93	17
999	93	16
1000	93	15
1001	93	15
1002	93	15
1003	93	14
1004	93	15
1005	93	15
1006	93	14
1007	93	13

Time (s)	Normalised speed (%)	Normalised torque (%)
1008	93	14
1009	93	14
1010	93	15
1011	93	16
1012	93	17
1013	93	20
1014	93	22
1015	93	20
1016	93	19
1017	93	20
1018	93	19
1019	93	19
1020	93	20
1021	93	32
1022	93	37
1023	93	28
1024	93	26
1025	93	24
1026	93	22
1027	93	22
1028	93	21
1029	93	20
1030	93	20
1031	93	20
1032	93	20
1033	93	19
1034	93	18
1035	93	20
1036	93	20
1037	93	20
1038	93	20
1039	93	19
1040	93	18
1041	93	18
1042	93	17
1043	93	16
1044	93	16
1045	93	15
1046	93	16
1047	93	18
1048	93	37
1049	93	48
1050	93	38
1051	93	31
1052	93	26
1053	93	21
1054	93	18
1055	93	16
1056	93	17
1057	93	18
1058	93	19
1059	93	21
1060	93	20
1061	93	18
1062	93	17
1063	93	17
1064	93	18
1065	93	18
1066	93	18
1067	93	19
1068	93	18
1069	93	18
1070	93	20
1071	93	23
1072	93	25
1073	93	25
1074	93	24
1075	93	24
1076	93	22
1077	93	22
1078	93	22
1079	93	19
1080	93	16
1081	95	17
1082	95	37
1083	93	43
1084	93	32
1085	93	27

Time (s)	Normalised speed (%)	Normalised torque (%)
1086	93	26
1087	93	24
1088	93	22
1089	93	22
1090	93	22
1091	93	23
1092	93	22
1093	93	22
1094	93	23
1095	93	23
1096	93	23
1097	93	22
1098	93	23
1099	93	23
1100	93	23
1101	93	25
1102	93	27
1103	93	26
1104	93	25
1105	93	27
1106	93	27
1107	93	27
1108	93	24
1109	93	20
1110	93	18
1111	93	17

Time (s)	Normalised speed (%)	Normalised torque (%)
1112	93	17
1113	93	18
1114	93	18
1115	93	18
1116	93	19
1117	93	22
1118	93	22
1119	93	19
1120	93	17
1121	93	17
1122	93	18
1123	93	18
1124	93	19
1125	93	19
1126	93	20
1127	93	19
1128	93	20
1129	93	25
1130	93	30
1131	93	31
1132	93	26
1133	93	21
1134	93	18
1135	93	20
1136	93	25
1137	93	24

Time (s)	Normalised speed (%)	Normalised torque (%)
1138	93	21
1139	93	21
1140	93	22
1141	93	22
1142	93	28
1143	93	29
1144	93	23
1145	93	21
1146	93	18
1147	93	16
1148	93	16
1149	93	16
1150	93	17
1151	93	17
1152	93	17
1153	93	17
1154	93	23
1155	93	26
1156	93	22
1157	93	18
1158	93	16
1159	93	16
1160	93	17
1161	93	19
1162	93	18
1163	93	16

Time (s)	Normalised speed (%)	Normalised torque (%)
1164	93	19
1165	93	22
1166	93	25
1167	93	29
1168	93	27
1169	93	22
1170	93	18
1171	93	16
1172	93	19
1173	93	19
1174	93	17
1175	93	17
1176	93	17
1177	93	16
1178	93	16
1179	93	15
1180	93	16
1181	93	15
1182	93	17
1183	93	21
1184	93	30
1185	93	53
1186	93	54
1187	93	38
1188	93	30
1189	93	24

Time (s)	Normalised speed (%)	Normalised torque (%)
1190	93	20
1191	95	20
1192	96	18
1193	96	15
1194	96	11
1195	95	9
1196	95	8
1197	96	7
1198	94	33
1199	93	46
1200	93	37
1201	16	8
1202	0	0
1203	0	0
1204	0	0
1205	0	0
1206	0	0
1207	0	0
1208	0	0
1209	0	0

ANNEX 5

METHOD FOR DATA EVALUATION AND CALCULATION

1. GENERAL REQUIREMENTS

Calculation of emissions shall be performed according to either Appendix A.1 (mass based calculations) or Appendix A.2 (molar based calculations). Mixture between the two methods is not permitted. It shall not be required to perform the calculations according to both Appendix A.1 and Appendix A.2.

The specific requirements for particle number (PN) measurement, where applicable, are laid down in Appendix A.6.

1.1. General symbols

Appendix A.1.	**Appendix A.2.**	**Unit**	**Quantity**
	A	m²	Area
	A_t	m²	Venturi throat cross-sectional area
b, D_0	a_0	t.b.d.[3]	y intercept of the regression line
A/F_{st}		-	Stoichiometric air to fuel ratio
	C	-	Coefficient
C_d	C_d	-	Discharge coefficient
	C_f	-	Flow coefficient
c	x	ppm, % vol	Concentration/mole fraction (µmol/mol = ppm)
c_d	([1])	ppm, % vol	Concentration on dry basis
c_w	([1])	ppm, % vol	Concentration on wet basis
c_b	([1])	ppm, % vol	Background concentration
D	x_{dil}	-	Dilution factor[(2)]
D_0		m^3/rev	PDP calibration intercept
d	d	m	Diameter
d_V		m	Throat diameter of venturi
e	e	g/kWh	Brake specific basis
e_{gas}	e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	e_{PM}	g/kWh	Specific emission of particulates
E	$1 – PF$	%	Conversion efficiency (PF = Penetration fraction)

Appendix A.1.	Appendix A.2.	Unit	Quantity
F_s		-	Stoichiometric factor
	f	Hz	Frequency
f_c		-	Carbon factor
	γ	-	Ratio of specific heats
H		g/kg	Absolute humidity
	K	-	Correction factor
K_V		$\left[\left(\sqrt{\mathrm{K}}\cdot\mathrm{m}^4\cdot\mathrm{s}\right)/\mathrm{kg}\right]$	CFV calibration function
k_f		m^3/kg fuel	Fuel specific factor
k_h		-	Humidity correction factor for NO_X, diesel engines
k_{Dr}	k_{Dr}	-	Downward adjustment factor
k_r	k_r	-	Multiplicative regeneration factor
k_{Ur}	k_{Ur}	-	Upward adjustment factor
$k_{w,a}$		-	Dry to wet correction factor for the intake air
$k_{w,d}$		-	Dry to wet correction factor for the dilution air
$k_{w,e}$		-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$		-	Dry to wet correction factor for the raw exhaust gas
μ	μ	kg/(m·s)	Dynamic viscosity
M	M	g/mol	Molar mass(3)
M_a	(1)	g/mol	Molar mass of the intake air
M_e	v	g/mol	Molar mass of the exhaust
M_{gas}	M_{gas}	g/mol	Molar mass of gaseous components
m	m	kg	Mass
m	a_1	t.b.d.3	Slope of the regression line
	v	m^2/s	Kinematic viscosity
m_d	v	kg	Mass of the dilution air sample passed through the particulate sampling filters

Appendix A.1.	Appendix A.2.	Unit	Quantity
m_{ed}	([1])	kg	Total diluted exhaust mass over the cycle
m_{edf}	([1])	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_{ew}	([1])	kg	Total exhaust mass over the cycle
m_f	([1])	mg	Particulate sample mass collected
$m_{f,d}$	([1])	mg	Particulate sample mass of the dilution air collected
m_{gas}	m_{gas}	g	Mass of gaseous emissions over the test cycle
m_{PM}	m_{PM}	g	Mass of particulate emissions over the test cycle
m_{se}	([1])	kg	Exhaust sample mass over the test cycle
m_{sed}	([1])	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	([1])	kg	Mass of diluted exhaust gas passing the particulate collection filters
m_{ssd}		kg	Mass of secondary dilution air
	N	-	Total number of a series
	n	mol	Amount of substance
	$\dot{n}$	mol/s	Amount of substance rate
n	f_n	min^{-1}	Engine rotational speed
n_p		r/s	PDP pump speed
P	P	kW	Power
p	p	kPa	Pressure
p_a		kPa	Dry atmospheric pressure
p_b		kPa	Total atmospheric pressure
p_d		kPa	Saturation vapour pressure of the dilution air
p_p	p_{abs}	kPa	Absolute pressure
p_r	p_{H2O}	kPa	Water vapour pressure
p_s		kPa	Dry atmospheric pressure
$1 – E$	PF	%	Penetration fraction

Appendix A.1.	Appendix A.2.	Unit	Quantity
q_m	$\dot{m}$	kg/s	Mass rate
q_{mad}	$\dot{m}$ (1)	kg/s	Intake air mass flow rate on dry basis
q_{maw}	(1)	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	(1)	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	(1)	kg/s	Carbon mass flow rate into the engine
q_{mCp}	(1)	kg/s	Carbon mass flow rate in the partial flow dilution system
q_{mdew}	(1)	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	(1)	kg/s	Dilution air mass flow rate on wet basis
q_{medf}	(1)	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	(1)	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	(1)	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	(1)	kg/s	Fuel mass flow rate
q_{mp}	(1)	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_V	$\dot{V}$	m³/s	Volume flow rate
q_{VCVS}	(1)	m³/s	CVS volume rate
q_{Vs}	(1)	dm³/min	System flow rate of exhaust analiser system
q_{Vt}	(1)	cm³/min	Tracer gas flow rate
ρ	ρ	kg/m³	Mass density
ρ_e		kg/m³	Exhaust gas density
	r	-	Ratio of pressures
r_d	DR	-	Dilution ratio[2]
	Ra	µm	Average surface roughness
RH		%	Relative humidity
r_D	β	m/m	Ratio of diameters (CVS systems)

Appendix A.1.	Appendix A.2.	Unit	Quantity
r_p		-	Pressure ratio of SSV
Re	*Re*[#]	-	Reynolds number
	S	K	Sutherland constant
σ	σ	-	Standard deviation
T	*T*	°C	Temperature
	T	Nm	Engine torque
T_a		K	Absolute temperature
t	*t*	s	Time
Δt	Δt	s	Time interval
u		-	Ratio between densities of gas component and exhaust gas
V	*V*	m^3	Volume
V_0		m^3/r	PDP gas volume pumped per revolution
W	*W*	kWh	Work
W_{act}	W_{act}	kWh	Actual cycle work of the test cycle
WF	*WF*	-	Weighting factor
w	*w*	g/g	Mass fraction
	$\overline{x}$	mol/mol	Flow-weighted mean concentration
X_0	K_s	s/rev	PDP calibration function
	y	-	Generic variable
$\overline{y}$	$\overline{y}$		Arithmetic mean
	Z	-	Compressibility factor

([1]) See subscripts; e.g.: $\dot{m}_{air}$ for mass rate of dry air, $\dot{m}_{fuel}$ for fuel mass rate, etc.

([2]) Dilution ratio r_d in Appendix A.1. and *DR* in Appendix A.2.: different symbols but same meaning and same equations. Dilution factor *D* in Appendix A.1. and x_{dil} in Appendix A.2.: different symbols but same physical meaning; equation (A.5-129) shows the relationship between x_{dil} and *DR*.

([3]) t.b.d.= to be defined

1.2. Subscripts

Appendix A.1.(1)	**Appendix A.2.**	**Quantity**
act	act	Actual quantity
i		Instantaneous measurement (e.g.: 1 Hz)
	i	An individual of a series

(1) In Appendix A.1. the meaning of subscript is determined by the associated quantity; for example, the subscript "d" can indicate a dry basis as in "c_d = concentration on dry basis", dilution air as in "p_d = saturation vapour pressure of the dilution air" or "$k_{w,d}$ = dry to wet correction factor for the dilution air", dilution

1.3. Symbols and abbreviations for the chemical components (used also as a subscript)

Appendix A.1.	**Appendix A.2.**	**Quantity**
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH_4	CH_4	Methane
C_2H_6	C_2H_6	Ethane
C_3H_8	C_3H_8	Propane
CO	CO	Carbon monoxide
CO_2	CO_2	Carbon dioxide
	H	Atomic hydrogen
	H_2	Molecular hydrogen
HC	HC	Hydrocarbon
H_2O	H_2O	Water
	He	Helium
	N	Atomic nitrogen
	N_2	Molecular nitrogen

NO_X	NO_X	Oxides of nitrogen
NO	NO	Nitric oxide
NO_2	NO_2	Nitrogen dioxide
	O	Atomic oxygen
PM	PM	Particulate matter
S	S	Sulphur

1.4. Symbols and abbreviations for the fuel composition

Appendix A.1. (1)	**Appendix A.2. (2)**	**Quantity**
w_C(4)	w_C(4)	Carbon content of fuel, mass fraction [g/g] or [% mass]
w_H	w_H	Hydrogen content of fuel, mass fraction [g/g] or [% mass]
w_N	w_N	Nitrogen content of fuel, mass fraction [g/g] or [% mass]
w_O	w_O	Oxygen content of fuel, mass fraction [g/g] or [% mass]
w_S	w_S	Sulphur content of fuel, mass fraction [g/g] or [% mass]
α	α	Atomic hydrogen-to-carbon ratio (H/C)
ε	β	Atomic oxygen-to-carbon ratio (O/C)(3)
γ	γ	Atomic sulphur-to-carbon ratio (S/C)
δ	δ	Atomic nitrogen-to-carbon ratio (N/C)

(1) Referred to a fuel with chemical formula $CH_\alpha O_\varepsilon N_\delta S_\gamma$

(2) Referred to a fuel with chemical formula $CH_\alpha O_\beta S_\gamma N_\delta$

(3) Attention should be paid to the different meaning of symbol β in the two emissions calculation clauses: in Appendix A.1. it refers to a fuel having the chemical formula $CH_\alpha S_\gamma N_\delta O_\varepsilon$ (i.e. the formula $C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon$ where $\beta = 1$, assuming one carbon atom per molecule), while in Appendix A.2 it refers to the oxygen-to-carbon ratio with $CH_\alpha O_\beta S_\gamma N_\delta$. Then β of Appendix A.2 corresponds to ε of Appendix A.1..

(4) Mass fraction *w* accompanied by the symbol of the chemical component as a subscript.

ANNEX 5 - APPENDIX A.1

MASS BASED EMISSIONS CALCULATIONS

A.1.1. Measurement of gaseous emissions in raw exhaust gas

A.1.1.1. Discrete-mode NRSC tests

The emission rate of a gaseous emission $q_{mgas,i}$ [g/h] for each mode *i* of the steady state test shall be calculated by multiplying the concentration of the gaseous emission with its respective flow, as follows:

$$q_{mgas,i} = k_h \cdot k \cdot u_{gas} \cdot q_{mew,i} \cdot c_{gas,i} \cdot 3600 \quad \text{(A.5-1)}$$

where:

k = 1 for $c_{gasr,w,i}$ in [ppm] and k = 10,000 for $c_{gasr,w,i}$ in [% vol]

k_h = NO_X correction factor [-], for NO_X emission calculation (see clause A.1.1.4.)

u_{gas} = component specific factor or ratio between densities of gas component and exhaust gas [-]

$q_{mew,i}$ = exhaust gas mass flow rate in mode *i* on a wet basis [kg/s]

$c_{gas,i}$ = emission concentration in the raw exhaust gas in mode *i*, on a wet basis [ppm] or [% vol]

A.1.1.2. Transient and ramped modal cycles tests

The total mass per test of a gaseous emission m_{gas} [g/test] shall be calculated by multiplication of the time aligned instantaneous concentrations and exhaust gas flows and integration over the test cycle by means of equation (A.5-2):

$$m_{gas} = \frac{1}{f} \cdot k_h \cdot k \cdot u_{gas} \cdot \sum_{i=1}^{N} \left(q_{mew,i} \cdot c_{gas,i} \right) \quad \text{(A.5-2)}$$

where:

f = data sampling rate [Hz]

k_h = NO_X correction factor [-], only to be applied for the NO_X emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm] and k = 10,000 for $c_{gasr,w,i}$ in [% vol]

u_{gas} = component specific factor [-] (see clause A.1.1.5.)

N = number of measurements [-]

$q_{mew,i}$ = instantaneous exhaust gas mass flow rate on a wet basis [kg/s]

$c_{gas,i}$ = instantaneous emission concentration in the raw exhaust gas, on a wet basis [ppm] or [% vol]

A.1.1.3. Dry-to-wet concentration conversion

If the emissions are measured on a dry basis, the measured concentration c_d on dry basis shall be converted to the concentration c_w on a wet basis by means of equation (A.5-3):

$$c_w = k_w \cdot c_d \tag{A.5-3}$$

where:

k_w = dry-to-wet conversion factor [-]

c_d = emission concentration on a dry basis [ppm] or [% vol]

For complete combustion, the dry-to-wet conversion factor for raw exhaust gas is written as $k_{w,a}$ [-] and shall be calculated by means of equation (A.5-4):

$$k_{w,a} = \frac{\left(1 - \frac{1.2442 \cdot H_a + 111.19 \cdot w_H \cdot \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \cdot H_a + \frac{q_{mf,i}}{q_{mad,i}} \cdot k_f \cdot 1000}\right)}{\left(1 - \frac{p_r}{p_b}\right)} \tag{A.5-4}$$

where:

H_a = intake air humidity [g H_2O/kg dry air]

$q_{mf,i}$ = instantaneous fuel flow rate [kg/s]

$q_{mad,i}$ = instantaneous dry intake air flow rate [kg/s]

p_r = water pressure after cooler [kPa]

p_b = total barometric pressure [kPa]

w_H = hydrogen content of the fuel [% mass]

k_f = combustion additional volume [m^3/kg fuel]

with:

$$k_f = 0.055594 \cdot w_H + 0.0080021 \cdot w_N + 0.0070046 \cdot w_O \tag{A.5-5}$$

where:

w_H = hydrogen content of fuel [% mass]

w_N = nitrogen content of fuel [% mass]

w_O = oxygen content of fuel [% mass]

In equation (A.5-4), the ratio p_r / p_b may be assumed:

$$\frac{1}{\left(1-\frac{p_r}{p_b}\right)} = 1.008 \qquad \text{(A.5-6)}$$

For incomplete combustion (rich fuel air mixtures) and also for emission tests without direct air flow measurements, a second method of $k_{w,a}$ calculation is preferred:

$$k_{w,a} = \frac{\frac{1}{1+\alpha \cdot 0.005 \cdot \left(c_{CO2}+c_{CO}\right)} - k_{w1}}{1-\frac{p_r}{p_b}} \qquad \text{(A.5-7)}$$

where:

c_{CO2} = concentration of CO_2 in the raw exhaust gas, on a dry basis [% vol]

c_{CO} = concentration of CO in the raw exhaust gas, on a dry basis [ppm]

p_r = water pressure after cooler [kPa]

p_b = total barometric pressure [kPa]

α = molar to carbon hydrogen ratio [-]

k_{w1} = intake air moisture [-]

$$k_{w1} = \frac{1.608 \cdot H_a}{1000 + 1.608 \cdot H_a} \qquad \text{(A.5-8)}$$

A.1.1.4. NO_X correction for humidity and temperature

As the NO_X emission depends on ambient air conditions, the NO_X concentration shall be corrected for ambient air temperature and humidity with the factors $k_{h,D}$ or $k_{h,G}$ [-] given in equations (A.5-9) and (A.5-10). These factors are valid for a humidity range between 0 and 25 g H_2O/kg dry air.

(a) for compression-ignition engines

$$k_{h,D} = \frac{15.698 \times H_a}{1{,}000} + 0.832 \qquad \text{(A.5-9)}$$

(b) for spark ignition engines

$k_{h,G} = 0.6272 + 44.030 \times 10^{-3} \times H_a - 0.862 \times 10^{-3} \times H_a^2$ (A.5-10)

where:

H_a = humidity of the intake air [g H_2O/kg dry air]

A.1.1.5 Component specific factor u

Two calculation procedures are described in clauses A.1.1.5.1. and A.1.1.5.2.. The procedure set out in clause A.1.1.5.1. is more straightforward, since it uses tabulated u values for the ratio between component and exhaust gas density. The procedure set out in clause A.1.1.5.2. is more accurate for fuel qualities that deviate from the specifications in Annex 6, but requires elementary analysis of the fuel composition.

A.1.1.5.1 Tabulated values

Applying some simplifications (assumption on the λ value and on intake air conditions as shown in Table A.5-1.) to the equations set out in clause A.1.1.5.2., the resulting values for u_{gas} are given in Table A.5-1..

Table A.5-1.
Raw Exhaust Gas u and Component Densities
(for Emission Concentration Expressed in ppm)

Fuel	ρ_e	Gas					
		NO_X	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m^3]					
		2.053	1.250	[a]	1.9636	1.4277	0.716
		u_{gas}[b]					
Diesel (non-road gas-oil)	1.2943	0.001586	0.000966	0.000482	0.001517	0.001103	0.000553
Ethanol for dedicated compression ignition engines (ED95)	1.2768	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
Natural gas / bio-methane[c]	1.2661	0.001621	0.000987	0.000528[d]	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG[e]	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E10)	1.2931	0.001587	0.000966	0.000499	0.001518	0.001104	0.000553
Ethanol (E85)	1.2797	0.001604	0.000977	0.000730	0.001534	0.001116	0.000559

[a] depending on fuel
[b] at λ = 2, dry air, 273 K, 101.3 kPa
[c] u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %
[d] NMHC on the basis of $CH_{2.93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)
[e] u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

A.1.1.5.2 Calculated values

The component specific factor, $u_{gas,i}$, may be calculated by the density ratio of the component and the exhaust or alternatively by the corresponding ratio of molar masses [equations (A.5-11) or (A.5-12)]:

$$u_{gas,i} = M_{gas} / \left(M_{e,i} \cdot 1000 \right) \quad \text{(A.5-11)}$$

or

$$u_{gas,i} = \rho_{gas} / \left(\rho_{e,i} \cdot 1000 \right) \quad \text{(A.5-12)}$$

where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{e,i}$ = instantaneous molar mass of the wet raw exhaust gas [g/mol]

ρ_{gas} = density of the gas component [kg/m^3]

$\rho_{e,i}$ = instantaneous density of the wet raw exhaust gas [kg/m^3]

The molar mass of the exhaust, $M_{e,i}$ shall be derived for a general fuel composition $CH_\alpha O_\varepsilon N_\delta S_\gamma$ under the assumption of complete combustion, and shall be calculated by means of equation (A.5-13):

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \cdot \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} + \frac{\frac{H_a \cdot 10^{-3}}{2 \cdot 1.00794 + 15.9994} + \frac{1}{M_a}}{1 + H_a \cdot 10^{-3}}} \quad \text{(A.5-13)}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate on wet basis [kg/s]

$q_{maw,i}$ = instantaneous intake air mass flow rate on wet basis [kg/s]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

γ = atomic sulphur-to-carbon ratio [-]

H_a = intake air humidity [g H_2O/kg dry air]

M_a = dry intake air molar mass = 28,965 g/mol

The instantaneous raw exhaust density $\rho_{e,i}$ [kg/m^3] shall be calculated by means of equation (A.5-14):

$$\rho_{e,i} = \frac{1000 + H_a + 1000 \cdot \left(q_{mf,i} / q_{mad,i} \right)}{773.4 + 1.2434 \cdot H_a + k_f \cdot 1000 \cdot \left(q_{mf,i} / q_{mad,i} \right)} \quad \text{(A.5-14)}$$

where:

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

$q_{mad,i}$ = instantaneous dry intake air mass flow rate [kg/s]

H_a = intake air humidity [g H_2O/kg dry air]

k_f = combustion additional volume [m^3/kg fuel] [see equation (A.5-5)]

A.1.1.6. Mass flow rate of the exhaust gas

A.1.1.6.1. Air and fuel measurement method

The method involves measurement of the air flow and the fuel flow with suitable flowmeters. The instantaneous wet exhaust gas mass flow rate $q_{mew,i}$ [kg/s] shall be calculated by means of equation (A.5-15):

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \quad \text{(A.5-15)}$$

where:

$q_{maw,i}$ = instantaneous wet intake air mass flow rate [kg/s]

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

A.1.1.6.2. Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust. The instantaneous exhaust gas flow $q_{mew,i}$ [kg/s] shall be calculated by means of equation (A.5-16):

$$q_{mew,i} = \frac{q_{Vt} \cdot \rho_e}{10^{-6} \cdot \left(c_{mix,i} - c_b\right)} \quad \text{(A.5-16)}$$

where:

q_{Vt} = tracer gas flow rate [m^3/s]

$c_{mix,i}$ = instantaneous concentration of the tracer gas after mixing [ppm]

ρ_e = density of the raw exhaust gas [kg/m^3]

c_b = background concentration of the tracer gas in the intake air [ppm]

The background concentration of the tracer gas c_b may be determined by averaging the background concentration measured immediately before the test run and after the test run. When the background concentration is less than 1 per cent of the concentration of the tracer gas after mixing $c_{mix,i}$ at maximum exhaust flow, the background concentration may be neglected.

A.1.1.6.3. Air flow and air to fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air to fuel ratio. The instantaneous exhaust gas mass flow $q_{mew,i}$[kg/s] shall be calculated by means of equation (A.5-17):

$$q_{mew,i} = q_{maw,i} \cdot \left(1 + \frac{1}{A/F_{st} \cdot \lambda_i}\right) \quad \text{(A.5-17)}$$

with:

$$A/F_{st} = \frac{138.0 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} \quad \text{(A.5-18)}$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \cdot 10^{-4}}{2} - c_{HCw} \cdot 10^{-4}\right) + \left(\frac{\alpha}{4} \cdot \frac{1 - \frac{2 \cdot c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}}{1 + \frac{c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \cdot \left(c_{CO2d} + c_{COd} \cdot 10^{-4}\right)}{4.764 \cdot \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \cdot \left(c_{CO2d} + c_{COd} \cdot 10^{-4} + c_{HCw} \cdot 10^{-4}\right)} \quad \text{(A.5-19)}$$

where:

$q_{maw,i}$ = wet intake air mass flow rate [kg/s]

A/F_{st} = stoichiometric air-to-fuel ratio [-]

λ_i = instantaneous excess air ratio [-]

c_{COd} = concentration of CO in the raw exhaust gas on a dry basis [ppm]

c_{CO2d} = concentration of CO_2 in the raw exhaust gas on a dry basis [per cent]

c_{HCw} = concentration of HC in the raw exhaust gas on a wet basis [ppm C1]

α = molar hydrogen-to-carbon ratio [-]

δ = molar nitrogen-to-carbon ratio [-]

ε = molar oxygen-to-carbon ratio [-]

γ = atomic sulphur-to-carbon ratio [-]

A.1.1.6.4. Carbon balance method, 1 step-procedure

The following 1-step formula set out in equation (A.5-20) can be used for the calculation of the wet exhaust mass flow rate $q_{mew,i}$[kg/s]:

$$q_{mew,i} = q_{mf,i} \cdot \left[\frac{1.4 \cdot w_C^2}{\left(1.0828 \cdot w_C + k_{fd} \cdot f_c\right) f_c} \left(1 + \frac{H_a}{1000}\right) + 1\right] \quad \text{(A.5-20)}$$

with the carbon factor f_c [-] given by:

$$f_c = 0.5441 \cdot \left(c_{CO2d} - c_{CO2d,a}\right) + \frac{c_{COd}}{18522} + \frac{c_{HCw}}{17355} \quad \text{(A.5-21)}$$

Where:

$q_{mf,i}$ = instantaneous fuel mass flow rate [kg/s]

w_C = carbon content of fuel [% mass] (see equation A.5-82 of clause A.2.3.3.1. or table A.2.1)

H_a = intake air humidity [g H_2O/kg dry air]

k_{fd} = combustion additional volume on a dry basis [m^3/kg fuel]

c_{CO2d} = dry CO_2 concentration in the raw exhaust [%]

$c_{CO2d,a}$ = dry CO_2 concentration in the ambient air [%]

c_{COd} = dry CO concentration in the raw exhaust [ppm]

c_{HCw} = wet HC concentration in the raw exhaust [ppm]

and factor k_{fd} [m^3/kg fuel] that is calculated by means of equation (A.5-22) on a dry basis by subtracting the water formed by combustion from k_f:

$$k_{fd} = k_f - 0.11118 \cdot w_H \quad \text{(A.5-22)}$$

where:

k_f = fuel specific factor of equation (A.5-5) [m^3/kg fuel]

w_H = hydrogen content of fuel [% mass]

A.1.2. DILUTED GASEOUS EMISSIONS

A.1.2.1. Mass of the gaseous emissions

The exhaust gas mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a positive displacement pump (PDP), a critical flow venturi (CFV) or a subsonic venturi (SSV).

For systems with constant mass flow (i.e. with heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined by means of equation (A.5-23):

$$m_{gas} = k_h \cdot k \cdot u_{gas} \cdot c_{gas} \cdot m_{ed} \quad \text{(A.5-23)}$$

where:

u_{gas} = the ratio between density of exhaust component and density of air, as given in Table A.1.2. or calculated by means of equation (A.5-34) [-]

c_{gas} = mean background corrected concentration of the component on a wet basis [ppm] or [% vol] respectively

k_h = NO_X correction factor [-], only to be applied for the NO_X emission calculation

k = 1 for $c_{gasr,w,i}$ in [ppm], k = 10.000 for $c_{gasr,w,i}$ in [% vol]

m_{ed} = total diluted exhaust gas mass over the cycle [kg/test]

For systems with flow compensation (without heat exchanger), the mass of the pollutants m_{gas} [g/test] shall be determined by calculation of the instantaneous mass emissions, by integration and by background correction by means of equation (A.5-24):

$$m_{gas} = k_h \cdot k \cdot \left\{ \sum_{i=1}^{N} \left[\left(m_{ed,i} \cdot c_e \cdot u_{gas} \right) \right] - \left[\left(m_{ed} \cdot c_d \cdot \left(1 - \frac{1}{D} \right) \cdot u_{gas} \right) \right] \right\}$$

(A.5-24)

Where:

c_e = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [% vol]

c_d = emission concentration in the dilution air, on a wet basis [ppm] or [% vol]

$m_{ed,i}$ = mass of the diluted exhaust gas during time interval i [kg]

m_{ed} = total mass of diluted exhaust gas over the cycle [kg]

u_{gas} = tabulated value from Table A.1.2. [-]

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

k_h = NO_X correction factor [-], only to be applied for the NO_X emission calculation

k = 1 for c in [ppm], k = 10,000 for c in [% vol]

The concentrations c_{gas}, c_e and c_d can be either values measured in a batch sample (bag, but not allowed for NO_X and HC) or be averaged by integration from continuous measurements. Also $m_{ed,i}$ has to be averaged by integration over the test cycle.

The following equations show how the needed quantities (c_e, u_{gas} and m_{ed}) shall be calculated.

A.1.2.2. Dry-to-wet concentration conversion

All concentrations set out in clause A.1.2.1. measured dry shall be converted to a wet basis by means of equation (A.5-3).

A.1.2.2.1. Diluted exhaust gas

Dry concentrations shall be converted to wet concentrations by means of one of the following two equations [(A.5-25) or (A.5-26)] applied to equation:

$$k_{w,e} = \left[\left(1 - \frac{\alpha \cdot c_{CO2w}}{200} \right) - k_{w2} \right] \cdot 1.008 \quad \text{(A.5-25)}$$

or

$$k_{w,e} = \left(\frac{\left(1 - k_{w2} \right)}{1 + \frac{\alpha \cdot c_{CO2d}}{200}} \right) \cdot 1.008 \quad \text{(A.5-26)}$$

where:

α = molar hydrogen to carbon ratio of the fuel [-]

c_{CO2w} = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

c_{CO2d} = concentration of CO_2 in the diluted exhaust gas on a dry basis [per cent vol]

The dry to wet correction factor k_{w2} takes into consideration the water content of both intake air and dilution air and shall be calculated by means of equation (A.5-27):

$$k_{w2} = \frac{1.608 \cdot \left[H_d \cdot \left(1 - \frac{1}{D} \right) + H_a \cdot \left(\frac{1}{D} \right) \right]}{1000 + \left\{ 1.608 \cdot \left[H_d \cdot \left(1 - \frac{1}{D} \right) + H_a \cdot \left(\frac{1}{D} \right) \right] \right\}} \quad \text{(A.5-27)}$$

Where:

H_a = intake air humidity [g H_2O/kg dry air]

H_d = dilution air humidity [g H_2O/kg dry air]

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

A.1.2.2.2. Dilution factor

The dilution factor D [-] (which is necessary for the background correction and the k_{w2} calculation) shall be calculated by means of equation (A.5-28):

$$D = \frac{F_S}{c_{CO2,e} + \left(c_{HC,e} + c_{CO,e} \right) \cdot 10^{-4}} \quad \text{(A.5-28)}$$

where:

F_S = stoichiometric factor [-]

$c_{CO2,e}$ = concentration of CO_2 in the diluted exhaust gas on a wet basis [per cent vol]

$c_{HC,e}$ = concentration of HC in the diluted exhaust gas on a wet basis [ppm C1]

$c_{CO,e}$ = concentration of CO in the diluted exhaust gas on a wet basis [ppm]

The stoichiometric factor shall be calculated by means of equation (A.5-29):

$$F_S = 100 \cdot \frac{1}{1 + \frac{\alpha}{2} + 3.76 \cdot \left(1 + \frac{\alpha}{4} \right)} \quad \text{(A.5-29)}$$

Where:

α = molar hydrogen to carbon ratio in the fuel [-]

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

F_S (diesel) = 13.4

F_S (LPG) = 11.6

F_S (NG) = 9.5

F_S (E10) = 13.3

F_S (E85) = 11.5

If a direct measurement is made of the exhaust gas flow, the dilution factor D [-] may be calculated by means of equation (A.5-30):

$$D = \frac{q_{VCVS}}{q_{Vew}} \quad \text{(A.5-30)}$$

Where:

q_{VCVS} = the volumetric flow rate of diluted exhaust gas [m^3/s]

q_{Vew} = volumetric flow rate of raw exhaust gas [m^3/s]

A.1.2.2.3. Dilution air

$$k_{w,d} = (1 - k_{w3}) \cdot 1.008 \quad \text{(A.5-31)}$$

with

$$k_{w3} = \frac{1.608 \cdot H_d}{1000 + 1.608 \cdot H_d} \quad \text{(A.5-32)}$$

where:

H_d = dilution air humidity [g H_2O/kg dry air]

A.1.2.2.4. Determination of the background corrected concentration

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be determined by the sample bag method or by continuous measurement with integration. Equation (A.5-33) shall be used:

$$c_{gas} = c_{gas,e} - c_d \cdot \left(1 - \frac{1}{D}\right) \quad \text{(A.5-33)}$$

Where:

c_{gas} = net concentration of the gaseous pollutant [ppm] or [% vol]

$c_{gas,e}$ = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [% vol]

c_d = emission concentration in the dilution air, on a wet basis [ppm] or [% vol]

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

A.1.2.3. Component specific factor u

The component specific factor u_{gas} of diluted gas can either be calculated by means of equation (A.5-34) or be taken from Table A.1.2.; in Table A.1.2. the density of the diluted exhaust gas has been assumed equal to air density.

$$u = \frac{M_{gas}}{M_{d,w} \cdot 1000} = \frac{M_{gas}}{\left[M_{da,w} \cdot \left(1 - \frac{1}{D}\right) + M_{r,w} \cdot \left(\frac{1}{D}\right)\right] \cdot 1000} \quad \text{(A.5-34)}$$

Where:

M_{gas} = molar mass of the gas component [g/mol]

$M_{d,w}$ = molar mass of diluted exhaust gas [g/mol]

$M_{da,w}$ = molar mass of dilution air [g/mol] (see equation (A.5-144) of

clause A.2.9.3)

$M_{r,w}$ = molar mass of raw exhaust gas [g/mol] (see clause A.5.5 of Appendix A.5 to Annex 5)

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

Table A.1.2.
Diluted Exhaust Gas u Values
(for Emission Concentration Expressed in ppm) and Component Densities

Fuel	ρ_e	Gas					
		NO_X	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m^3]					
		2.053	1.250	[a]	1.9636	1.4277	0.716
		u_{gas}[b]					
Diesel (non-road gas-oil)	1.2943	0.001586	0.000966	0.000482	0.001517	0.001103	0.000553
Ethanol for dedicated compression ignition engines (ED95)	1.2768	0.001609	0.000980	0.000780	0.001539	0.001119	0.000561
Natural gas / bio-methane[c]	1.2661	0.001621	0.000987	0.000528[d]	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG[e]	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559
Petrol (E10)	1.2931	0.001587	0.000966	0.000499	0.001518	0.001104	0.000553
Ethanol (E85)	1.2797	0.001604	0.000977	0.000730	0.001534	0.001116	0.000559

[a] depending on fuel

[b] at $\lambda = 2$, dry air, 273 K, 101.3 kPa

[c] u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %

[d] NMHC on the basis of $CH_{2.93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)

[e] u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

A.1.2.4. Exhaust gas mass flow calculation

A.1.2.4.1. PDP-CVS system

The mass of the diluted exhaust [kg/test] over the cycle shall be calculated by means of equation (A.5-35), if the temperature of the diluted exhaust m_{ed} is kept within ±6 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \cdot V_0 \cdot n_P \cdot \frac{p_p}{101.325} \cdot \frac{273.15}{T} \quad \text{(A.5-35)}$$

where:

V_0 = volume of gas pumped per revolution under test conditions [m³/rev]

n_P = total revolutions of pump per test [rev/test]

p_p = absolute pressure at pump inlet [kPa]

$\overline{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated by means of equation (A.5-36):

$$m_{ed,i} = 1.293 \cdot V_0 \cdot n_{P,i} \cdot \frac{p_p}{101.325} \cdot \frac{273.15}{\overline{T}} \quad \text{(A.5-36)}$$

where:

V_0 = volume of gas pumped per revolution under test conditions [m³/rev]

p_p = absolute pressure at pump inlet [kPa]

$n_{P,i}$ = total revolutions of pump per time interval i [rev/Δt]

$\overline{T}$ = average temperature of the diluted exhaust gas at pump inlet [K]

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

A.1.2.4.2. CFV-CVS system

The mass flow over the cycle m_{ed} [g/test] shall be calculated by means of equation (A.5-37), if the temperature of the diluted exhaust is kept within ±11 K over the cycle by using a heat exchanger:

$$m_{ed} = \frac{1.293 \cdot t \cdot K_V \cdot p_p}{T^{0.5}} \quad \text{(A.5-37)}$$

Where:

t = cycle time [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\mathrm{K}}\cdot\mathrm{m}^4\cdot\mathrm{s}\right)/\mathrm{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated by means of equation (A.5-38):

$$m_{ed,i} = \frac{1.293\cdot\Delta t_i\cdot K_V\cdot p_p}{T^{0.5}} \quad \text{(A.5-38)}$$

where:

Δt_i = time interval of the test [s]

K_V = calibration coefficient of the critical flow venturi for standard conditions $\left[\left(\sqrt{\mathrm{K}}\cdot\mathrm{m}^4\cdot\mathrm{s}\right)/\mathrm{kg}\right]$

p_p = absolute pressure at venturi inlet [kPa]

T = absolute temperature at venturi inlet [K]

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

A.1.2.4.3. SSV-CVS system

The diluted exhaust gas mass over the cycle m_{ed} [kg/test] shall be calculated by means of equation (A.5-39), if the temperature of the diluted exhaust is kept within ±11K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293\cdot q_{VSSV}\cdot\Delta t \quad \text{(A.5-39)}$$

Where:

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

Δt = cycle time [s]

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

with

$$q_{VSSV} = \frac{A_0}{60} d_V{}^2 C_d p_p \sqrt{\left[\frac{1}{T}\left(r_p{}^{1.4286} - r_p{}^{1.7143}\right)\cdot\left(\frac{1}{1-r_D{}^4 r_p{}^{1.4286}}\right)\right]} \quad \text{(A.5-40)}$$

Where:

A_0 = collection of constants and units conversions = 0.0056940 $\left[\frac{\mathrm{m}^3}{\mathrm{min}}\cdot\frac{\mathrm{K}^{\frac{1}{2}}}{\mathrm{kPa}}\cdot\frac{1}{\mathrm{mm}^2}\right]$

d_V = diameter of the SSV throat [mm]

C_d = discharge coefficient of the SSV [-]

p_p = absolute pressure at venturi inlet [kPa]

T_{in} = temperature at the venturi inlet [K]

r_p = ratio of the SSV throat to inlet absolute static pressure, $\left(1-\frac{\Delta p}{p_a}\right)$ [-]

r_D = ratio of the SSV throat diameter to the inlet pipe inner diameter $\frac{d}{D}$ [-]

If a system with flow compensation is used (i.e. without heat exchanger), the mass of the diluted exhaust gas $m_{ed,i}$ [kg] during the time interval shall be calculated by means of equation (A.5-41):

$$m_{ed,i} = 1.293 \cdot q_{VSSV} \cdot \Delta t_i \quad \text{(A.5-41)}$$

Where:

1.293 kg/m^3 = air density at 273.15 K and 101.325 kPa

Δt_i = time interval [s]

q_{VSSV} = volumetric flow rate of the SSV [m^3/s]

A.1.3. CALCULATION OF PARTICULATE EMISSION

A.1.3.1. Transient (NRTC and LSI-NRTC) and ramped modal test cycles

The particulate mass shall be calculated after buoyancy correction of the particulate sample mass according to clause 8.1.12.2.5. of Annex 4.

A.1.3.1.1. Partial flow dilution system

A.1.3.1.1.1. Calculation based on sample ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated by means of equation (A.5-42):

$$m_{PM} = \frac{m_f}{r_s \cdot 1000} \quad \text{(A.5-42)}$$

where:

m_f = particulate mass sampled over the cycle [mg]

r_s = average sample ratio over the test cycle [-]

with:

$$r_s = \frac{m_{se}}{m_{ew}} \cdot \frac{m_{sep}}{m_{sed}} \quad \text{(A.5-43)}$$

Where:

m_{se} = sample mass of raw exhaust over the cycle [kg]

m_{ew} = total mass of raw exhaust over the cycle [kg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sed} = mass of diluted exhaust gas passing the dilution tunnel [kg]

In case of the total sampling type system, m_{sep} and m_{sed} are identical.

A.1.3.1.1.2. Calculation based on dilution ratio

The particulate emission over the cycle m_{PM} [g] shall be calculated by means of equation (A.5-44):

$$m_{PM} = \frac{m_f}{m_{sep}} \cdot \frac{m_{edf}}{1000} \quad \text{(A.5-44)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{edf} = mass of equivalent diluted exhaust gas over the cycle [kg]

The total mass of equivalent diluted exhaust gas mass over the cycle m_{edf} [kg] shall be determined by means of equation (A.5-45):

$$m_{edf} = \frac{1}{f} \cdot \sum_{i=1}^{N} q_{medf,i} \quad \text{(A.5-45)}$$

With:

$$q_{medf,i} = q_{mew,i} \cdot r_{d,i} \quad \text{(A.5-46)}$$

$$r_{d,i} = \frac{q_{mdew,i}}{q_{mdew,i} - q_{mdw,i}} \quad \text{(A.5-47)}$$

Where:

$q_{medf,i}$ = instantaneous equivalent diluted exhaust mass flow rate [kg/s]

$q_{mew,i}$ = instantaneous exhaust mass flow rate on a wet basis [kg/s]

$r_{d,i}$ = instantaneous dilution ratio [-]

$q_{mdew,i}$ = instantaneous diluted exhaust mass flow rate on a wet basis [kg/s]

$q_{mdw,i}$ = instantaneous dilution air mass flow rate [kg/s]

f = data sampling rate [Hz]

N = number of measurements [-]

A.1.3.1.2. Full flow dilution system

The mass emission shall be calculated by means of equation (A.5-48):

$$m_{PM} = \frac{m_f}{m_{sep}} \cdot \frac{m_{ed}}{1000} \quad \text{(A.5-48)}$$

where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{ed} = mass of diluted exhaust gas over the cycle [kg]

with

$$m_{sep} = m_{set} - m_{ssd} \quad \text{(A.5-49)}$$

Where:

m_{set} = mass of double diluted exhaust gas through particulate filter [kg]

m_{ssd} = mass of secondary dilution air [kg]

A.1.3.1.2.1. Background correction

The particulate mass $m_{PM,c}$ [g] may be background corrected by means of equation (A.5-50):

$$m_{PM,c} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_b}{m_{sd}} \cdot \left(1 - \frac{1}{D} \right) \right] \right\} \cdot \frac{m_{ed}}{1000} \quad \text{(A.5-50)}$$

Where:

m_f = particulate mass sampled over the cycle [mg]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

m_{sd} = mass of dilution air sampled by background particulate sampler [kg]

m_b = mass of collected background particulates of dilution air [mg]

m_{ed} = mass of diluted exhaust gas over the cycle [kg]

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

A.1.3.2. Calculation for steady-state discrete-mode cycles

A.1.3.2.1. Dilution system

All calculations shall be based upon the average values of the individual modes *i* during the sampling period.

(a) For partial-flow dilution, the equivalent mass flow of diluted exhaust gas shall be determined by means of equation (A.5-51) and the system with flow measurement shown in Figure A.4-6 of Annex 4:

$$q_{medf} = q_{mew} \cdot r_d \quad \text{(A.5-51)}$$

$$r_{\mathrm{d}} = \frac{q_{m\mathrm{dew}}}{q_{m\mathrm{dew}} - q_{m\mathrm{dw}}} \quad \text{(A.5-52)}$$

Where:

$q_{m\mathrm{edf}}$ = equivalent diluted exhaust mass flow rate [kg/s]

$q_{m\mathrm{ew}}$ = exhaust mass flow rate on a wet basis [kg/s]

r_{d} = dilution ratio [-]

$q_{m\mathrm{dew}}$ = diluted exhaust mass flow rate on a wet basis [kg/s]

$q_{m\mathrm{dw}}$ = dilution air mass flow rate [kg/s]

(b) For full-flow dilution systems $q_{m\mathrm{dew}}$ is used as $q_{m\mathrm{edf}}$.

A.1.3.2.2. Calculation of the particulate mass flow rate

The particulate emission flow rate over the cycle q_{mPM} [g/h] shall be calculated by means of equations (A.5-53), (A.5-56), (A.5-57) or (A.5-58):

(a) For the single-filter method

$$q_{m\mathrm{PM}} = \frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} \cdot \overline{q_{m\mathrm{edf}}} \cdot \frac{3600}{1000} \quad \text{(A.5-53)}$$

$$\overline{q_{m\mathrm{edf}}} = \sum_{i=1}^{\mathrm{N}} q_{m\mathrm{edf}i} \cdot WF_i \quad \text{(A.5-54)}$$

$$m_{\mathrm{sep}} = \sum_{i=1}^{\mathrm{N}} m_{\mathrm{sep}i} \quad \text{(A.5-55)}$$

Where:

$q_{m\mathrm{PM}}$ = particulate mass flow rate [g/h]

m_{f} = particulate mass sampled over the cycle [mg]

$\overline{q_{m\mathrm{edf}}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

$q_{m\mathrm{edf}i}$ = equivalent diluted exhaust gas mass flow rate on wet basis at mode i [kg/s]

WF_i = weighting factor for the mode i [-]

m_{sep} = mass of diluted exhaust gas passing the particulate collection filters [kg]

$m_{\mathrm{sep}i}$ = mass of diluted exhaust sample passed through the particulate sampling filter at mode i [kg]

N = number of measurements [-]

(b) For the multiple-filter method

$$q_{mPMi} = \frac{m_{fi}}{m_{sepi}} \cdot q_{medfi} \cdot \frac{3600}{1000} \quad \text{(A.5-56)}$$

Where:

q_{mPMi} = particulate mass flow rate for the mode *i* [g/h]

m_{fi} = particulate sample mass collected at mode *i* [mg]

q_{medfi} = equivalent diluted exhaust gas mass flow rate on wet basis at mode *i* [kg/s]

m_{sepi} = mass of diluted exhaust sample passed through the particulate sampling filter at mode *i* [kg]

The PM mass is determined over the test cycle by summation of the average values of the individual modes *i* during the sampling period.

The particulate mass flow rate q_{mPM} [g/h] or q_{mPMi} [g/h] may be background corrected as follows:

(c) For the single-filter method

$$q_{mPM} = \left\{ \frac{m_f}{m_{sep}} - \left[\frac{m_{f,d}}{m_d} \cdot \sum_{i=1}^{N} \left(1 - \frac{1}{D_i} \right) \cdot WF_i \right] \right\} \cdot \overline{q_{medf}} \cdot \frac{3600}{1000} \quad \text{(A.5-57)}$$

Where:

q_{mPM} = particulate mass flow rate [g/h]

m_f = particulate sample mass collected [mg]

m_{sep} = mass of diluted exhaust sample passed through the particulate sampling filter [kg]

$m_{f,d}$ = particulate sample mass of the dilution air collected [mg]

m_d = mass of the dilution air sample passed through the particulate sampling filters [kg]

D_i = dilution factor at mode *i* [see equation (A.5-28) of clause A.1.2.2.2.] [-]

WF_i = weighting factor for the mode *i* [-]

$\overline{q_{medf}}$ = average equivalent diluted exhaust gas mass flow rate on wet basis [kg/s]

(d) For the multiple-filter method

$$q_{mPMi} = \left\{ \frac{m_{fi}}{m_{sepi}} - \left[\frac{m_{f,d}}{m_d} \cdot \left(1 - \frac{1}{D} \right) \right] \right\} \cdot q_{medfi} \cdot \frac{3600}{1000} \quad \text{(A.5-58)}$$

Where:

q_{mPMi} = particulate mass flow rate at mode *i* [g/h]

m_{fi} = particulate sample mass collected at mode *i* [mg]

m_{sepi} = mass of diluted exhaust sample passed through the particulate sampling filter at mode *i* [kg]

$m_{f,d}$ = particulate sample mass of the dilution air collected [mg]

m_d = mass of the dilution air sample passed through the particulate sampling filters [kg]

D = dilution factor [see equation (A.5-28) of clause A.1.2.2.2.] [-]

q_{medfi} = equivalent diluted exhaust gas mass flow rate on wet basis at mode i [kg/s]

If more than one measurement is made, $m_{f,d}/m_d$ shall be replaced with $\overline{m_{f,d}/m_d}$.

A.1.4. CYCLE WORK AND SPECIFIC EMISSIONS

A.1.4.1. Gaseous emissions

A.1.4.1.1. Transient (NRTC and LSI-NRTC) and ramped modal test cycles (RMC)

Reference is made to clause A.1.1. and A.1.2. for raw and diluted exhaust respectively. The resulting values for power P [kW] shall be integrated over a test interval. The total work W_{act} [kWh] is calculated by means of equation (A.5-59):

$$W_{act} = \sum_{i=1}^{N} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^{N} \left(n_i \cdot T_i \right) \qquad \text{(A.5-59)}$$

Where:

P_i = instantaneous engine power [kW]

Δt_i = the measurement interval [s]

n_i = instantaneous engine speed [rpm]

T_i = instantaneous engine torque [Nm]

W_{act} = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

Where auxiliaries were fitted in accordance with Appendix A.2 of Annex 4 there shall be no adjustment to the instantaneous engine torque in equation (A.5-59). Where, according to clauses 6.3.2. or 6.3.3. of Annex 4 to this Part necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value of T_i used in equation (A.5-59) shall be adjusted by means of equation (A.5-60):

$$T_i = T_{i,meas} + T_{i,AUX} \qquad \text{(A.5-60)}$$

Where:

$T_{i,meas}$ = measured value of instantaneous engine torque

$T_{i,AUX}$ = corresponding value of torque required to drive auxiliaries determined according to equation (A.4-18) of Annex 4 to this Part.

The specific emissions e_{gas} [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{gas} = \frac{m_{gas}}{W_{act}} \quad \text{(A.5-61)}$$

Where:

m_{gas} = total mass of emission [g/test]

W_{act} = cycle work [kWh]

In case of the NRTC, for gaseous emissions other than CO_2 the final test result e_{gas} [g/kWh] shall be a weighted average from cold start test and hot start test by means of equation (A.5-62):

$$e_{gas} = \frac{(0.1 \cdot m_{cold}) + (0.9 \cdot m_{hot})}{(0.1 \cdot W_{act,cold}) + (0.9 \cdot W_{act,hot})} \quad \text{(A.5-62)}$$

Where:

m_{cold} = the gas mass emissions of the cold start NRTC [g]

$W_{act,\ cold}$ = the actual cycle work of the cold start NRTC [kWh]

m_{hot} = the gas mass emissions of the hot start NRTC [g]

$W_{act,\ hot}$ = the actual cycle work of the hot start NRTC [kWh]

In case of the NRTC, for CO_2 the final test result e_{CO2} [g/kWh] shall be calculated from the hot start test by means of equation (A.5-63):

$$e_{CO2,hot} = \frac{m_{CO2,hot}}{W_{act,hot}} \quad \text{(A.5-63)}$$

Where:

$m_{CO2,\ hot}$ = the CO_2 mass emissions of the hot start NRTC [g]

$W_{act,\ hot}$ = the actual cycle work of the hot start NRTC [kWh]

A.1.4.1.2. Discreate-mode NRSC

The specific emissions e_{gas} [g/kWh] are calculated by means of equation (A.5-64):

$$e_{gas} = \frac{\sum_{i=1}^{N_{mode}} \left(\dot{q}_{mgasi} \cdot WF_i \right)}{\sum_{i=1}^{N_{mode}} \left(P_i \cdot WF_i \right)} \quad \text{(A.5-64)}$$

where:

$q_{mgas,i}$ = mean emission mass flow rate for the mode *i* [g/h]

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = weighting factor for the mode *i* [-]

N_{mode} = number of modes in applicable discrete-mode NRSC

A.1.4.2. Particulate emissions

A.1.4.2.1. Transient (NRTC and LSI-NRTC) and ramped modal test cycles (RMC)

The particulate specific emissions shall be calculated with equation (A.5-61) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{PM} = \frac{m_{PM}}{W_{act}} \quad \text{(A.5-65)}$$

where:

m_{PM} = total mass of particulates emission, calculated in accordance with clause A.1.3.1.1. or A.1.3.1.2. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in clause A.1.4.1.1..

A.1.4.2.2. Discrete-mode NRSC

The particulate specific emission e_{PM} [g/kWh] shall be calculated by means of equations (A.5-66) or (A.5-67):

(a) For the single-filter method

$$e_{PM} = \frac{q_{mPM}}{\sum_{i=1}^{N_{mode}} (P_i \cdot WF_i)} \quad \text{(A.5-66)}$$

where:

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas} [kW] the power required to drive auxiliaries P_{AUX} [kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = weighting factor for the mode *i* [-]

q_{mPM} = particulate mass flow rate [g/h]

N_{mode} = number of modes in applicable discrete-mode NRSC

(b) For the multiple-filter method

$$e_{PM} = \frac{\sum_{i=1}^{N_{mode}} (q_{mPMi} \cdot WF_i)}{\sum_{i=1}^{N_{mode}} (P_i \cdot WF_i)} \quad \text{(A.5-67)}$$

Where:

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = weighting factor for the mode *i* [-]

q_{mPMi} = particulate mass flow rate at mode *i* [g/h]

N_{mode} = number of modes in applicable discrete-mode NRSC

For the single-filter method, the effective weighting factor, WF_{ei}, for each mode shall be calculated by means of equation (A.5-68):

$$WF_{ei} = \frac{m_{sepi} \cdot \overline{q_{medf}}}{m_{sep} \cdot q_{medfi}} \quad \text{(A.5-68)}$$

Where:

m_{sepi} = mass of the diluted exhaust sample passed through the particulate sampling filters at mode *i* [kg]

$\overline{q_{medf}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

q_{medfi} = equivalent diluted exhaust gas mass flow rate at mode *i* [kg/s]

m_{sep} = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

The value of the effective weighting factors shall be within ± 0.005 (absolute value) of the weighting factors listed in Appendix A.6 of Annex 4.

A.1.4.3. Adjustment for emission controls that are regenerated on an infrequent (periodic) basis

In case of engines equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis (see clause 6.6.2. of Annex 4), the specific emissions of gaseous and particulate pollutants calculated according to clauses A.1.4.1. and A.1.4.2. shall be corrected with either the applicable multiplicative adjustment factor or with the applicable additive adjustment factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$). In the case of the discrete-mode cycle, where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result.

A.1.4.4. Adjustment for deterioration factor

The specific emissions of gaseous and particulate pollutants calculated according to clauses A.1.4.1. and A.1.4.2., where applicable inclusive of the infrequent regeneration adjustment factor according to clause A.1.4.3., shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex 8.

A.1.5. Diluted Exhaust Flow (CVS) Calibration and Related Calculations The CVS system shall be calibrated by using an accurate flowmeter and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various types of flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbine meter.

A.1.5.1 Positive displacement pump (PDP)

All the parameters related to the pump shall be simultaneously measured along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m^3/s at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used.

Temperature stability shall be maintained during calibration.

Leaks in all the connections and ducting between the calibration venturi and the CVS pump shall be maintained lower than 0.3 per cent of the lowest flow point (highest restriction and lowest PDP speed point).

The airflow rate (q_{VCVS}) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure by means of equation (A.5-69):

$$V_0 = \frac{q_{VCVS}}{n} \cdot \frac{T}{273.15} \cdot \frac{101.325}{p_p} \qquad \text{(A.5-69)}$$

where:

q_{VCVS} = airflow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

T = temperature at pump inlet [K]

p_p = absolute pressure at pump inlet [kPa]

n = pump speed [rev/s]

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) [s/rev] between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated by means of equation (A.5-70):

$$X_0 = \frac{1}{n} \cdot \sqrt{\frac{\Delta p_p}{p_p}} \qquad \text{(A.5-70)}$$

Where:

Δp_p = pressure differential from pump inlet to pump outlet [kPa]

p_p = absolute outlet pressure at pump outlet [kPa]

n = pump speed [rev/s]

A linear least-square fit shall be performed to generate the calibration by means of equation (A.5-71):

$$V_0 = D_0 - m \cdot X_0 \qquad \text{(A.5-71)}$$

with D_0 [m^3/rev] and m [m^3/s], intercept and slope respectively, describing the regression line.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D_0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ± 0.5 per cent of the measured value of V_0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

A.1.5.2 Critical flow venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of venturi inlet pressure and temperature.

To determine the range of critical flow, K_V shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, K_V will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_V decreases, which indicates that the CFV is operated outside the permissible range.

The airflow rate (q_{VCVS}) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient K_V $\left[\left(\sqrt{K}\cdot m^4\cdot s\right)/kg\right]$ shall be calculated from the calibration data for each setting by means of equation (A.5-72):

$$K_V = \frac{q_{VCVS}\cdot\sqrt{T}}{p_p} \qquad \text{(A.5-72)}$$

Where:

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

T = temperature at the venturi inlet [K]

p_p = absolute pressure at venturi inlet [kPa]

The average K_V and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0.3 per cent of the average K_V.

A.1.5.3. Subsonic venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown in equation (A.5-40).

The airflow rate (q_{VSSV}) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting by means of equation (A.5-73):

$$C_d = \frac{q_{VSSV}}{\frac{A_0}{60} d_V^{\,2} p_p \sqrt{\left[\frac{1}{T_{in,V}}\left(r_p^{\,1.4286} - r_p^{\,1.7143}\right)\left(\frac{1}{1-r_D^{\,4} r_p^{\,1.4286}}\right)\right]}} \qquad \text{(A.5-73)}$$

Where:

A_0 = collection of constants and units conversions = 0.0056940 $\left[\frac{m^3}{min}\cdot\frac{K^{\frac{1}{2}}}{kPa}\cdot\frac{1}{mm^2}\right]$

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

$T_{in,V}$ = temperature at the venturi inlet [K]

d_V = diameter of the SSV throat [mm]

r_p = ratio of the SSV throat to inlet absolute static pressure = $1-\Delta p/p_p$ [-]

r_D = ratio of the SSV throat diameter, d_V, to the inlet pipe inner diameter D [-]

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number *Re*, at the SSV throat. The *Re* at the SSV throat shall be calculated by means of equation (A.5-74):

$$Re = A_1 \cdot 60 \cdot \frac{q_{VSSV}}{d_V \cdot \mu} \quad \text{(A.5-74)}$$

with

$$\mu = \frac{b \times T^{1.5}}{S + T} \quad \text{(A.5-75)}$$

Where:

A_1 = collection of constants and units conversions = 27.43831 $\left[\frac{Kg}{m^3}\cdot\frac{min}{s}\cdot\frac{mm}{m}\right]$

q_{VSSV} = air flow rate at standard conditions (101.325 kPa, 273.15 K) [m^3/s]

d_V = diameter of the SSV throat [mm]

μ = absolute or dynamic viscosity of the gas [kg/(m・s)]

b = 1.458 x 10^6 (empirical constant) [kg/(m・s・$K^{0.5}$)]

S = 110.4 (empirical constant) [K]

Because q_{VSSV} is an input to the *Re* equation, the calculations shall be started with an initial guess for q_{VSSV} or C_d of the calibration venturi, and repeated until q_{VSSV} converges. The convergence method shall be accurate to 0.1 per cent of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ± 0.5 per cent of the measured C_d for each calibration point.

A.1.6. DRIFT CORRECTION

A.1.6.1. General procedure

The calculations in this clause shall be performed to determine if gas analiser drift invalidates the results of a test interval. If drift does not invalidate the

results of a test interval, the test interval's gas analiser responses shall be corrected for drift in accordance with clause A.1.6.4.. The drift-corrected gas analiser responses shall be used in all subsequent emission calculations. The acceptable threshold for gas analiser drift over a test interval is specified in clause 8.2.2.2. of Annex 4.

A.1.6.2. Correction principles

The calculations in this Appendix use a gas analiser's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analiser's responses that were recorded during a test interval. The correction is based on an analiser's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validation and correction for drift shall be performed as follows:

A.1.6.3. Drift validation

After applying all the other corrections–except drift correction–to all the gas analiser signals, brake-specific emissions shall be calculated in accordance with clause A.1.4.. Then all gas analiser signals shall be corrected for drift according to this Appendix. Brake-specific emissions shall be recalculated using all of the drift-corrected gas analiser signals. The brake-specific emission results shall be validated and reported before and after drift correction according to clause 8.2.2.2. of Annex 4.

A.1.6.4. Drift correction

All gas analiser signals shall be corrected as follows:

(a) Each recorded concentration, c_i, shall be corrected for continuous sampling or for batch sampling, $\overline{c}$;

(b) Correction for drift shall be calculated by means of equation (A.5-76):

$$c_{i\text{driftcor}} = c_{\text{refzero}} + \left(c_{\text{refspan}} - c_{\text{refzero}}\right)\frac{2c_i - \left(c_{\text{prezero}} + c_{\text{postzero}}\right)}{\left(c_{\text{prespan}} + c_{\text{postspan}}\right) - \left(c_{\text{prezero}} + c_{\text{postzero}}\right)}$$

(A.5-76)

Where:

$c_{i\text{driftcor}}$ = concentration corrected for drift [ppm]

c_{refzero} = reference concentration of the zero gas, which is usually zero unless known to be otherwise [ppm]

c_{refspan} = reference concentration of the span gas [ppm]

c_{prespan} = pre-test interval gas analyser response to the span gas concentration [ppm]

c_{postspan} = post-test interval gas analyser response to the span gas concentration [ppm]

c_i or $\overline{c}$ = concentration recorded, i.e. measured, during test, before drift correction [ppm]

$c_{prezero}$ = pre-test interval gas analyser response to the zero gas concentration [ppm]

$c_{postzero}$ = post-test interval gas analyser response to the zero gas concentration [ppm]

(c) For any pre-test interval concentrations, concentrations determined most recently before the test interval shall be used. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals;

(d) For any post-test interval concentrations, concentrations determined most recently after the test interval shall be used. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals;

(e) If any pre-test interval analiser response to the span gas concentration, $c_{prespan}$, is not recorded, $c_{prespan}$ shall be set equal to the reference concentration of the span gas: $c_{prespan} = c_{refspan}$;

(f) If any pre-test interval analiser response to the zero gas concentration, $c_{prezero}$, is not recorded, $x_{prezero}$ shall be set equal to the reference concentration of the zero gas: $c_{prezero} = c_{refzero}$;

(g) Usually the reference concentration of the zero gas, $c_{refzero}$, is zero: $c_{refzero}$ = 0 µmol/mol. However, in some cases it might be known that $c_{refzero}$ has a non-zero concentration. When an analiser is zeroed using a non-zero $c_{refzero}$, the analiser shall be set to output the actual $c_{refzero}$ concentration.

ANNEX 5 - APPENDIX A.2

MOLAR BASED EMISSIONS CALCULATIONS

A.2.1. SUBSCRIPTS

	Quantity
abs	Absolute quantity
act	Actual quantity
air	Air, dry
atmos	Atmospheric
bkgnd	Background
C	Carbon
cal	Calibration quantity
CFV	Critical flow venture
cor	Corrected quantity
dil	Dilution air
dexh	Diluted exhaust
dry	Dry quantity
exh	Raw exhaust
exp	Expected quantity
eq	Equivalent quantity
fuel	Fuel
	Instantaneous measurement (e.g.: 1 Hz)
i	An individual of a series
idle	Condition at idle
in	Quantity in
init	Initial quantity, typically before an emission test
max	Maximum (i.e. peak) value
meas	Measured quantity
min	Minimum value
mix	Molar mass of air
out	Quantity out
part	Partial quantity
PDP	Positive displacement pump
raw	Raw exhaust
ref	Reference quantity
rev	Revolution

sat	Saturated condition
slip	PDP slip
smpl	Sampling
span	Span quantity
SSV	Subsonic venture
std	Standard quantity
test	Test quantity
total	Total quantity
uncor	Uncorrected quantity
vac	Vacuum quantity
weight	Calibration weight
wet	Wet quantity
zero	Zero quantity

A.2.2. SYMBOLS FOR CHEMICAL BALANCE

$x_{dil/exh}$ = Amount of dilution gas or excess air per mole of exhaust

x_{H2Oexh} = Amount of water in exhaust per mole of exhaust

$x_{Ccombdry}$ = Amount of carbon from fuel in the exhaust per mole of dry exhaust

$x_{H2Oexhdry}$ = Amount of water in exhaust per dry mole of dry exhaust

$x_{prod/intdry}$ = Amount of dry stoichiometric products per dry mole of intake air

$x_{dil/exhdry}$ = Amount of dilution gas and/or excess air per mole of dry exhaust

$x_{int/exhdry}$ = Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust

$x_{raw/exhdry}$ = Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust

$x_{O2intdry}$ = Amount of intake air O_2 per mole of dry intake air

$x_{CO2intdry}$ = Amount of intake air CO_2 per mole of dry intake air

$x_{H2Ointdry}$ = Amount of intake air H_2O per mole of dry intake air

x_{CO2int} = Amount of intake air CO_2 per mole of intake air

x_{CO2dil} = Amount of dilution gas CO_2 per mole of dilution gas

$x_{CO2dildry}$ = Amount of dilution gas CO_2 per mole of dry dilution gas

$x_{H2Odildry}$ = Amount of dilution gas H_2O per mole of dry dilution gas

x_{H2Odil} = Amount of dilution gas H_2O per mole of dilution gas

$x_{[emission]meas}$ = Amount of measured emission in the sample at the respective gas analiser

$x_{[emission]dry}$ = Amount of emission per dry mole of dry sample

$x_{H2O[emission]meas}$ = Amount of water in sample at emission-detection location

x_{H2Oint} = Amount of water in the intake air, based on a humidity measurement of intake air

A.2.3. BASIC PARAMETERS AND RELATIONSHIPS

A.2.3.1. Dry air and chemical species

This clause uses the following values for dry air composition:

$x_{O2airdry} = 0.209445$ mol/mol

$x_{Arairdry} = 0.00934$ mol/mol

$x_{N2airdry} = 0.78084$ mol/mol

$x_{CO2airdry} = 375$ µmol/mol

This clause uses the following molar masses or effective molar masses of chemical species:

M_{air} = 28.96559 g/mol (dry air)

M_{Ar} = 39.948 g/mol (argon)

M_{C} = 12.0107 g/mol (carbon)

M_{CO} = 28.0101 g/mol (carbon monoxide)

M_{CO2} = 44.0095 g/mol (carbon dioxide)

M_{H} = 1.00794 g/mol (atomic hydrogen)

M_{H2} = 2.01588 g/mol (molecular hydrogen)

M_{H2O} = 18.01528 g/mol (water)

M_{He} = 4.002602 g/mol (helium)

M_{N} = 14.0067 g/mol (atomic nitrogen)

M_{N2} = 28.0134 g/mol (molecular nitrogen)

M_{NOx} = 46.0055 g/mol (oxides of nitrogen[(a)])

M_{O} = 15.9994 g/mol (atomic oxygen)

M_{O2} = 31.9988 g/mol (molecular oxygen)

M_{C3H8} = 44.09562 g/mol (propane)

M_{S} = 32.065 g/mol (sulphur)

M_{HC} = 13.875389 g/mol (total hydrocarbon[(b)])

(a) The effective molar mass of NOx is defined by the molar mass of nitrogen dioxide, NO_2.

(b) The effective molar mass of HC is defined by an atomic hydrogen-to-carbon ratio, α, of 1.85;

This clause uses the following molar gas constant R for ideal gases:

$R = 8.314472 \mathrm{J}/(\mathrm{mol}\cdot\mathrm{K})$

This clause uses the following ratios of specific heats $\gamma[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]/[\mathrm{J}/(\mathrm{kg}\cdot\mathrm{K})]$ for dilution air and diluted exhaust:

γ_{air} = 1.399 (ratio of specific heats for intake air or dilution air)

γ_{dil} = 1.399 (ratio of specific heats for diluted exhaust)

γ_{exh} = 1.385 (ratio of specific heats for raw exhaust)

A.2.3.2. Wet air

This clause describes how to determine the amount of water in an ideal gas:

A.2.3.2.1. Vapour pressure of water

The vapour pressure of water p_{H2O} [kPa] for a given saturation temperature condition, T_{sat} [K], shall be calculated by means of equations (A.5-1) or (A.5-2):

(a) For humidity measurements made at ambient temperatures from 273.15 to 373.15 K (0 to 100 °C) or for humidity measurements made over super-cooled water at ambient temperatures from 223.15 to 273.15 K (- 50 to 0 °C):

$$\log_{10}(p_{H2O}) = 10.79574 \cdot \left(1 - \frac{273.16}{T_{sat}}\right) - 5.02800 \cdot \log_{10}\left(\frac{T_{sat}}{273.16}\right) + \\ +1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{T_{sat}}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{sat}}\right)} - 1\right) - 0.2138602$$

(A.5-77)

Where:

p_{H2O} = vapour pressure of water at saturation temperature condition [kPa]

T_{sat} = saturation temperature of water at measured condition [K]

(b) For humidity measurements made over ice at ambient temperatures from -100 to 0 °C:

$$\log_{10}(p_{H_2O}) = -9.096853 \cdot \left(\frac{273.16}{T_{sat}} - 1\right) - 3.566506 \cdot \log_{10}\left(\frac{273.16}{T_{sat}}\right) + 0.876812 \\ \cdot \left(1 - \frac{T_{sat}}{273.16}\right) - 0.2138602$$

(A.5-78)

Where:

p_{H2O} = vapour pressure of water at saturation temperature condition [kPa]

T_{sat} = saturation temperature of water at measured condition [K]

A.2.3.2.2. Dew point

If humidity is measured as a dew point, the amount of water in an ideal gas x_{H2O} [mol/mol] shall be obtained by means of equation (A.5-79):

$$x_{H2O} = \frac{p_{H2O}}{p_{abs}} \quad \text{(A.5-79)}$$

Where:

x_{H2O} = amount of water in an ideal gas [mol/mol]

p_{H2O} = vapour pressure of water at the measured dew point, $T_{sat}=T_{dew}$ [kPa]

p_{abs} = wet static absolute pressure at the location of dew point measurement [kPa]

A.2.3.2.3. Relative humidity

If humidity is measured as a relative humidity *RH%*, the amount of water of an ideal gas x_{H2O} [mol/mol] is calculated by means of equation (A.5-80):

$$x_{H2O} = \frac{RH\%}{100} \cdot \frac{p_{H2O}}{p_{abs}} \quad \text{(A.5-80)}$$

Where:

RH% = relative humidity [%]

p_{H2O} = water vapour pressure at 100 % relative humidity at the location of relative humidity measurement, $T_{sat}=T_{amb}$ [kPa]

p_{abs} = wet static absolute pressure at the location of relative humidity measurement [kPa]

A.2.3.2.4. Dew point determination from relative humidity and dry bulb temperature

If humidity is measured as a relative humidity, *RH%*, the dew point, T_{dew}, shall be determined from *RH%* and dry bulb temperature by means of equation (A.5-81):

$$T_{dew} = \frac{2.0798233 \cdot 10^{2} - 2.0156028 \cdot 10^{1} \cdot \ln(p_{H2O}) + 4.6778925 \cdot 10^{-1} \cdot \ln(p_{H2O})^{2} - 9.2288067 \cdot 10^{-6} \cdot \ln(p_{H2O})^{3}}{1 - 1.3319669 \cdot 10^{-1} \cdot \ln(p_{H2O}) + 5.6577518 \cdot 10^{-3} \cdot \ln(p_{H2O})^{2} - 7.5172865 \cdot 10^{-5} \cdot \ln(p_{H2O})^{3}} \quad \text{(A.5-81)}$$

Where

p_{H2O} = water vapor pressure scaled to the relative humidity at the location of relative humidity measurement, $T_{sat} = T_{amb}$

T_{dew} = dew point as determined from relative humidity and dry bulb temperature measurements

A.2.3.3. Fuel properties

The general chemical formula of fuel is $CH_\alpha O_\beta S_\gamma N_\delta$ with α atomic hydrogen-to-carbon ratio (H/C), β atomic oxygen-to-carbon ratio (O/C), γ atomic sulphur-to-carbon ratio (S/C) and δ atomic nitrogen-to-carbon ratio (N/C). Based on this formula the carbon mass fraction of fuel w_C can be calculated. In case of diesel fuel the simple formula $CH_\alpha O_\beta$ may be used. Default values for fuel composition may be derived from Table A.2.1.:

Table A.2.1

Default Values of Atomic Hydrogen-to-Carbon Ratio, α Atomic Oxygen-to-Carbon Ratio, β Atomic Sulphur-to-Carbon Ratio, γ, Atomic Nitrogen-to-Carbon ratio, δ, and Carbon Mass Fraction of Fuel, w_C for Reference Fuels

Fuel	Atomic hydrogen, oxygen, sulphur and nitrogen-to-carbon ratios $CH\alpha O\beta S_\gamma N_\delta$	Carbon mass concentration, w_C [g/g]
Diesel (non-road gas-oil)	$CH_{1,80}O_0S_0N_0$	0.869
Ethanol for dedicated compression ignition engines (ED95)	$CH_{2.92}O_{0.46}S_0N_0$	0.538
Petrol (E10)	$CH_{1,92}O_{0,03}S_0N_0$	0.833
Petrol (E0)	$CH_{1,85}O_0S_0N_0$	0.866
Ethanol (E85)	$CH_{2,73}O_{0,36}S_0N_0$	0.576
LPG	$CH_{2,64}O_0S_0N_0$	0.819
Natural Gas/Biomethane	$CH_{3,78}O_{0,016}S_0N_0$	0.747

A.2.3.3.1 Calculation of carbon mass concentration w_C

As an alternative to the default values in Table A.2.1, or where default values are not given for the reference fuel being used, the carbon mass concentration w_C may be calculated from measured fuel properties by means of equation (A.5-82). Values for α and β shall be determined for the fuel and inserted into the equation in all cases, but γ and δ may optionally be set to zero if they are zero in the corresponding line of Table A.2.1:

$$w_C = \frac{1 \cdot M_C}{1 \cdot M_C + \alpha \cdot M_H + \beta \cdot M_O + \gamma \cdot M_S + \delta \cdot M_N} \quad \text{(A.5-82)}$$

where:

M_C = molar mass of carbon.

α = atomic hydrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_H = molar mass of hydrogen.

β = atomic oxygen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_O = molar mass of oxygen.

γ = atomic sulphur-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_S = molar mass of sulphur.

δ = atomic nitrogen-to-carbon ratio of the mixture of fuel(s) being combusted, weighted by molar consumption.

M_N = molar mass of nitrogen.

A.2.3.4. Total HC (THC) concentration initial contamination correction

For HC measurement, $x_{THC[THC\text{-}FID]}$ shall be calculated by using the initial THC contamination concentration $x_{THC[THC\text{-}FID]init}$ from clause 7.3.1.2. of Annex 4 by means of equation (A.5-83):

$$x_{THC[THC\text{-}FID]cor} = x_{THC[THC\text{-}FID]uncorr} - x_{THC[THC\text{-}FID]init} \quad \text{(A.5-83)}$$

Where:

$x_{THC[THC\text{-}FID]cor}$ = THC concentration corrected for contamination [mol/mol]

$x_{THC[THC\text{-}FID]uncorr}$ = THC uncorrected concentration [mol/mol]

$x_{THC[THC\text{-}FID]init}$ = initial THC contamination concentration [mol/mol]

A.2.3.5. Flow-weighted mean concentration

In some points of this clause, it may be necessary to calculate a flow-weighted mean concentration to determine the applicability of certain provisions. A flow-weighted mean is the mean of a quantity after it is weighted proportional to a corresponding flow rate. For example, if a gas concentration is measured continuously from the raw exhaust of an engine, its flow-weighted mean concentration is the sum of the products of each recorded concentration times its respective exhaust molar flow rate, divided by the sum of the recorded flow rate values. As another example, the bag concentration from a CVS system is the same as the flow-weighted mean concentration because the CVS system itself flow-weights the bag concentration. A certain flow-weighted mean concentration of an emission at the emission limit value might be already expected based on previous testing with similar engines or testing with similar equipment and instruments.

A.2.4. CHEMICAL BALANCES OF FUEL, INTAKE AIR, AND EXHAUST

A.2.4.1. General

Chemical balances of fuel, intake air and exhaust may be used to calculate flows, the amount of water in their flows, and the wet concentration of constituents in their flows. With one flow rate of either fuel, intake air or exhaust, chemical balances may be used to determine the flows of the other two. For example, chemical balances along with either intake air or fuel flow to determine raw exhaust flow may be used.

A.2.4.2. Procedures that require chemical balances

Chemical balances are required to determine the following:

(a) The amount of water in a raw or diluted exhaust flow, x_{H2Oexh}, when the amount of water to correct for the amount of water removed by a sampling system is not measured;

(b) The flow-weighted mean fraction of dilution air in diluted exhaust, $x_{dil/exh,}$ when dilution air flow is not measured to correct for background emissions. It has to

be noted that if chemical balances are used for this purpose, the exhaust is assumed to be stoichiometric, even if it is not.

A.2.4.3. Chemical balance procedure

The calculations for a chemical balance involve a system of equations that require iteration. The initial values of up to three quantities shall be guessed: the amount of water in the measured flow, x_{H2Oexh}, fraction of dilution air in diluted exhaust (or excess air in the raw exhaust), $x_{dil/exh}$, and the amount of products on a C1 basis per dry mole of dry measured flow, $x_{Ccombdry}$. Time-weighted mean values of combustion air humidity and dilution air humidity in the chemical balance may be used; as long as combustion air and dilution air humidity remain within tolerances of ± 0.0025 mol/mol of their respective mean values over the test interval. For each emission concentration, x, and amount of water x_{H2Oexh}, their completely dry concentrations, x_{dry} and $x_{H2Oexhdry}$ shall be determined. The fuel atomic hydrogen-to-carbon ratio, α, oxygen-to-carbon ratio, β and carbon mass fraction of fuel, w_C shall also be used. For the test fuel, α and β or the default values in Table A.2.1. may be used.

Use the following steps to complete a chemical balance:

(a) Measured concentrations such as, $x_{CO2meas}$, x_{NOmeas}, and x_{H2Oint}, shall be converted to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example: $x_{H2OxCO2meas}$, $x_{H2OxNOmeas}$, and x_{H2Oint}. If the amount of water present during a "wet" measurement is the same as the unknown amount of water in the exhaust flow, x_{H2Oexh}, it has to be iteratively solved for that value in the system of equations. If only total NO_X are measured and not NO and NO_2 separately, good engineering judgement shall be used to estimate a split in the total NO_X concentration between NO and NO_2 for the chemical balances. The molar concentration of NO_X, x_{NOx}, may be assumed to be 75 per cent NO and 25 per cent NO_2. For NO_2 storage aftertreatment systems, x_{NOx} may be assumed to be 25 per cent NO and 75 per cent NO_2. For calculating the mass of NO_X emissions, the molar mass of NO_2 for the effective molar mass of all NO_X species, regardless of the actual NO_2 fraction of NO_X, shall be used;

(b) Equations (A.5-6) to (A.5-23) in sub- clause (d) of this clause have to be entered into a computer program to iteratively solve for x_{H2Oexh}, $x_{Ccombdry}$ and $x_{dil/exh}$. Good engineering judgment shall be used to guess initial values for x_{H2Oexh}, $x_{Ccombdry}$, and $x_{dil/exh}$. Guessing an initial amount of water that is about twice the amount of water in the intake or dilution air is recommended. Guessing an initial value of $x_{Ccombdry}$ as the sum of the measured CO_2, CO, and THC values is recommended. Guessing an initial x_{dil} between 0.75 and 0.95, such as 0.8 is also recommended. Values in the system of equations shall be iterated until the most recently updated guesses are all within ± 1 per cent of their respective most recently calculated values values;

(c) The following symbols and subscripts are used in the equation system of sub-clause (d) of this where x unit is mol/mol:

Symbol	Description
$x_{dil/exh}$	Amount of dilution gas or excess air per mole of exhaust

x_{H2Oexh}	Amount of H_2O in exhaust per mole of exhaust
$x_{Combdry}$	Amount of carbon from fuel in the exhaust per mole of dry exhaust
$x_{H2Oexhdry}$	Amount of water in exhaust per dry mole of dry exhaust
$x_{prod/intdry}$	Amount of dry stoichiometric products per dry mole of intake air
$x_{dil/exhdry}$	Amount of dilution gas and/or excess air per mole of dry exhaust
$x_{int/exhdry}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust
$x_{raw/exhdry}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust
$x_{O2intdry}$	Amount of intake air O_2 per mole of dry intake air; $x_{O2intdry}$ = 0.209445 mol/mol may be assumed
$x_{CO2intdry}$	Amount of intake air CO_2 per mole of dry intake air. $x_{CO2intdry}$ = 375 µmol/mol may be used, but measuring the actual concentration in the intake air is recommended
$x_{H2Ointdry}$	Amount of the intake air H_2O per mole of dry intake air
x_{CO2int}	Amount of intake air CO_2 per mole of intake air
x_{CO2dil}	Amount of dilution gas CO_2 per mole of dilution gas
$x_{CO2dildry}$	Amount of dilution gas CO_2 per mole of dry dilution gas. If air is used as diluent, $x_{CO2dildry}$ = 375 µmol/mol may be used, but measuring the actual concentration in the intake air is recommended
$x_{H2Odildry}$	Amount of dilution gas H_2O per mole of dry dilution gas
x_{H2Odil}	Amount of dilution gas H_2O per mole of dilution gas
$x_{[emission]meas}$	Amount of measured emission in the sample at the respective gas analiser

$x_{[emission]dry}$	Amount of emission per dry mole of dry sample
$x_{H2O[emission]meas}$	Amount of water in sample at emission-detection location. These values shall be measured or estimated according to clause 9.3.2.3.1.
x_{H2Oint}	Amount of water in the intake air, based on a humidity measurement of intake air
K_{H2Ogas}	Water-gas reaction equilibrium coefficient. You may use 3.5 or calculate your own value using good engineering judgement.
α	Atomic hydrogen-to-carbon ratio of the mixture of fuel(s) ($CH_\alpha O_\beta$) being combusted, weighted by molar consumption
β	Atomic oxygen-to-carbon ratio of the mixture of fuel(s) ($CH_\alpha O_\beta$) being combusted, weighted by molar consumption

(d) The following equations [(A.5-84) to (A.5-101)] shall be used to iteratively solve for $x_{dil/exh}$, x_{H2Oexh} and $x_{Ccombdry}$:

$$x_{dil/exh} = 1 - \frac{x_{raw/exhdry}}{1 + x_{H2Oexhdry}} \quad \text{(A.5-84)}$$

$$x_{H2Oexh} = \frac{x_{H2Oexhdry}}{1 + x_{H2Oexhdry}} \quad \text{(A.5-85)}$$

$$x_{Ccombdry} = x_{CO2dry} + x_{COdry} + x_{THCdry} - x_{CO2dil} \cdot x_{dil/exhdry} - x_{CO2int} \cdot x_{int/exhdry} \quad \text{(A.5-86)}$$

$$x_{H2dry} = \frac{x_{COdry} \cdot \left(x_{H2Oexhdry} - x_{H2Odil} \cdot x_{dil/exhdry}\right)}{K_{H2Ogas} \cdot \left(x_{CO2dry} - x_{CO2dil} \cdot x_{dil/exhdry}\right).} \quad \text{(A.5-87)}$$

$$x_{H2Oexhdry} = \frac{\alpha}{2}\left(x_{Ccombdry} - x_{THCdry}\right) + x_{H2Odil} \cdot x_{dil/exhdry} + x_{H2Oint} \cdot x_{int/exhdry} - x_{H2dry} \quad \text{(A.5-88)}$$

$$x_{dil/exhdry} = \frac{x_{dil/exh}}{1 - x_{H2Oexh}} \quad \text{(A.5-89)}$$

$$x_{int/exhdry} = \frac{1}{2 \cdot x_{O2int}}\left[\left(\frac{\alpha}{2} - \beta + 2 + 2\gamma\right)\left(x_{Ccombdry} - x_{THCdry}\right) - \left(x_{COdry} - x_{NOdry} - 2x_{NO2dry} + x_{H2dry}\right)\right] \quad \text{(A.5-90)}$$

$$x_{raw/exhdry} = \frac{1}{2}\left[\left(\frac{\alpha}{2} + \beta + \delta\right)\left(x_{Ccombdry} - x_{THCdry}\right) + \left(2x_{THCdry} + x_{COdry} - x_{NO2dry} + x_{H2dry}\right)\right] + x_{int/exhdry} \quad \text{(A.5-91)}$$

$$x_{O2int} = \frac{0.209820 - x_{CO2intdry}}{1 + x_{H2Ointdry}} \quad \text{(A.5-92)}$$

$$x_{CO2int} = \frac{x_{CO2intdry}}{1 + x_{H2Ointdry}} \quad \text{(A.5-93)}$$

$$x_{H2Ointdry} = \frac{x_{H2Oint}}{1 - x_{H2Oint}} \quad \text{(A.5-94)}$$

$$x_{CO2dil} = \frac{x_{CO2dildry}}{1 + x_{H2Odildry}} \quad \text{(A.5-95)}$$

$$x_{H2Odildry} = \frac{x_{H2Odil}}{1 - x_{H2Odil}} \quad \text{(A.5-96)}$$

$$x_{COdry} = \frac{x_{COmeas}}{1 - x_{H2OCOmeas}} \quad \text{(A.5-97)}$$

$$x_{CO2dry} = \frac{x_{CO2meas}}{1 - x_{H2OCO2meas}} \quad \text{(A.5-98)}$$

$$x_{NOdry} = \frac{x_{NOmeas}}{1 - x_{H2ONOmeas}} \quad \text{(A.5-99)}$$

$$x_{NO2dry} = \frac{x_{NO2meas}}{1 - x_{H2ONO2meas}} \quad \text{(A.5-100)}$$

$$x_{THCdry} = \frac{x_{THCmeas}}{1 - x_{H2OTHCmeas}} \quad \text{(A.5-101)}$$

At the end of the chemical balance, the molar flow rate is calculated as specified in clauses A.2.5.3. and A.2.6.3..

A.2.4.4. NO_X correction for humidity

All the NO_X concentrations, including dilution air background concentrations, shall be corrected for intake-air humidity using equation (A.5-102) or (A.5-103):

(a) For compression-ignition engines

$$x_{NOxcor} = x_{NOxuncor} \cdot \left(9.953 \cdot x_{H2O} + 0.832\right) \quad \text{(A.5-102)}$$

(b) For spark-ignition engines

$$x_{NOxcor} = x_{NOxuncor} \cdot \left(18.840 \cdot x_{H2O} + 0.68094\right) \quad \text{(A.5-103)}$$

Where:

$x_{NOxuncor}$ = uncorrected NO_X molar concentration in the exhaust gas [µmol/mol]

x_{H2O} = amount of water in the intake air [mol/mol]

A.2.5. MEASUREMENT OF GASEOUS EMISSIONS IN RAW EXHAUST GAS

A.2.5.1. Mass of gaseous emissions

To calculate the total mass per test of gaseous emission m_{gas} [g/test], its molar concentration shall be multiplied by its respective molar flow and by exhaust gas molar mass; then integration over test cycle shall be performed equation (A.5-104):

$$m_{gas} = M_{gas} \cdot \int \dot{n}_{exh} \cdot x_{gas} \cdot dt \qquad \text{(A.5-104)}$$

Where:

M_{gas} = molar mass of the generic gaseous emission [g/mol]

$\dot{n}_{exh}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gas} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

t = time [s]

Since equation (A.5-104) has to be solved by numerical integration, it is transformed in equation (A.5-105):

$$m_{gas} = M_{gas} \cdot \int \dot{n}_{exh} \cdot x_{gas} \cdot dt \quad \Rightarrow m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi}$$

(A.5-105)

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gasi} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

General equation may be modified according to which measurement system is used, batch or continuous sampling, and if a varying rather than a constant flow rate is sampled.

(a) For continuous sampling, in the general case of varying flow rate, the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of equation (A.5-106):

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi} \qquad \text{(A.5-106)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gasi} = instantaneous gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(b) Still for continuous sampling but in the particular case of constant flow rate the mass of the gaseous emission m_{gas} [g/test] shall be calculated by means of equation (A.5-107):

$$m_{gas} = M_{gas} \cdot \dot{n}_{exh} \cdot \overline{x}_{gas} \cdot \Delta t \qquad \text{(A.5-107)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exh}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(c) For the batch sampling, regardless the flow rate is varying or constant, equation (A.5-104) can be simplified by means of equation (A.5-108):

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \overline{x}_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \qquad \text{(A.5-108)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

A.2.5.2. Dry-to-wet concentration conversion

Parameters of this clause are obtained from the results of the chemical balance calculated in clause A.2.4.3.. The following relation exists between gas molar concentrations in the measured flow x_{gasdry} and x_{gas} [mol/mol] expressed on a dry and wet basis respectively equations (A.5-109) and (A.5-110):

$$x_{gasdry} = \frac{x_{gas}}{1 - x_{H2O}} \qquad \text{(A.5-109)}$$

$$x_{gas} = \frac{x_{gasdry}}{1 + x_{H2Odry}} \quad \text{(A.5-110)}$$

where:

x_{H2O} = molar fraction of water in the measured flow on a wet basis [mol/mol]

x_{H2Odry} = molar fraction of water in the measured flow on a dry basis [mol/mol]

For gaseous emissions a removed water correction shall be performed for the generic concentration *x* [mol/mol] by means of equation (A.5-111):

$$x = x_{[emission]meas}\left[\frac{(1 - x_{H2Oexh})}{1 - x_{H2O[emission]meas}}\right] \quad \text{(A.5-111)}$$

Where:

$x_{[emission]meas}$ = molar fraction of emission in the measured flow at measurement location [mol/mol]

$x_{H2O[emission]meas}$ = amount of water in the measured flow at the concentration measurement [mol/mol]

x_{H2Oexh} = amount of water at the flowmeter [mol/mol]

A.2.5.3. Exhaust gas molar flow rate

The flow rate of the raw exhaust gases can be directly measured or can be calculated based on the chemical balance of clause A.2.4.3.. Calculation of raw exhaust molar flow rate is performed from measured intake air molar flow rate or fuel mass flow rate. The raw exhaust molar flow rate can be calculated from the sampled emissions, $\dot{n}_{exh}$, based on the measured intake air molar flow rate, $\dot{n}_{int}$, or the measured fuel mass flow rate, $\dot{m}_{fuel}$, and the values calculated using the chemical balance in clause A.2.4.3.. It shall be solved for the chemical balance in clause A.2.4.3. at the same frequency that $\dot{n}_{int}$ or $\dot{m}_{fuel}$ is updated and recorded.

(a) Crankcase flow rate. The raw exhaust flow can be calculated based on $\dot{n}_{int}$ or $\dot{m}_{fuel}$ only if at least one of the following is true about crankcase emission flow rate:

(i) The test engine has a production emission-control system with a closed crankcase that routes crankcase flow back to the intake air, downstream of intake air flowmeter;

(ii) During emission testing open crankcase flow shall be routed to the exhaust according to clause 6.10. of Annex 4;

(iii) Open crankcase emissions and flow are measured and added brake-specific emission calculations;

(iv) Using emission data or an engineering analysis, it can be demonstrated that neglecting the flow rate of open crankcase emissions does not adversely affect compliance with the applicable standards;

(b) Molar flow rate calculation based on intake air.

Based on $\dot{n}_{int}$, exhaust gas molar flow rate $\dot{n}_{exh}$ [mol/s] shall be calculated by means of equation (A.5-112):

$$\dot{n}_{exh} = \frac{\dot{n}_{int}}{\left[1 + \frac{\left(x_{int/exhdry} - x_{raw/exhdry}\right)}{\left(1 + x_{H2Oexhdry}\right)}\right]} \quad \text{(A.5-112)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured [mol/s]

$\dot{n}_{int}$ = intake air molar flow rate including humidity in intake air [mol/s]

$x_{int/exhdry}$ = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust [mol/mol]

$x_{raw/exhdry}$ = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust [mol/mol]

$x_{H2Oexhdry}$ = amount of water in exhaust per mole of dry exhaust [mol/mol]

(c) Molar flow rate calculation based on fuel mass flow rate

Based on $\dot{m}_{fuel}$, $\dot{n}_{exh}$ [mol/s] shall be calculated as follows:

When conducting laboratory testing this calculation may only be used for discrete-mode and ramped-modal steady-state cycles equation (A.5-113):

$$\dot{n}_{exh} = \frac{\dot{m}_{fuel} \cdot w_C \cdot \left(1 + x_{H2Oexhdry}\right)}{M_C \cdot x_{Ccombdry}} \quad \text{(A.5-113)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured

$\dot{m}_{fuel}$ = fuel flow rate including humidity in intake air [g/s]

w_C = carbon mass fraction for the given fuel [g/g]

$x_{H2Oexhdry}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_C = molar mass of carbon 12.011 g/mol

$x_{Ccombdry}$ = amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]

(d) Exhaust molar flow rate calculation based on measured intake air molar flow rate, diluted exhaust molar flow rate, and dilute chemical balance

Exhaust gas molar flow rate $\dot{n}_{exh}$ [mol/s] may be calculated based on the measured intake air molar flow rate, $\dot{n}_{int}$, the measured diluted exhaust molar flow rate, $\dot{n}_{dexh}$, and the values calculated using the chemical balance in clause A.2.4.3.. Note that the chemical balance must be based on diluted exhaust gas concentrations. For continuous-flow calculations, solve for the

chemical balance in clause A.2.4.3. at the same frequency that $\dot{n}_{int}$ and $\dot{n}_{dexh}$ are updated and recorded. This calculated $\dot{n}_{dexh}$ may be used for the PM dilution ratio verification, the calculation of dilution air molar flow rate in the background correction in clause A.2.6.1. and the calculation of mass of emissions in clause A.2.5.1. for species that are measured in the raw exhaust.

Based on diluted exhaust and intake air molar flow rate, exhaust gas molar flow rate, $\dot{n}_{exh}$ [mol/s] shall be calculated as follows:

$$\dot{n}_{exh} = \left(x_{raw/exhdry} - x_{int/exhdry}\right) \cdot \left(1 - x_{H2Oexh}\right) \cdot \dot{n}_{dexh} + \dot{n}_{int} \quad \text{(A.5-114)}$$

where

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured [mol/s];

$x_{int/exhdry}$ = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust [mol/mol];

$x_{raw/exhdry}$ = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust [mol/mol];

x_{H2Oexh} = amount of water in exhaust per mole of exhaust[mol/mol];

$\dot{n}_{dexh}$ = diluted exhaust molar flow rate from which emissions are measured [mol/s];

$\dot{n}_{int}$ = intake air molar flow rate including humidity in intake air [mol/s].

A.2.6. DILUTED GASEOUS EMISSIONS

A.2.6.1. Emission mass calculation and background correction

The calculation of gaseous emissions mass m_{gas} [g/test] as a function of molar emissions flow rates shall be calculated as follows:

(a) Continuous sampling, varying flow rate, shall be calculated by means of equation (A.5-106) from clause A.2.5.1.(a)):

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \cdot x_{gasi} \quad \text{(A.5-106)}$$

Where:

M_{gas} = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

x_{gasi} = instantaneous generic gas molar concentration on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(b) Continuous sampling, constant flow rate, shall be calculated by means of equation (A.5-107 from clause A.2.5.1.(b)):

$$m_{gas} = M_{gas} \cdot \dot{n}_{exh} \cdot \overline{x}_{gas} \cdot \Delta t \quad \text{(A.5-107)}$$

Where:

Mgas = generic emission molar mass [g/mol]

$\dot{n}_{exh}$ = exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

Δt = time duration of test interval

(c) Batch sampling, regardless the flow rate is varying or constant, shall be calculated by means of equation (A.5-108) from clause A.2.5.1.(c)):

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \overline{x}_{gas} \cdot \sum_{i=1}^{N} \dot{n}_{exhi} \qquad \text{(A.5-108)}$$

Where:

Mgas = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$ = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\overline{x}_{gas}$ = mean gaseous emission molar fraction on a wet basis [mol/mol]

f = data sampling rate [Hz]

N = number of measurements [-]

(d) In case of diluted exhaust gases calculated values for mass of the pollutants shall be corrected by subtracting the mass of background emissions, due to dilution air:

(i) Firstly, the molar flow rate of dilution air $\dot{n}_{airdil}$ [mol/s] shall be determined over the test interval. This may be a measured quantity or a quantity calculated from the diluted exhaust flow and the flow-weighted mean fraction of dilution air in diluted exhaust, $\overline{x}_{dil/exh}$;

(ii) The total flow of dilution air n_{airdil} [mol] shall be multiplied by the mean concentration of background emission. This may be a time-weighted mean or a flow-weighted mean (e.g., a proportionally sampled background). The product of n_{airdil} and the mean concentration of a background emission is the total amount of a background emission;

(iii) If the result is a molar quantity, it shall be converted to a mass of the background emission m_{bkgnd} [g] by multiplying it by emission molar mass, M_{gas} [g/mol];

(iv) Total background mass shall be subtracted from total mass to correct for background emissions;

(v) The total flow of dilution air may be determined by a direct flow measurement. In this case, the total mass of background shall be calculated, using the dilution air flow, n_{airdil}. The background mass shall be subtracted from the total mass. The result shall be used in brake-specific emission calculations;

(vi) The total flow of dilution air may be determined from the total flow of diluted exhaust and a chemical balance of the fuel, intake air, and exhaust as described in clause A.2.4. In this case, the total mass of background shall be calculated, using the total flow of diluted exhaust, n_{dexh}. Then this result shall be multiplied by the flow-weighted mean fraction of dilution air in diluted exhaust, $\overline{x}_{dil/exh}$.

Considering the two cases (v) and (vi), equations (A.5-115) and (A.5-116) shall be used:

$$m_{bkgnd} = M_{gas} \cdot x_{gasdil} \cdot n_{airdil} \quad \text{or}$$

$$m_{bkgnd} = M_{gas} \cdot \overline{x}_{dil/exh} \cdot \overline{x}_{bkgnd} \cdot n_{dexh} \qquad \text{(A.5-115)}$$

$$m_{gascor} = m_{gas} - m_{bkgnd} \qquad \text{(A.5-116)}$$

where:

m_{gas} = total mass of the gaseous emission [g]

m_{bkgnd} = total background masses [g]

m_{gascor} = mass of gas corrected for background emissions [g]

M_{gas} = molar mass of generic gaseous emission [g/mol]

x_{gasdil} = gaseous emission concentration in dilution air [mol/mol]

n_{airdil} = dilution air molar flow [mol]

$\overline{x}_{dil/exh}$ = flow-weighted mean fraction of dilution air in diluted exhaust [mol/mol]

$\overline{x}_{bkgnd}$ = gas fraction of background [mol/mol]

n_{dexh} = total flow of diluted exhaust [mol]

A.2.6.2. Dry-to wet concentration conversion

The same relations for raw gases (clause A.2.5.2.) shall be used for dry-to-wet conversion on diluted samples. For dilution air a humidity measurement shall be performed with the aim to calculate its water vapour fraction $x_{H2Odildry}$ [mol/mol] by means of equation (A.5-96) from clause A.2.4.3.(d):

$$x_{H2Odildry} = \frac{x_{H2Odil}}{1 - x_{H2Odil}} \qquad \text{(A.5-96)}$$

Where:

x_{H2Odil} = water molar fraction in the dilution air flow [mol/mol]

A.2.6.3 Exhaust gas molar flow rate

(a) Calculation via chemical balance;

The molar flow rate $\dot{n}_{exh}$ [mol/s] can be calculated based on fuel mass flow rate $\dot{m}_{fuel}$ by means of equation (A.5-113) from clause A.2.5.3.(c):

$$\dot{n}_{exh} = \frac{\dot{m}_{fuel} \cdot w_C \cdot \left(1 + x_{H2Oexhdry}\right)}{M_C \cdot x_{Ccombdry}} \quad \text{(A.5-113)}$$

Where:

$\dot{n}_{exh}$ = raw exhaust molar flow rate from which emissions are measured [mol/s]

$\dot{m}_{fuel}$ = fuel flow rate including humidity in intake air [g/s]

w_C = carbon mass fraction for the given fuel [g/g]

$x_{H2Oexhdry}$ = amount of H_2O per dry mole of measured flow [mol/mol]

M_C = molar mass of carbon 12.0107 g/mol

$x_{Ccombdry}$ = amount of carbon from fuel in the exhaust per mole of dry exhaust [mol/mol]

(b) Measurement

The exhaust gas molar flow rate may be measured by means of three systems:

(i) PDP molar flow rate. Based upon the speed at which the Positive Displacement Pump (PDP) operates for a test interval, the corresponding slope a_1, and intercept, a_0 [-], as calculated with the calibration procedure set out in clause 8.1.8.4.2. of Annex 4, shall be used to calculate molar flow rate $\dot{n}$ [mol/s] by means of equation (A.5-117):

$$\dot{n} = f_{n,PDP} \cdot \frac{p_{in} \cdot V_{rev}}{R \cdot T_{in}} \quad \text{(A.5-117)}$$

with:

$$V_{rev} = \frac{a_1}{f_{n,PDP}} \cdot \sqrt{\frac{p_{out} - p_{in}}{p_{in}}} + a_0 \quad \text{(A.5-118)}$$

where:

a_1 = calibration coefficient [m^3/s]

a_0 = calibration coefficient [m^3/rev]

p_{in}, p_{out} = inlet/outlet pressure [Pa]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

V_{rev} = PDP pumped volume [m^3/rev]

$f_{n.,PDP}$ = PDP speed [rev/s]

(ii) SSV molar flow rate. Based on the C_d versus $R_e^{\#}$ equation determined according to clause 8.1.8.4.4. of Annex 4, the Sub-Sonic Venturi (SSV) molar flow rate during an emission test $\dot{n}$ [mol/s] shall be calculated by means of equation (A.5-119):

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{(A.5-119)}$$

Where:

p_{in} = inlet pressure [Pa]

A_t = Venturi throat cross-sectional area [m^2]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

Z = compressibility factor

M_{mix} = molar mass of diluted exhaust [kg/mol]

C_d = discharge coefficient of the SSV [-]

C_f = flow coefficient of the SSV [-]

(iii) CFV molar flow rate. To calculate the molar flow rate through one venturi or one combination of venturis, its respective mean C_d and other constants, determined according to clause 8.1.8.4.3. of Annex 4, shall be used. The calculation of its molar flow rate $\dot{n}$ [mol/s] during an emission test shall be calculated by means of equation (A.5-120):

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{(A.5-120)}$$

Where:

p_{in} = inlet pressure [Pa]

A_t = Venturi throat cross-sectional area [m^2]

R = molar gas constant [J/(mol K)]

T_{in} = inlet temperature [K]

Z = compressibility factor

M_{mix} = molar mass of diluted exhaust [kg/mol]

C_d = discharge coefficient of the CFV [-]

C_f = flow coefficient of the CFV [-]

A.2.7. DETERMINATION OF PARTICULATES

A.2.7.1 Sampling

(a) Sampling from a varying flow rate:

If a batch sample from a changing exhaust flow rate is collected, a sample proportional to the changing exhaust flow rate shall be extracted. The flow rate shall be integrated over a test interval to determine the total flow. The mean PM concentration $\overline{M}_{PM}$ (which is already in units of mass per mole of sample) shall be multiplied by the total flow to obtain the total mass of PM m_{PM} [g] by means of equation (A.5-121):

$$m_{PM} = \bar{M}_{PM} \cdot \sum_{i=1}^{N} (\dot{n}_i \cdot \Delta t_i) \quad \text{(A.5-121)}$$

Where:

$\dot{n}_i$ = instantaneous exhaust molar flow rate [mol/s]

$\bar{M}_{PM}$ = mean PM concentration [g/mol]

Δt_t = sampling interval [s]

(b) Sampling from a constant flow rate

If a batch sample from a constant exhaust flow rate is collected, the mean molar flow rate from which the sample is extracted shall be determined. The mean PM concentration shall be multiplied by the total flow to obtain the total mass of PM m_{PM}[g] by means of equation (A.5-122):

$$m_{PM} = \bar{M}_{PM} \cdot \dot{n} \cdot \Delta t \quad \text{(A.5-122)}$$

where:

$\dot{n}$ = exhaust molar flow rate [mol/s]

$\bar{M}_{PM}$ = mean PM concentration [g/mol]

Δt = time duration of test interval [s]

For sampling with a constant dilution ratio (*DR*), m_{PM} [g] shall be calculated by means of equation (A.5-123):

$$m_{PM} = m_{PMdil} \cdot DR \quad \text{(A.5-123)}$$

where:

m_{PMdil} = PM mass in dilution air [g]

DR = dilution ratio [-] defined as the ratio between the mass of the emission *m* and the mass of diluted exhaust $m_{dil/exh}$ ($DR = m/m_{dil/exh}$).

The dilution ratio *DR* can be expressed as a function of $x_{dil/exh}$ [equation (A.5-124)]:

$$DR = \frac{1}{1 - x_{dil/exh}} \quad \text{(A.5-124)}$$

A.2.7.2. Background correction

The same approach as that of clause A.2.6.1. shall be applied to correct the mass of PM for the background. Multiplying $\overline{M}_{PMbkgnd}$ by the total flow of dilution air, the total background mass of PM ($m_{PMbkgnd}$ [g]) is obtained. Subtraction of total background mass from total mass gives background corrected mass of particulates m_{PMcor} [g] [equation (7-125)]:

$$m_{PMcor} = m_{PMuncor} - \bar{M}_{PMbkgnd} \cdot n_{airdil} \quad \text{(A.5-125)}$$

where:

$m_{PMuncor}$ = uncorrected PM mass [g]

$\overline{M}_{PMbkgnd}$ = mean PM concentration in dilution air [g/mol]

n_{airdil} = dilution air molar flow [mol]

A.2.8. CYCLE WORK AND SPECIFIC EMISSIONS

A.2.8.1. Gaseous emissions

A.2.8.1.1. Transient test cycles (NRTC and LSI-NRTC) and ramped modal cycles (RMC)

Reference is made to clauses A.2.5.1. and A.2.6.1. for raw and diluted exhaust respectively. The resulting values for power P_i[kW] shall be integrated over a test interval. The total work W_{act} [kWh] shall be calculated by means of equation (A.5-126):

$$W_{act} = \sum_{i=1}^{N} P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \cdot \frac{2 \cdot \pi}{60} \cdot \sum_{i=1}^{N} (n_i \cdot T_i) \quad \text{(A.5-126)}$$

Where:

P_i = instantaneous engine power [kW]

n_i = instantaneous engine speed [rpm]

T_i = instantaneous engine torque [N·m]

W_{act} = actual cycle work [kWh]

f = data sampling rate [Hz]

N = number of measurements [-]

Δt_i = the measurement interval [s]

Where auxiliaries were fitted in accordance with Appendix A.2 of Annex 4 there shall be no adjustment to the instantaneous engine torque in equation (A.5-126). Where, according to clause 6.3.2. or 6.3.3. of Annex 4 to this Part necessary auxiliaries that should have been fitted for the test are not installed, or auxiliaries that should have been removed for the test are installed, the value of T_i used in equation (A.5-126) shall be adjusted by means of equation (A.5-127):

$$T_i = T_{i,meas} + T_{i,AUX} \quad \text{(A.5-127)}$$

Where:

$T_{i,meas}$ = measured value of instantaneous engine torque

$T_{i,AUX}$ = corresponding value of torque required to drive auxiliaries determined according to clause 7.7.2.3.(b) of Annex 4 to this Part.

The specific emissions e_{gas} [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{gas} = \frac{m_{gas}}{W_{act}} \quad \text{(A.5-128)}$$

where:

m_{gas} = total mass of emission [g/test]

W_{act} = cycle work [kWh]

In case of the NRTC, for gaseous emissions other than CO_2 the final test result e_{gas} [g/kWh] shall be a weighted average from cold start test and hot start test calculated by means of equation (A.5-129):

$$e_{gas} = \frac{(0.1 \cdot m_{cold}) + (0.9 \cdot m_{hot})}{(0.1 \cdot W_{actcold}) + (0.9 \cdot W_{acthot})} \quad \text{(A.5-129)}$$

Where:

m_{cold} is the gas mass emissions of the cold start NRTC [g]

$W_{act,\ cold}$ is the actual cycle work of the cold start NRTC [kWh]

m_{hot} is the gas mass emissions of the hot start NRTC [g]

$W_{act,\ hot}$ is the actual cycle work of the hot start NRTC [kWh]

In case of the NRTC, for CO_2 the final test result e_{CO2} [g/kWh] shall be calculated from the hot start test calculated by means of equation (A.5-130):

$$e_{CO2,hot} = \frac{m_{CO2,hot}}{W_{act,hot}} \quad \text{(A.5-130)}$$

Where:

$m_{CO2,\ hot}$ is the CO_2 mass emissions of the hot start NRTC [g]

$W_{act,\ hot}$ is the actual cycle work of the hot start NRTC [kWh]

A.2.8.1.2. Discrete-mode NRSC

The specific emissions e_{gas} [g/kWh] shall be calculated by means of equation (A.5-131):

$$e_{gas} = \frac{\sum_{i=1}^{N_{mode}} (\dot{m}_{gasi} \cdot WF_i)}{\sum_{i=1}^{N_{mode}} (P_i \cdot WF_i)} \quad \text{(A.5-131)}$$

where:

$\dot{m}_{gas,i}$ = mean emission mass flow rate for the mode i [g/h]

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = weighting factor for the mode i [-]

N_{mode} = number of modes in applicable discrete-mode NRSC

A.2.8.2. Particulate emissions

A.2.8.2.1 Transient test cycles (NRTC and LSI-NRTC) and ramped modal cycles (RMC)

The particulate specific emissions shall be calculated by transforming equation (A.5-128) into equation (A.5-132) where e_{gas} [g/kWh] and m_{gas} [g/test] are substituted by e_{PM} [g/kWh] and m_{PM} [g/test] respectively:

$$e_{PM} = \frac{m_{PM}}{W_{act}} \quad \text{(A.5-132)}$$

Where:

m_{PM} = total mass of particulates emission, calculated according to clause A.2.7.1. [g/test]

W_{act} = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in clause A.2.8.1.1..

A.2.8.2.2. Discrete-mode NRSC

The particulate specific emission e_{PM} [g/kWh] shall be calculated in the following way:

A.2.8.2.2.1. For the single-filter method by means of equation (A.5-133):

$$e_{PM} = \frac{\dot{m}_{PM}}{\sum_{i=1}^{N_{mode}}(P_i \cdot WF_i)} \quad \text{(A.5-133)}$$

Where:

Pi = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WFi = weighting factor for the mode i [-]

$\dot{m}_{PM}$ = particulate mass flow rate [g/h]

N_{mode} = number of modes in applicable discrete-mode NRSC

A.2.8.2.2.2. For the multiple-filter method by means of equation (A.5-134):

$$e_{PM} = \frac{\sum_{i=1}^{N_{mode}}(\dot{m}_{PM} \cdot WF_i)}{\sum_{i=1}^{N_{mode}}(P_i \cdot WF_i)} \quad \text{(A.5-134)}$$

Where:

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = weighting factor for the mode *i* [-]

$\dot{m}_{PM_i}$ = particulate mass flow rate at mode *i* [g/h]

N_{mode} = number of modes in applicable discrete-mode NRSC

For the single-filter method, the effective weighting factor, WF_{effi}, for each mode shall be calculated by means of equation (A.5-135):

$$WF_{effi} = \frac{m_{smpldexhi} \cdot \overline{\dot{m}_{eqdexhwet}}}{m_{smpldex} \cdot \dot{m}_{eqdexhweti}} \quad \text{(A.5-135)}$$

Where:

$m_{smpldexhi}$ = mass of the diluted exhaust sample passed through the particulate sampling filters at mode *i* [kg]

$m_{smpldexh}$ = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

$\dot{m}_{eqdexhweti}$ = equivalent diluted exhaust gas mass flow rate at mode *i* [kg/s]

$\overline{\dot{m}_{eqdexhwet}}$ = average equivalent diluted exhaust gas mass flow rate [kg/s]

The value of the effective weighting factors shall be within 0.005 (absolute value) of the weighting factors listed in Appendix A.6 of Annex 4.

A.2.8.3. Adjustment for emission controls that are regenerated on an infrequent (periodic) basis

In case of engines equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis (see clause 6.6.2. of Annex 4), the specific emissions of gaseous and particulate pollutants calculated according to clauses A.2.8.1. and A.2.8.2. shall be corrected with either the applicable multiplicative adjustment factor or with the applicable additive adjustment factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$). In the case of the discrete-mode cycle, where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result.

A.2.8.4. Adjustment for deterioration factor

The specific emissions of gaseous and particulate pollutants calculated according to clauses A.2.8.1. and A.2.8.2., where applicable inclusive of the infrequent regeneration adjustment factor according to clause A.2.8.3., shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex 8.

A.2.9. Diluted Exhaust Flow (CVS) Calibration and Related Calculations

This section describes the calculations for calibrating various flowmeters. Clause A.2.9.1. first describes how to convert reference flowmeter outputs for use in the calibration equations, which are presented on a molar basis. The remaining points describe the calibration calculations that are specific to certain types of flowmeters.

A.2.9.1. Reference meter conversions

The calibration equations in this clause use molar flow rate, $\dot{n}_{ref}$, as a reference quantity. If the adopted reference meter outputs a flow rate in a different quantity, such as standard volume rate, $\dot{V}_{stdref}$, actual volume rate, $\dot{V}_{actdref}$, or mass rate, $\dot{m}_{ref}$, the reference meter output shall be converted to a molar flow rate by means of equations (A.5-136), (A.5-137) and (A.5-138), noting that while values for volume rate, mass rate, pressure, temperature, and molar mass may change during an emission test, they should be kept as constant as practical for each individual set point during a flowmeter calibration:

$$\dot{n}_{ref} = \frac{\dot{V}_{stdref} \cdot p_{std}}{T_{std} \cdot R} = \frac{\dot{V}_{actref} \cdot p_{act}}{T_{act} \cdot R} = \frac{\dot{m}_{ref}}{M_{mix}} \quad \text{(A.5-136)}$$

where:

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

$\dot{V}_{stdref}$ = reference volume flow rate, corrected to a standard pressure and a standard temperature [m^3/s]

$\dot{V}_{actref}$ = reference volume flow rate, at the actual pressure and temperature [m^3/s]

$\dot{m}_{ref}$ = reference mass flow [g/s]

p_{std} = standard pressure [Pa]

p_{act} = actual pressure of the gas [Pa]

T_{std} = standard temperature [K]

T_{act} = actual temperature of the gas [K]

R = molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

M_{mix} = molar mass of the gas [g/mol]

A.2.9.2. PDP calibration calculations

For each restrictor position, the following values shall be calculated from the mean values determined in clause 8.1.8.4. of Annex 4, as follows:

(a) PDP volume pumped per revolution, V_{rev} (m^3/rev):

$$V_{rev} = \frac{\overline{\dot{n}}_{ref} \cdot R \cdot \overline{T}_{in}}{\overline{p}_{in} \cdot \overline{f}_{nPDP}} \qquad \text{(A.5-137)}$$

where:

$\overline{\dot{n}}_{ref}$ = mean value of reference molar flow rate [mol/s]

R = molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

$\overline{T}_{in}$ = mean inlet temperature [K]

$\overline{p}_{in}$ = mean inlet pressure [Pa]

$\overline{f}_{nPDP}$ = mean rotational speed [rev/s]

(b) PDP slip correction factor, K_s [s/rev]:

$$K_s = \frac{1}{\overline{f}_{nPDP}} \cdot \sqrt{\frac{\overline{p}_{out} - \overline{p}_{in}}{\overline{p}_{out}}} \qquad \text{(A.5-138)}$$

Where:

$\overline{\dot{n}}_{ref}$ = mean reference molar flow rate [mol/s]

$\overline{T}_{in}$ = mean inlet temperature [K]

$\overline{p}_{in}$ = mean inlet pressure [Pa]

$\overline{p}_{out}$ = mean outlet pressure [Pa]

$\overline{f}_{nPDP}$ = mean PDP revolution speed [rev/s]

R = molar gas constant $\left[\mathrm{J/(mol \cdot K)}\right]$

(c) A least-squares regression of PDP volume pumped per revolution, V_{rev}, versus PDP slip correction factor, K_s, shall be performed by calculating slope, a_1, and intercept, a_0, as described in Appendix A.6;

(d) The procedure in sub- clauses (a) to (c) of this clause shall be repeated for every speed that PDP is operated;

(e) Table A.5-2 illustrates these calculations for different values of $\overline{f}_{nPDP}$

Table A.5-2
Example of PDP Calibration Data

$\overline{f}_{nPDP}$ [rev/min]	$\overline{f}_{nPDP}$ [rev/s]	a_1 [m^3/min]	a_1 [m^3/s]	a_0 [m^3/rev]
755.0	12.58	50.43	0.8405	0.056
987.6	16.46	49.86	0.831	-0.013
1254.5	20.9	48.54	0.809	0.028
1401.3	23.355	47.30	0.7883	-0.061

(f) For each speed at which the PDP is operated, the corresponding slope, a_1, and intercept, a_0, shall be used to calculate flow rate during emission testing as described in clause A.2.6.3.(b).

A.2.9.3. Venturi governing equations and permissible assumptions

This clause describes the governing equations and permissible assumptions for calibrating a venturi and calculating flow using a venturi. Because a subsonic venturi (SSV) and a critical-flow venturi (CFV) both operate similarly, their governing equations are nearly the same, except for the equation describing their pressure ratio, r (i.e., r_{SSV} versus r_{CFV}). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In clause A.2.9.3.(d), other assumptions that may be made are described. If the assumption of an ideal gas for the measured flow is not allowed, the governing equations include a first-order correction for the behaviour of a real gas; namely, the compressibility factor, Z. If good engineering judgment dictates using a value other than Z= 1, an appropriate equation of state to determine values of Z as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed based on good engineering judgment. It shall be noted that the equation for the flow coefficient, C_f, is based on the ideal gas assumption that the isentropic exponent, γ, is equal to the ratio of specific heats, c_p/c_V. If good engineering judgment dictates using a real gas isentropic exponent, an appropriate equation of state to determine values of γ as a function of measured pressures and temperatures may be used, or specific calibration equations may be developed. Molar flow rate, $\dot{n}$ [mol/s], shall be calculated by means of equation (A.5-139):

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad \text{(A.5-139)}$$

Where:

C_d = Discharge coefficient, as determined in sub- clause A.2.9.3.(a) [-]

C_f = Flow coefficient, as determined in sub- clause A.2.9.3.(b) [-]

A_t = Venturi throat cross-sectional area [m^2]

p_{in} = Venturi inlet absolute static pressure [Pa]

Z = Compressibility factor [-]

M_{mix} = Molar mass of gas mixture [kg/mol]

R = Molar gas constant $\left[\text{J/(mol} \cdot \text{K)}\right]$

T_{in} = Venturi inlet absolute temperature [K]

(a) Using the data collected in clause 8.1.8.4. of Annex 4, C_d is calculated by means of equation (A.5-140):

$$C_d = \dot{n}_{ref} \cdot \frac{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}}{C_f \cdot A_t \cdot p_{in}} \quad \text{(A.5-140)}$$

Where:

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

Other symbols as per equation (A.5-139).

(b) C_f shall be determined using one of the following methods:

(i) For CFV flowmeters only, C_{fCFV} is derived from Table A.5-3 based on values for β (ratio of venturi throat to inlet diameters) and γ (ratio of specific heats of the gas mixture), using linear interpolation to find intermediate values:

Table A.5-3

C_{fCFV} versus β and γ for CFV Flowmeters

C_{fCFV}		
β	γ_{exh}=1.385	γ_{dexh}=γ_{air}=1.399
0.000	0.6822	0.6846
0.400	0.6857	0.6881
0.500	0.6910	0.6934
0.550	0.6953	0.6977
0.600	0.7011	0.7036

C_{fCFV}		
β	γ_{exh}=1.385	γ_{dexh}=γ_{air}=1.399
0.625	0.7047	0.7072
0.650	0.7089	0.7114
0.675	0.7137	0.7163
0.700	0.7193	0.7219
0.720	0.7245	0.7271
0.740	0.7303	0.7329
0.760	0.7368	0.7395
0.770	0.7404	0.7431
0.780	0.7442	0.7470
0.790	0.7483	0.7511
0.800	0.7527	0.7555
0.810	0.7573	0.7602
0.820	0.7624	0.7652
0.830	0.7677	0.7707
0.840	0.7735	0.7765
0.850	0.7798	0.7828

(ii) For any CFV or SSV flowmeter, equation (A.5-141) may be used to calculate C_f:

$$C_f = \left[\frac{2\cdot\gamma\cdot\left(r^{\frac{\gamma-1}{\gamma}}-1\right)}{(\gamma-1)\cdot\left(\beta^4-r^{\frac{-2}{\gamma}}\right)}\right]^{\frac{1}{2}} \qquad \text{(A.5-141)}$$

Where:

γ = isentropic exponent [-]. For an ideal gas, this is the ratio of specific heats of the gas mixture, c_p/c_V

r = pressure ratio, as determined in sub-clause (c) of this clause

β = ratio of venturi throat to inlet diameters

(c) The pressure ratio *r* shall be calculated as follows:

(i) For SSV systems only, r_{SSV} shall be calculated by means of equation (A.5-142):

$$r_{SSV} = 1 - \frac{\Delta p_{SSV}}{p_{in}} \quad \text{(A.5-142)}$$

Where:

Δp_{SSV} = differential static pressure; venturi inlet minus venturi throat [Pa]

(ii) For CFV systems only, r_{CFV} shall be calculated iteratively by means of equation (A.5-143):

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma - 1}{2}\right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma + 1}{2} \quad \text{(A.5-143)}$$

(d) Any of the following simplifying assumptions of the governing equations may be made, or good engineering judgment may be used to develop more appropriate values for testing:

(i) For emission testing over the full ranges of raw exhaust, diluted exhaust and dilution air, the gas mixture may be assumed to behave as an ideal gas: Z= 1;

(ii) For the full range of raw exhaust a constant ratio of specific heats of γ = 1.385 may be assumed;

(iii) For the full range of diluted exhaust and air (e.g., calibration air or dilution air), a constant ratio of specific heats of γ = 1.399 may be assumed;

(iv) For the full range of diluted exhaust and air, the molar mass of the mixture, M_{mix} [g/mol], may be considered as a function only of the amount of water in the dilution air or calibration air, x_{H2O}, determined as described in clause A.2.3.2. and shall be calculated by means of equation (A.5-144):

$$M_{mix} = M_{air} \cdot (1 - x_{H2O}) + M_{H2O} \cdot (x_{H2O}) \quad \text{(A.5-144)}$$

Where:

M_{air} = 28.96559 g/mol

M_{H2O} = 18.01528 g/mol

x_{H2O} = amount of water in the dilution or calibration air [mol/mol]

(v) For the full range of diluted exhaust and air, a constant molar mass of the mixture, M_{mix}, may be assumed for all calibration and all testing as long as assumed molar mass differs no more than ± 1 per cent from the estimated minimum and maximum molar mass during calibration and testing. This assumption may be made if sufficient control of the amount of water in calibration air and in dilution air is ensured, or if sufficient water is removed from both calibration air and dilution air.

Table A.5-4 provides for examples of permissible ranges of dilution air dew point versus calibration air dew point.

Table A.5-4

Examples of Dilution Air and Calibration Air Dew Points at which a Constant M_{mix} may be Assumed

If calibration T_{dew} (^{0}C) is...	the following constant Mmix (g/mol) is assumed	for the following ranges of T_{dew} (^{0}C) during emission tests [(a)]
dry	28.96559	dry to 18
0	28.89263	dry to 21
5	28.86148	dry to 22
10	28.81911	dry to 24
15	28.76224	dry to 26
20	28.68685	-8 to 28
25	28.58806	12 to 31
30	28.46005	23 to 34

[(a)] Range valid for all calibration and emission testing over the atmospheric pressure range (80.000 to 103.325) kPa.

A.2.9.4. SSV calibration

(a) Molar based approach. To calibrate an SSV flowmeter the following steps shall be performed:

(i) The Reynolds number, $Re^{\#}$, for each reference molar flow rate, shall be calculated using the throat diameter of the venturi, d_t in equation (A.5-145). Because the dynamic viscosity, μ, is needed to compute $Re^{\#}$, a specific viscosity model may be used to determine μ for calibration gas (usually air), using good engineering judgment, in equation (A.5-146). Alternatively, the Sutherland three-coefficient viscosity model may be used to approximate μ (see Table A.5-5):

$$Re^{\#} = \frac{4 \cdot M_{mix} \cdot \dot{n}_{ref}}{\pi \cdot d_t \cdot \mu} \quad \text{(A.5-145)}$$

Where:

d_t = diameter of the SSV throat [m]

M_{mix} = mixture molar mass [kg/mol]

$\dot{n}_{ref}$ = reference molar flow rate [mol/s]

and, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \left(\frac{T_{in}}{T_0} \right)^{\frac{3}{2}} \cdot \left(\frac{T_0 + S}{T_{in} + S} \right) \quad \text{(A.5-146)}$$

Where:

μ = Dynamic viscosity of calibration gas [kg/(m•s)]

μ_0 = Sutherland reference viscosity [kg /(m·s)]

S = Sutherland constant [K]

T_0 = Sutherland reference temperature [K]

T_{in} = Absolute temperature at the venturi inlet [K]

Table A.5-5

Sutherland Three-Coefficient Viscosity Model Parameters

Gas[(a)]	μ_0	T_0	S	Temp range within ±2% error	Pressure limit
	kg /(m•s)	K	K	K	kPa
Air	1.716×10^{-5}	273	111	170 to 1,900	≤ 1,800
CO_2	1.370×10^{-5}	273	222	190 to 1,700	≤ 3,600
H_2O	1.12×10^{-5}	350	1,064	360 to 1,500	≤ 10,000
O_2	1.919×10^{-5}	273	139	190 to 2,000	≤ 2,500
N_2	1.663×10^{-5}	273	107	100 to 1,500	≤ 1,600
(a) Tabulated parameters only for the pure gases. as listed. shall be used. Parameters to calculate viscosities of gas mixtures shall not be combined.					

(ii) An equation for C_d versus $Re^{\#}$shall be created, using paired values of ($Re^{\#}$, C_d). C_d is calculated according to equation (A.5-140), with C_f obtained from equation (A.5-141), or any mathematical expression may be used, including a polynomial or a power series. Equation (A.5-147) is an example of a commonly used mathematical expression for relating C_d and $Re^{\#}$;

$$C_d = a_0 - a_1 \cdot \sqrt{\frac{10^6}{Re^{\#}}} \quad \text{(A.5-147)}$$

(iii) A least-squares regression analysis shall be performed to determine the best-fit coefficients to the equation and calculate the equation's regression statistics, the standard estimate error *SEE* and the coefficient of determination r^2, in accordance with Appendix A.5;

(iv) If the equation meets the criteria of *SEE*< 0,5 % $n_{\text{ref max}}$ (or $\dot{m}_{\text{refmax}}$) and $r^2 \geq 0.995$, the equation may be used to determine C_d for emission tests, as described in clause A.2.6.3.(b);

(v) If the *SEE* and r^2 criteria are not met, good engineering judgment may be used to omit calibration data points to meet the regression statistics. At least seven calibration data points shall be used to meet the criteria;

(vi) If omitting points does not resolve outliers, corrective action shall be taken. For example, another mathematical expression for the C_d versus $Re^{\#}$ equation shall be selected, leaks are to be checked, or the calibration process has to be repeated. If the process shall be repeated, tighter tolerances shall be applied to measurements and more time for flows to stabilise shall be allowed;

(vii) Once the equation meets the regression criteria, the equation may be used only to determine flow rates that are within the range of the reference flow rates used to meet the C_d versus $Re^{\#}$ equation's regression criteria.

A.2.9.5. CFV calibration

Some CFV flowmeters consist of a single venturi and some consist of multiple venturis, where different combinations of venturis are used to meter different flow rates. For CFV flowmeters that consist of multiple venturis, either calibration of each venturi independently to determine a separate discharge coefficient, C_d, for each venturi, or calibration of each combination of venturis as one venturi may be performed. In the case where a combination of venturis is calibrated, the sum of the active venturi throat areas is used as A_t, the square root of the sum of the squares of the active venturi throat diameters as d_t, and the ratio of the venturi throat to inlet diameters is the ratio of the square root of the sum of the active venturi throat diameters (d_t) to the diameter of the common entrance to all of the venturis (D). To determine the C_d for a single venturi or a single combination of venturis, the following steps shall be performed:

(a) With the data collected at each calibration set point an individual C_d for each point shall be calculated using equation (A.5-140);

(b) The mean and standard deviation of all the C_d values shall be calculated in accordance with equations (A.5-155) and (A.5-156);

(c) If the standard deviation of all the C_d values is less than or equal to 0.3 per cent of the mean C_d, then the mean C_d shall be used in equation (A.5-120), and the CFV shall be used only down to the lowest r measured during calibration;

$$r = 1 - \left(\Delta p / p_{in}\right) \qquad \text{(A.5-148)}$$

(d) If the standard deviation of all the C_d values exceeds 0.3 per cent of the mean C_d, the C_d values corresponding to the data point collected at the lowest r measured during calibration shall be omitted;

(e) If the number of remaining data points is less than seven, corrective action shall be taken by checking calibration data or repeating the calibration process.

If the calibration process is repeated, checking for leaks, applying tighter tolerances to measurements and allowing more time for flows to stabilise, is recommended;

(f) If the number of remaining C_d values is seven or greater, the mean and standard deviation of the remaining C_d values shall be recalculated;

(g) If the standard deviation of the remaining C_d values is less than or equal to 0.3 per cent of the mean of the remaining C_d, that mean C_d shall be used in equation (A.5-120) and the CFV values only down to the lowest r associated with the remaining C_d shall be used;

(h) If the standard deviation of the remaining C_d still exceeds 0.3 per cent of the mean of the remaining C_d values, the steps set out in sub-clauses (d) to (g) of this clause shall be repeated.

A.2.10 DRIFT CORRECTION

A.2.10.1 Scope and frequency

The calculations in this Appendix shall be performed to determine if gas analiser drift invalidates the results of a test interval. If drift does not invalidate the results of a test interval, the test interval's gas analiser responses shall be corrected for drift according to this Appendix. The drift-corrected gas analiser responses shall be used in all subsequent emission calculations. The acceptable threshold for gas analiser drift over a test interval is specified in clause 8.2.2.2. of Annex 4.

A.2.10.2. Correction principles

The calculations in this Appendix use a gas analiser's responses to reference zero and span concentrations of analytical gases, as determined sometime before and after a test interval. The calculations correct the gas analiser's responses that were recorded during a test interval. The correction is based on an analiser's mean responses to reference zero and span gases, and it is based on the reference concentrations of the zero and span gases themselves. Validation and correction for drift shall be performed as follows:

A.2.10.3. Drift validation

After applying all the other corrections–except drift correction–to all the gas analiser signals, brake-specific emissions shall be calculated in accordance with clause A.2.8. of this Appendix. Then all gas analiser signals shall be corrected for drift according to this Appendix. Brake-specific emissions shall be recalculated using all of the drift-corrected gas analiser signals. The brake-specific emission results shall be validated and reported before and after drift correction according to clause 8.2.2.2. of Annex 4.

A.2.10.4. Drift correction

All gas analiser signals shall be corrected as follows:

(a) Each recorded concentration, x_i, shall be corrected for continuous sampling or for batch sampling, $\overline{x}$;

(b) Correction for drift shall be calculated by means of equation (A.5-149):

$$x_{idriftcor} = x_{refzero} + \left(x_{refspan} - x_{refzero}\right)\frac{2x_i - \left(x_{prezero} + x_{postzero}\right)}{\left(x_{prespan} + x_{postspan}\right) - \left(x_{prezero} + x_{postzero}\right)}$$

(A.5-149)

Where:

$x_{idriftcor}$ = concentration corrected for drift [µmol/mol]

$x_{refzero}$ = reference concentration of the zero gas, which is usually zero unless known to be otherwise [µmol/mol]

$x_{refspan}$ = reference concentration of the span gas [µmol/mol]

$x_{prespan}$ = pre-test interval gas analiser response to the span gasconcentration [µmol/mol]

$x_{postspan}$ = post-test interval gas analiser response to the span gas concentration [µmol/mol]

x_i or $\overline{x}$ = concentration recorded, i.e. measured, during test, before drift correction [µmol/mol]

$x_{prezero}$ = pre-test interval gas analiser response to the zero gas concentration [µmol/mol]

$x_{postzero}$ = post-test interval gas analiser response to the zero gas concentration [µmol/mol]

(c) For any pre-test interval concentrations, concentrations determined most recently before the test interval shall be used. For some test intervals, the most recent pre-zero or pre-span might have occurred before one or more previous test intervals;

(d) For any post-test interval concentrations, concentrations determined most recently after the test interval shall be used. For some test intervals, the most recent post-zero or post-span might have occurred after one or more subsequent test intervals;

(e) If any pre-test interval analiser response to the span gas concentration, $x_{prespan}$, is not recorded, $x_{prespan}$ shall be set equal to the reference concentration of the span gas: $x_{prespan} = x_{refspan}$;

(f) If any pre-test interval analiser response to the zero gas concentration, $x_{prezero}$, is not recorded, $x_{prezero}$ shall be set equal to the reference concentration of the zero gas: $x_{prezero} = x_{refzero}$;

(g) Usually the reference concentration of the zero gas, $x_{refzero}$, is zero: $x_{refzero} = 0$ µmol/mol. However, in some cases it might be known that $x_{refzero}$ has a non-zero concentration. For example, if a CO_2 analiser is zeroed using ambient air, the default ambient air concentration of CO_2, which is 375 µmol/mol, may be used. In this case, $x_{refzero} = 375$ µmol/mol. When an analiser is zeroed using a non-zero $x_{refzero}$, the analiser shall be set to output the actual xrefzero concentration. For example, if $x_{refzero} = 375$ µmol/mol, the analiser shall be set to output a value of 375 µmol/mol when the zero gas is flowing to the analyser.

ANNEX 5 - APPENDIX A.3

STATISTICS

A.3.1. ARITHMETIC MEAN

The arithmetic mean, $\overline{y}$, shall be calculated as follows:

$$\overline{y} = \frac{\sum_{i=1}^{N} y_i}{N} \tag{A.5-150}$$

A.3.2. STANDARD DEVIATION

The standard deviation for a non-biased (*e.g.*, *N*–1) sample, σ, shall be calculated as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - \overline{y}\right)^2}{\left(N-1\right)}} \tag{A.5-151}$$

A.3.3. ROOT MEAN SQUARE

The root mean square, rms_y, shall be calculated as follows:

$$rms_y = \sqrt{\frac{1}{N}\sum_{i=1}^{N} y_i^2} \tag{A.5-152}$$

A.3.4. t-TEST

It shall be determined if the data passes a *t*-test by using the following equations and tables:

(a) For an unpaired *t*-test, the *t* statistic and its number of degrees of freedom, *v*, shall be calculated as follows:

$$t = \frac{\left|\overline{y}_{ref} - \overline{y}\right|}{\sqrt{\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}}} \tag{A.5-153}$$

$$v = \frac{\left(\frac{\sigma_{ref}^2}{N_{ref}} + \frac{\sigma_y^2}{N}\right)^2}{\frac{\left(\sigma_{ref}^2/N_{ref}\right)^2}{N_{ref}-1} + \frac{\left(\sigma_y^2/N\right)^2}{N-1}} \tag{A.5-154}$$

(b) For a paired *t*-test, the *t* statistic and its number of degrees of freedom, *v*, shall be calculated as follows, noting that the ε_i are the errors (*e.g.*, differences) between each pair of y_{refi} and y_i:

$$t = \frac{|\bar{\varepsilon}| \cdot \sqrt{N}}{\sigma_{\varepsilon}} \qquad \nu = N - 1$$

(A.5-155)

(c) Table A.5.6 of this clause shall be used to compare t to the t_{crit} values tabulated versus the number of degrees of freedom. If t is less than t_{crit}, then t passes the t-test.

Table A.5.6

Critical *t* Values Versus Number of Degrees of Freedom, ν

ν	Confidence	
	90 per cent	95 per cent
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
18	1.734	2.101

ν	Confidence	
	90 per cent	95 per cent
20	1.725	2.086
22	1.717	2.074
24	1.711	2.064
26	1.706	2.056
28	1.701	2.048
30	1.697	2.042
35	1.690	2.030
40	1.684	2.021
50	1.676	2.009
70	1.667	1.994
100	1.660	1.984
1000+	1.645	1.960

Linear interpolation shall be used to establish values not shown here.

A.3.5. F-TEST

The *F* statistic shall be calculated as follows:

$$F_y = \frac{\sigma_y^2}{\sigma_{\text{ref}}^2} \qquad \text{(A.5-156)}$$

(a) For a 90 per cent confidence *F*-test, Table A.5.7 of this clause is used to compare *F* to the F_{crit90} values tabulated versus (N−1) and (N_{ref}−1). If *F* is less than F_{crit90}, then *F* passes the *F*-test at 90 per cent confidence;

(b) For a 95 per cent confidence *F*-test, Table A.5.8 of this clause is used to compare *F* to the F_{crit95} values tabulated versus (N−1) and (N_{ref}−1). If *F* is less than F_{crit95}, then *F* passes the *F*-test at 95 per cent confidence.

Table A.5.7

Critical *F* values, F_{crit90}, versus *N*-1 and N_{ref}-1 at 90 per cent confidence

N-1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000
N_{ref}-1																			
1	39.8	49.5	53.5	55.8	57.2	58.2	58.9	59.4	59.8	60.1	60.7	61.2	61.7	62.0	62.2	62.5	62.7	63.0	63.32
2	8.52	9.00	9.16	9.24	9.29	9.32	9.34	9.36	9.38	9.39	9.40	9.42	9.44	9.45	9.45	9.46	9.47	9.48	9.491
3	5.53	5.46	5.39	5.34	5.30	5.28	5.26	5.25	5.24	5.23	5.21	5.20	5.18	5.17	5.16	5.16	5.15	5.14	5.134
4	4.54	4.32	4.19	4.10	4.05	4.01	3.97	3.95	3.93	3.92	3.89	3.87	3.84	3.83	3.81	3.80	3.79	3.77	3.761
5	4.06	3.78	3.61	3.52	3.45	3.40	3.36	3.33	3.31	3.29	3.26	3.23	3.20	3.19	3.17	3.15	3.14	3.12	3.105
6	3.77	3.46	3.28	3.18	3.10	3.05	3.01	2.98	2.95	2.93	2.90	2.87	2.83	2.81	2.80	2.78	2.76	2.74	2.722
7	3.58	3.25	3.07	2.96	2.88	2.82	2.78	2.75	2.72	2.70	2.66	2.63	2.59	2.57	2.55	2.53	2.51	2.49	2.471
8	3.45	3.11	2.92	2.80	2.72	2.66	2.62	2.58	2.56	2.53	2.50	2.46	2.42	2.40	2.38	2.36	2.33	2.31	2.293
9	3.36	3.00	2.81	2.69	2.61	2.55	2.50	2.46	2.44	2.41	2.37	2.34	2.29	2.27	2.25	2.23	2.20	2.18	2.159
10	3.28	2.92	2.72	2.60	2.52	2.46	2.41	2.37	2.34	2.32	2.28	2.24	2.20	2.17	2.15	2.13	2.10	2.08	2.055
11	3.22	2.86	2.66	2.53	2.45	2.38	2.34	2.30	2.27	2.24	2.20	2.16	2.12	2.10	2.07	2.05	2.02	2.00	1.972
12	3.17	2.80	2.60	2.48	2.39	2.33	2.28	2.24	2.21	2.18	2.14	2.10	2.06	2.03	2.01	1.98	1.96	1.93	1.904
13	3.13	2.76	2.56	2.43	2.34	2.28	2.23	2.19	2.16	2.13	2.09	2.05	2.00	1.98	1.95	1.93	1.90	1.87	1.846
14	3.10	2.72	2.52	2.39	2.30	2.24	2.19	2.15	2.12	2.09	2.05	2.01	1.96	1.93	1.91	1.88	1.85	1.82	1.797
15	3.07	2.69	2.49	2.36	2.27	2.20	2.15	2.11	2.08	2.05	2.01	1.97	1.92	1.89	1.87	1.84	1.81	1.78	1.755
16	3.04	2.66	2.46	2.33	2.24	2.17	2.12	2.08	2.05	2.02	1.98	1.94	1.89	1.86	1.83	1.81	1.78	1.75	1.718
17	3.02	2.64	2.43	2.30	2.21	2.15	2.10	2.06	2.02	2.00	1.95	1.91	1.86	1.83	1.80	1.78	1.75	1.71	1.686

18	3.00	2.62	2.41	2.28	2.19	2.13	2.07	2.03	2.00	1.97	1.93	1.88	1.83	1.81	1.78	1.75	1.72	1.69	1.657
19	2.99	2.60	2.39	2.26	2.17	2.10	2.05	2.01	1.98	1.95	1.91	1.86	1.81	1.78	1.75	1.73	1.69	1.66	1.631
20	2.97	2.58	2.38	2.24	2.15	2.09	2.04	1.99	1.96	1.93	1.89	1.84	1.79	1.76	1.73	1.70	1.67	1.64	1.607
21	2.96	2.57	2.36	2.23	2.14	2.07	2.02	1.98	1.94	1.92	1.87	1.82	1.77	1.74	1.71	1.68	1.65	1.62	1.586
22	2.94	2.56	2.35	2.21	2.12	2.06	2.00	1.96	1.93	1.90	1.85	1.81	1.75	1.73	1.70	1.67	1.63	1.60	1.567
23	2.93	2.54	2.33	2.20	2.11	2.04	1.99	1.95	1.91	1.89	1.84	1.79	1.74	1.71	1.68	1.65	1.62	1.58	1.549
24	2.92	2.53	2.32	2.19	2.10	2.03	1.98	1.94	1.90	1.87	1.83	1.78	1.73	1.70	1.67	1.64	1.60	1.57	1.533
25	2.91	2.52	2.31	2.18	2.09	2.02	1.97	1.92	1.89	1.86	1.82	1.77	1.71	1.68	1.65	1.62	1.59	1.55	1.518
26	2.90	2.51	2.30	2.17	2.08	2.01	1.96	1.91	1.88	1.85	1.80	1.76	1.70	1.67	1.64	1.61	1.58	1.54	1.504
27	2.90	2.51	2.29	2.16	2.07	2.00	1.95	1.90	1.87	1.84	1.79	1.74	1.69	1.66	1.63	1.60	1.56	1.53	1.491
28	2.89	2.50	2.29	2.15	2.06	1.99	1.94	1.90	1.86	1.83	1.79	1.74	1.68	1.65	1.62	1.59	1.55	1.52	1.478
29	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.89	1.85	1.82	1.78	1.73	1.67	1.64	1.61	1.58	1.54	1.50	1.467
30	2.88	2.48	2.27	2.14	2.04	1.98	1.92	1.88	1.84	1.81	1.77	1.72	1.66	1.63	1.60	1.57	1.53	1.49	1.456
40	2.83	2.44	2.22	2.09	1.99	1.92	1.87	1.82	1.79	1.76	1.71	1.66	1.60	1.57	1.54	1.50	1.46	1.42	1.377
60	2.79	2.39	2.17	2.04	1.94	1.87	1.81	1.77	1.73	1.70	1.65	1.60	1.54	1.51	1.47	1.43	1.39	1.34	1.291
120	2.74	2.34	2.13	1.99	1.89	1.82	1.76	1.72	1.68	1.65	1.60	1.54	1.48	1.44	1.40	1.36	1.32	1.26	1.193
1000+	2.70	2.30	2.08	1.94	1.84	1.77	1.71	1.67	1.63	1.59	1.54	1.48	1.42	1.38	1.34	1.29	1.24	1.16	1.000

Table A.5.8

Critical *F* Values, F_{crit95}, versus *N*-1 and N_{ref}-1 at 95 per cent Confidence

N-1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000
N_{ref}-1																			
1	161.	199.	215.	224.	230.	233.	236.	238.	240.	241.	243.	245.	248.	249.	250.	251.	252.	253.	254.3
2	18.5	19.0	19.1	19.2	19.2	19.3	19.3	19.3	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.49
3	10.1	9.55	9.27	9.11	9.01	8.94	8.88	8.84	8.81	8.78	8.74	8.70	8.66	8.63	8.61	8.59	8.57	8.54	8.526
4	7.70	6.94	6.59	6.38	6.25	6.16	6.09	6.04	5.99	5.96	5.91	5.85	5.80	5.77	5.74	5.71	5.68	5.65	5.628
5	6.60	5.78	5.41	5.19	5.05	4.95	4.87	4.81	4.77	4.73	4.67	4.61	4.55	4.52	4.49	4.46	4.43	4.39	4.365
6	5.98	5.14	4.75	4.53	4.38	4.28	4.20	4.14	4.09	4.06	4.00	3.93	3.87	3.84	3.80	3.77	3.74	3.70	3.669
7	5.59	4.73	4.34	4.12	3.97	3.86	3.78	3.72	3.67	3.63	3.57	3.51	3.44	3.41	3.37	3.34	3.30	3.26	3.230
8	5.31	4.45	4.06	3.83	3.68	3.58	3.50	3.43	3.38	3.34	3.28	3.21	3.15	3.11	3.07	3.04	3.00	2.96	2.928
9	5.11	4.25	3.86	3.63	3.48	3.37	3.29	3.23	3.17	3.13	3.07	3.00	2.93	2.90	2.86	2.82	2.78	2.74	2.707
10	4.96	4.10	3.70	3.47	3.32	3.21	3.13	3.07	3.02	2.97	2.91	2.84	2.77	2.73	2.70	2.66	2.62	2.58	2.538
11	4.84	3.98	3.58	3.35	3.20	3.09	3.01	2.94	2.89	2.85	2.78	2.71	2.64	2.60	2.57	2.53	2.49	2.44	2.405
12	4.74	3.88	3.49	3.25	3.10	2.99	2.91	2.84	2.79	2.75	2.68	2.61	2.54	2.50	2.46	2.42	2.38	2.34	2.296
13	4.66	3.80	3.41	3.17	3.02	2.91	2.83	2.76	2.71	2.67	2.60	2.53	2.45	2.42	2.38	2.33	2.29	2.25	2.206
14	4.60	3.73	3.34	3.11	2.95	2.84	2.76	2.69	2.64	2.60	2.53	2.46	2.38	2.34	2.30	2.26	2.22	2.17	2.131
15	4.54	3.68	3.28	3.05	2.90	2.79	2.70	2.64	2.58	2.54	2.47	2.40	2.32	2.28	2.24	2.20	2.16	2.11	2.066
16	4.49	3.63	3.23	3.00	2.85	2.74	2.65	2.59	2.53	2.49	2.42	2.35	2.27	2.23	2.19	2.15	2.10	2.05	2.010
17	4.45	3.59	3.19	2.96	2.81	2.69	2.61	2.54	2.49	2.45	2.38	2.30	2.23	2.19	2.14	2.10	2.05	2.01	1.960

18	4.41	3.55	3.16	2.92	2.77	2.66	2.57	2.51	2.45	2.41	2.34	2.26	2.19	2.15	2.10	2.06	2.01	1.96	1.91
19	4.38	3.52	3.12	2.89	2.74	2.62	2.54	2.47	2.42	2.37	2.30	2.23	2.15	2.11	2.07	2.02	1.98	1.93	1.87
20	4.35	3.49	3.09	2.86	2.71	2.59	2.51	2.44	2.39	2.34	2.27	2.20	2.12	2.08	2.03	1.99	1.94	1.89	1.84
21	4.32	3.46	3.07	2.84	2.68	2.57	2.48	2.42	2.36	2.32	2.25	2.17	2.09	2.05	2.01	1.96	1.91	1.86	1.81
22	4.30	3.44	3.04	2.81	2.66	2.54	2.46	2.39	2.34	2.29	2.22	2.15	2.07	2.02	1.98	1.93	1.88	1.83	1.78
23	4.27	3.42	3.02	2.79	2.64	2.52	2.44	2.37	2.32	2.27	2.20	2.12	2.04	2.00	1.96	1.91	1.86	1.81	1.75
24	4.26	3.40	3.00	2.77	2.62	2.50	2.42	2.35	2.30	2.25	2.18	2.10	2.02	1.98	1.93	1.89	1.84	1.79	1.73
25	4.24	3.38	2.99	2.75	2.60	2.49	2.40	2.33	2.28	2.23	2.16	2.08	2.00	1.96	1.91	1.87	1.82	1.76	1.71
26	4.22	3.36	2.97	2.74	2.58	2.47	2.38	2.32	2.26	2.22	2.14	2.07	1.99	1.94	1.90	1.85	1.80	1.74	1.69
27	4.21	3.35	2.96	2.72	2.57	2.45	2.37	2.30	2.25	2.20	2.13	2.05	1.97	1.93	1.88	1.83	1.78	1.73	1.67
28	4.19	3.34	2.94	2.71	2.55	2.44	2.35	2.29	2.23	2.19	2.11	2.04	1.95	1.91	1.86	1.82	1.76	1.71	1.65
29	4.18	3.32	2.93	2.70	2.54	2.43	2.34	2.27	2.22	2.17	2.10	2.02	1.94	1.90	1.85	1.80	1.75	1.69	1.63
30	4.17	3.31	2.92	2.69	2.53	2.42	2.33	2.26	2.21	2.16	2.09	2.01	1.93	1.88	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.83	2.60	2.45	2.33	2.24	2.18	2.12	2.07	2.00	1.92	1.83	1.79	1.74	1.69	1.63	1.57	1.50
60	4.00	3.15	2.75	2.52	2.36	2.25	2.16	2.09	2.04	1.99	1.91	1.83	1.74	1.70	1.64	1.59	1.53	1.46	1.38
120	3.92	3.07	2.68	2.44	2.29	2.17	2.08	2.01	1.95	1.91	1.83	1.75	1.65	1.60	1.55	1.49	1.42	1.35	1.25
1000	3.84	2.99	2.60	2.37	2.21	2.09	2.01	1.93	1.88	1.83	1.75	1.66	1.57	1.51	1.45	1.39	1.31	1.22	1.00

A.3.6. SLOPE

The least-squares regression slope, a_{1y}, shall be calculated as follows:

$$a_{1y} = \frac{\sum_{i=1}^{N}\left(y_i - \bar{y}\right)\cdot\left(y_{refi} - \bar{y}_{ref}\right)}{\sum_{i=1}^{N}\left(y_{refi} - \bar{y}_{ref}\right)^2} \quad \text{(A.5-157)}$$

A.3.7. INTERCEPT

The least-squares regression intercept, a_{0y}, shall be calculated as follows:

$$a_{0y} = \bar{y} - \left(a_{1y}\cdot\bar{y}_{ref}\right) \quad \text{(A.5-158)}$$

A.3.8. STANDARD ESTIMATE OF ERROR

The standard estimate of error, *SEE*, shall be calculated as follows:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^{N}\left[y_i - a_{0y} - \left(a_{1y}\cdot y_{refi}\right)\right]^2}{N-2}} \quad \text{(A.5-159)}$$

A.3.9. COEFFICIENT OF DETERMINATION

The coefficient of determination, r^2, shall be calculated as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^{N}\left[y_i - a_{0y} - \left(a_{1y}\cdot y_{refi}\right)\right]^2}{\sum_{i=1}^{N}\left[y_i - \bar{y}\right]^2} \quad \text{(A.5-160)}$$

ANNEX 5 - APPENDIX A.4

1980 INTERNATIONAL GRAVITY FORMULA

The acceleration of Earth's gravity, a_g, varies depending on the location and a_g is calculated for a respective latitude, as follows:

$$a_g = 9.7803267715\left[1 + 5.2790414\times10^{-3}\sin^2\theta + 2.32718\times10^{-5}\sin^4\theta + 1.262\times10^{-7}\sin^6\theta + 7\times10^{-10}\sin^8\theta\right] \quad \text{(A.5-161)}$$

Where:

θ = Degrees north or south latitude

ANNEX 5 - APPENDIX A.5

CARBON FLOW CHECK

A.5.1. INTRODUCTION

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO_2. This is the basis for a system verification check based on CO_2 measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO_2 concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure A.5-1 shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given in the following clauses.

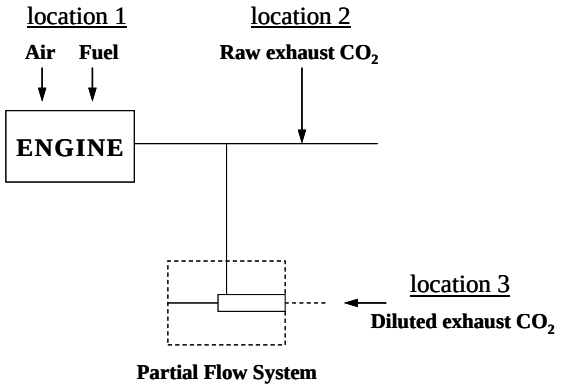


Figure A.5-1

Measuring Points for Carbon Flow Check

A.5.2. CARBON FLOW RATE INTO THE ENGINE (LOCATION 1)

The carbon mass flow rate into the engine q_{mCf} [kg/s] for a fuel CHαOε is given by:

$$q_{mCf} = \frac{12.011}{12.011 + \alpha + 15.9994 \cdot \varepsilon} \cdot q_{mf} \qquad \text{(A.5-162)}$$

Where:

q_{mf} = fuel mass flow rate [kg/s]

A.5.3. CARBON FLOW RATE IN THE RAW EXHAUST (LOCATION 2)

The carbon mass flow rate in the exhaust pipe of the engine q_{mCe} [kg/s] shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left(\frac{c_{CO2,r} - c_{CO2,a}}{100} \right) \cdot q_{mew} \cdot \frac{12.011}{M_e} \qquad \text{(A.5-163)}$$

Where:

$c_{CO2,r}$ = wet CO_2 concentration in the raw exhaust gas [per cent]

$c_{CO2,a}$ = wet CO_2 concentration in the ambient air [per cent]

q_{mew} = exhaust gas mass flow rate on wet basis [kg/s]

M_e = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to clause A.1.1.3 or A.2.5.2

A.5.4. CARBON FLOW RATE IN THE DILUTION SYSTEM (LOCATION 3)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate in an equivalent dilution system q_{mCp} [kg/s] (with equivalent meaning equivalent to a full flow system where the total flow is diluted) shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate; the new equation is identical to equation (A.5- 163,)being only supplemented by the dilution factor q_{mdew} / q_{mp}

.

$$q_{mCp} = \left(\frac{c_{CO2,d} - c_{CO2,a}}{100} \right) \cdot q_{mew} \cdot \frac{12.011}{M_e} \cdot \frac{q_{mdew}}{q_{mp}} \qquad \text{(A.5-164)}$$

Where:

$c_{CO2,d}$ = wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel [per cent]

$c_{CO2,a}$ = wet CO_2 concentration in the ambient air [per cent]

q_{mdew} = diluted sample flow in the partial flow dilution system [kg/s]

q_{mew} = exhaust gas mass flow rate on wet basis [kg/s]

q_{mp} = sample flow of exhaust gas into partial flow dilution system [kg/s]

M_e = molar mass of exhaust gas [g/mol]

If CO_2 is measured on a dry basis, it shall be converted to wet basis according to clause A.1.1.3 or A.2.5.2

.

A.5.5. CALCULATION OF THE MOLAR MASS OF THE EXHAUST GAS

The molar mass of the exhaust gas shall be calculated according to equation (A.8- 14) (see clause A.1.1.5.2)

Alternatively, the following exhaust gas molar masses may be used:

M_e (diesel) = 28.9 g/mol

ANNEX 5 - APPENDIX A.6

PARTICLE NUMBER CALCULATION

A.6.1. DETERMINATION OF PARTICLE NUMBERS

A.6.1.1. Time alignment

For partial flow dilution systems residence time in the particle number sampling and measurement system shall be accounted for by time aligning the particle number signal with the test cycle and the exhaust gas mass flow rate according to the procedure in clause 8.2.1.2. of Annex 4. The transformation time of the particle number sampling and measurement system shall be determined in accordance with clause A.1.2.1.3.7. of Appendix 1 of Annex 4.

A.6.1.2. Determination of particle numbers for transient (NRTC and LSI-NRTC) and ramped modal cycles (RMC) with a partial flow dilution system

Where particle numbers are sampled using a partial flow dilution system according to the specifications set out in clause 9.2.3. of Annex 4, the number of particles emitted over the test cycle shall be calculated by means of equation (A.5-165):

$$N = \frac{m_{edf}}{1.293} \cdot k \cdot \overline{c_s} \cdot \overline{f_r} \cdot 10^6 \qquad \text{(A.5-165)}$$

Where:

N is the number of particles emitted over the test cycle, [#/test],

m_{edf} is the mass of equivalent diluted exhaust gas over the cycle, determined by means of equation (A.5-45) (clause A.1.3.1.1.2.), [kg/test],

k is the calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in equation (A.5-165),

$\overline{c_s}$ is the average concentration of particles from the diluted exhaust gas corrected to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\overline{c_s} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad \text{(A.5-166)}$$

Where:

$c_{s,i}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken over the duration of the test.

A.6.1.3. Determination of particle numbers for transient (NRTC and LSI-NRTC) and ramped modal cycles (RMC) with a full flow dilution system

Where particle numbers are sampled using a full flow dilution system according to the specifications set out in clause 9.2.2. of Annex 4, the number of particles emitted over the test cycle shall be calculated by means of equation (A.5-167):

$$N = \frac{m_{ed}}{1.293} \cdot k \cdot \bar{c}_S \cdot \bar{f}_r \cdot 10^6 \qquad \text{(A.5-167)}$$

Where:

N is the number of particles emitted over the test cycle, [#/test],

m_{ed} is the total diluted exhaust gas flow over the cycle calculated according to any one of the methods described in clauses A.1.2.4.1. to A.1.2.4.3., of Appendix A.1 of Annex 5, kg/test,

k is the calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for *k* in equation (A.5-167),

$\bar{c}_s$ is the average corrected concentration of particles from the diluted exhaust gas corrected to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\bar{c} = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \qquad \text{(A.5-168)}$$

Where:

$c_{s,i}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken over the duration of the test

A.6.1.4. Determination of particle numbers for discrete-mode NRSC with a partial flow dilution system

Where particle numbers are sampled using a partial flow dilution system according to the specifications set out in clause 9.2.3. of Annex 4, the rate of emission of particles during each individual discrete mode shall be calculated by means of equation (A.5-169) using the average values for the mode:

$$\dot{N} = \frac{q_{medf}}{1.293} \times k \times \bar{c}_s \times \overline{f_r} \times 10^6 \times 3600 \quad \text{(A.5-169)}$$

Where:

$\dot{N}$ is the rate of emission of particles during the individual discrete mode, [#/h],

q_{medf} is the equivalent diluted exhaust mass flow rate on a wet basis during the individual discrete mode, determined in accordance with equation (A.5-51) (clause A.1.3.2.1.), [kg/s],

k is the calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in the equation (A.5-169),

$\bar{c}_s$ is the average concentration of particles from the diluted exhaust gas during the individual discrete mode corrected to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\bar{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \quad \text{(A.5-170)}$$

Where:

$c_{s,i}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken during the individual discrete mode sampling period

A.6.1.5. Determination of particle numbers for discrete-mode cycles with a full flow dilution system

Where particle numbers are sampled using a full flow dilution system according to the specifications set out in clause 9.2.2. of Annex 4, the rate of emission of particles during each individual discrete mode shall be calculated by means of equation (A.5-171) using the average values for the mode:

$$\dot{N} = \frac{q_{mdew}}{1.293} \times k \times \bar{c}_s \times \overline{f_r} \times 10^6 \times 3600 \quad \text{(A.5-171)}$$

Where:

$\dot{N}$ is the rate of emission of particles during the individual discrete mode, [#/h],

q_{mdew} is the total diluted exhaust mass flow rate on a wet basis during the individual discrete mode, [kg/s],

k is the calibration factor to correct the particle number counter measurements to the level of the reference instrument where this is not applied internally within the particle number counter. Where the calibration factor is applied internally within the particle number counter, a value of 1 shall be used for k in equation (A.5-171),

$\overline{c}_s$ is the average concentration of particles from the diluted exhaust gas during the individual discrete mode corrected to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

$\overline{f_r}$ is the mean particle concentration reduction factor of the volatile particle remover specific to the dilution settings used for the test.

with

$$\overline{c}_s = \frac{\sum_{i=1}^{i=n} c_{s,i}}{n} \quad \text{(A.5-172)}$$

Where:

$c_{s,i}$ is a discrete measurement of particle concentration in the diluted gas exhaust from the particle counter, corrected for coincidence and to standard conditions (273.15 K and 101.33 kPa), particles per cubic centimetre,

n is the number of particle concentration measurements taken during the individual discrete mode sampling period.

A.6.2. TEST RESULT

A.6.2.1. Calculation of the specific emissions for transient (NRTC and LSI-NRTC) and ramped modal cycles (RMC)

For each applicable individual RMC NRSC, hot NRTC and cold NRTC the specific emissions in number of particles/kWh shall be calculated by means of equation (A.5-173):

$$e = \frac{N}{W_{act}} \quad \text{(A.5-173)}$$

Where:

N is the number of particles emitted over the applicable RMC, hot NRTC or cold NRTC,

W_{act} is the actual cycle work in accordance with clause7.8.3.4. of Annex 4, [kWh].

For an RMC, in case of an engine with infrequent (periodic) exhaust regeneration (see clause 6.6.2. of Annex 4), the specific emissions shall be corrected with either the applicable multiplicative adjustment factor or with the applicable adjustment additive factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or

$k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$).

For an RMC the final result shall also be adjusted with the applicable multiplicative or additive deterioration factor established according to the requirements of Annex 8.

A.6.2.1.1. Weighted average NRTC test result

For the NRTC, the final test result shall be a weighted average from cold start and hot start (including infrequent regeneration where relevant) tests shall be calculated by means of equation (A.5-174) or (A.5-175):

(a) In the case of multiplicative regeneration adjustment, or engines without infrequently regenerating after-treatment

$$e = k_r \left(\frac{(0.1 \times N_{cold}) + (0.9 \times N_{hot})}{(0.1 \times W_{act,cold}) + (0.9 \times W_{act.hot})} \right) \quad \text{(A.5-174)}$$

(b) In the case of additive regeneration adjustment

$$e = k_r + \left(\frac{(0.1 \times N_{cold}) + (0.9 \times N_{hot})}{(0.1 \times W_{act,cold}) + (0.9 \times W_{act.hot})} \right) \quad \text{(A.5-175)}$$

Where:

N_{cold} is the total number of particles emitted over the NRTC cold test cycle,

N_{hot} is the total number of particles emitted over the NRTC hot test cycle,

$W_{act,cold}$ is the actual cycle work over the NRTC cold test cycle in accordance with clause 7.8.3.4. of Annex 4, [kWh],

$W_{act,\ hot}$ is the actual cycle work over the NRTC hot test cycle in accordance with clause 7.8.3.4. of Annex 4, [kWh],

k_r is the regeneration adjustment, according to clause 6.6.2. of Annex 4, or in the case of engines without infrequently regenerating after-treatment $k_r = 1$

In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$).

The result, where applicable inclusive of infrequent regeneration adjustment factor, shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex 8.

A.6.2.2. Calculation of the specific emissions for discrete-mode NRSC tests

The specific emissions e [#/kWh] shall be calculated by means of equation (A.5-176):

$$e = \frac{\sum_{i=1}^{\mathrm{N\,mode}} (\dot{N}_i \cdot WF_i)}{\sum_{i=1}^{\mathrm{N\,mode}} (P_i \cdot WF_i)} \quad \text{(A.5-176)}$$

Where:

P_i = engine power for the mode i [kW] calculated by adding to the measured power P_{meas}[kW] the power required to drive auxiliaries P_{AUX}[kW] determined according to equation (A.4-8) of Annex 4. ($P_i = P_{meas} + P_{AUX}$)

WF_i = the weighting factor for the mode i [-]

$\dot{N}_i$ = the mean emission number flow rate for the mode i [#/h] from equation (A.5-169) or (A.5-171) depending upon the dilution method

In case of an engine with infrequent (periodic) exhaust regeneration (see clause 6.6.2. of Annex 4), the specific emissions shall be corrected with either the applicable multiplicative adjustment factor or with the applicable adjustment additive factor. In the case that infrequent regeneration did not take place during the test the upward factor shall be applied ($k_{ru,m}$ or $k_{ru,a}$). In the case that infrequent regeneration took place during the test the downward factor shall be applied ($k_{rd,m}$ or $k_{rd,a}$). Where the adjustment factors have been determined for each mode they shall be applied to each mode during the calculation of the weighted emission result at equation (A.5-176).

The result, where applicable inclusive of infrequent regeneration adjustment factor, shall also be adjusted by the applicable multiplicative or additive deterioration factor established according to the requirements of Annex 8.

A.6.2.3. Rounding of final results

The final NRSC and weighted average NRTC test results shall be rounded in one step to three significant figures in accordance with ASTM E 29–06B. No rounding of intermediate values leading to the final brake specific emission result is permissible.

A.6.2.4. Determination of particle number background

A.6.2.4.1. At the engine manufacturer's request, dilution tunnel background particle number concentrations may be sampled, prior to or after the test, from a paragraph downstream of the particle and hydrocarbon filters into the particle number measurement system, to determine the tunnel background particle concentrations.

A.6.2.4.2. Subtraction of particle number tunnel background concentrations shall not be allowed for type approval, but may be used at the manufacturer's request, with the prior approval of the Test Agency, for conformity of production testing, if it can be demonstrated that tunnel background contribution is significant, which can then be subtracted from the values measured in the diluted exhaust gas.

ANNEX 5 - APPENDIX A.7

AMMONIA EMISSION CALCULATION

A.7.1. Calculation of the mean concentration for transient (NRTC and LSI-NRTC) and ramped modal cycles (RMC)

The mean NH3 concentration in the exhaust gas over the test cycle c_{NH_3} [ppm] shall be determined by integrating the instantaneous values over the cycle. Equation (A.5-177) shall be applied:

$$c_{NH_3} = \frac{1}{n}\sum_{i=1}^{i=n} c_{NH_{3,i}} \quad \text{(A.5-177)}$$

Where:

$c_{NH_{3,i}}$ is the instantaneous NH_3 concentration in the exhaust gas [ppm]

n is the number of measurements

For the NRTC, the final test result shall be calculated by means of equation (A.5-178):

$$c_{NH_3} = (0.1 \text{ x } c_{NH_{3,cold}}) + (0.9 \text{ x } c_{NH_{3,hot}}) \quad \text{(A.5-178)}$$

Where:

$c_{NH_{3,cold}}$ is the mean NH3 concentration of the cold start test [ppm]

$c_{NH_{3,hot}}$ is the mean NH3 concentration of the hot start test [ppm]

A.7.2. CALCULATION OF THE MEAN CONCENTRATION FOR DISCRETE-MODE NRSC

The mean NH_3 concentration in the exhaust gas over the test cycle c_{NH_3} [ppm] shall be determined by measuring the mean concentration for each mode and weighting the result in accordance with the weighting factors applicable to the test cycle. Equation (A.5-179) shall be applied:

$$c_{NH_3} = \sum_{i=1}^{N_{mode}} \bar{c}_{NH_{3,i}} \cdot WF_i \quad \text{(A.5-179)}$$

Where:

$\bar{c}_{NH_{3,i}}$ is the mean NH3 concentration in the exhaust gas for mode i [ppm]

N_{mode} is the number of modes in the test cycle

WF_i is the weighting factor for the mode i [-]

ANNEX 6

TECHNICAL CHARACTERISTICS OF REFERENCE FUELS PRESCRIBED FOR APPROVAL TESTS AND TO VERIFY CONFORMITY OF PRODUCTION

1. Technical data on fuels for testing compression-ignition engines

1.1. Type: Diesel (non-road gas-oil)

For Type Approval and Conformity of Production (COP) test, fuel shall be reference fuel or commercial fuel as recommended by manufacturer.

ANNEX 6 - APPENDIX 1
REFERENCE DIESEL FUEL CHARACTERISTICS

REFERENCE DIESEL FUEL SPECIFICATION FOR BHARAT STAGE (AGRICULTURAL TRACTOR, CONSTRUCTION EQUIPMENT VEHICLE OR COMBINE HARVESTER) BS V

Parameter	Unit	Limits [1]		Test method
		Minimum	Maximum	
Cetane Index		46.0		EN ISO 4264
Cetane number [2]		52.0	56.0	EN ISO 5165
Density at 15 °C	kg/m^3	833.0	837.0	EN ISO 12185
Distillation:				
- 50% point	°C	245.0	—	EN ISO 3405
- 95% point	°C	345.0	360.0	EN ISO 3405
- final boiling point	°C	—	370.0	EN ISO 3405
Flash point	°C	55	—	EN ISO 2719
Cloud point	°C	-	-10	EN 23015
Viscosity at 40 °C	mm^2/s	2.30	3.30	EN ISO 3104
Polycyclic aromatic hydrocarbons	% m/m	2.0	4.0	EN 12916
Sulphur content	mg/kg	—	10.0	EN ISO 20846 EN ISO 20884
Copper corrosion 3hrs, 50 °C		—	Class 1	EN ISO 2160
Conradson carbon residue (10 % DR)	% m/m	—	0.20	EN ISO 10370
Ash content	% m/m	—	0.010	EN ISO 6245
Total contamination	mg/kg	-	24	EN 12662
Water content	mg/kg	—	200	EN ISO 12937
Acid number	mg KOH/g	—	0.10	EN ISO 6618
Lubricity (HFRR wear scan diameter at 60 °C)	µm	—	400	EN ISO 12156
Oxidation stability @ 110 °C [3]	h	20.0		EN 15751
FAME [4]	% v/v	6.0	7.0	EN 14078

1 The values quoted in the specifications are 'true values'. In establishment of their limit values the terms of ISO 4259 Petroleum products – Determination and application of precision data in relation to methods of test have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

2 The range for cetane number is not in accordance with the requirements of a minimum range of 4R. However, in the case of a dispute between fuel supplier and fuel user, the terms of ISO 4259 may be used to resolve such disputes provided replicate measurements, of sufficient number to archive the necessary precision, are made in preference to single determinations.

3 Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice shall be sought from the supplier as to storage conditions and life.

4 FAME content to meet the specification of EN 14214.

ANNEX 6 - APPENDIX 2
COMMERCIAL DIESEL FUEL CHARACTERISTICS

COMMERCIAL DIESEL FUEL SPECIFICATION FOR BHARAT STAGE (AGRICULTURAL TRACTOR, CONSTRUCTION EQUIPMENT VEHICLE OR COMBINE HARVESTER) BS V

Characteristics	Unit	Requirements
Ash, max	% mass	0.01
Carbon Residue (Ramsbottom) on 10 % residue, max	% mass	0.3 without additives
Cetane number (CN), min		51
Cetane Index (CI), min		46
Distillation :		
95% vol. recovery at ^{0}C, max	^{0}C	360
Flash point :		
a) Abel, min	^{0}C	35
Kinematic Viscosity @ 40 ^{0}C	cst	2.0-4.5
Density @15 ^{0}C	kg/m^3	845
Total Sulphur, max.	mg/kg	10
Water content, max	mg/kg	200
Cold filter Plugging point (CFPP)		
a) Summer, max	^{0}C	18
b) Winter, max	^{0}C	6
Total contaminations, max	mg/kg	24
Oxidation stability, max	g/m^3	25
Polycyclic Aromatic Hydrocarbon (PAH), max	% mass	8
Lubricity, corrected wear scar diameter @ 60 ^{0}C, max	µm (microns)	460
Copper strip corrosion for 3 hrs @ 50^{0}C	rating	Class – 1
FAME content max.	% v/v	7.0

Note :

- Test methods and other provisions / details along with the requirements as given above shall be issued by Bureau of Indian Standards.
- The Cetane number (CN),(min) shall be permitted up to 48 in North Eastern States till 01.04.2023

1.2. Type: Ethanol for dedicated compression ignition engines (ED95)[1]

Parameter	Unit	Limits[2]		Test method[3]
		Minimum	Maximum	
Total alcohol (Ethanol incl. content on higher saturated alcohols)	per cent m/m	92.4		EN 15721
Other higher saturated mono-alcohols (C_3-C_5)	per cent m/m		2.0	EN 15721
Methanol	per cent m/m		0.3	EN 15721
Density 15ºC	kg/m^3	793.0	815.0	EN ISO 12185

Acidity, calculated as acetic acid	per cent m/m		0.0025	EN 15491
Appearance		Bright and clear		
Flashpoint	ºC	10		EN 3679
Dry residue	mg/kg		15	EN 15691
Water content	per cent m/m		6.5	EN 15489[4] EN-ISO 12937 EN15692
Aldehydes calculated as acetaldehyde	per cent m/m		0.0050	ISO 1388-4
Esters calculated as ethylacetat	per cent m/m		0.1	ASTM D1617
Sulphur content	mg/kg		10.0	EN 15485 EN 15486
Sulphates	mg/kg		4.0	EN 15492
Particulate contamination	mg/kg		24	EN 12662
Phosphorus	mg/l		0.20	EN 15487
Inorganic chloride	mg/kg		1.0	EN 15484 or EN 15492
Copper	mg/kg		0.100	EN 15488
Electrical Conductivity	µS/cm		2.50	DIN 51627-4 or prEN 15938

[1] Additives, such as cetane improver as specified by the engine manufacturer, may be added to the ethanol fuel, as long as no negative side effects are known. If these conditions are satisfied, the maximum allowed amount is 10 per cent m/m.

[2] The values quoted in the specifications are "true values". In establishment of their limit values the terms of ISO 4259 Petroleum products – Determination and application of precision data in relation to methods of test have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[3] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[4] Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of EN 15489 shall be applied.

2. TECHNICAL DATA ON FUELS FOR TESTING SPARK IGNITION ENGINES

2.1. Type: Petrol (E10)

Parameter	**Unit**	**Limits[1]**		**Test method[2]**
		Minimum	**Maximum**	
Research octane number, RON		91.0	98.0	EN ISO 5164:2005[3]
Motor octane number, MON		83.0	89.0	EN ISO 5163:2005[3]
Density at 15 °C	kg/m^3	743	756	EN ISO 3675 EN ISO 12185
Vapour pressure	kPa	45.0	60.0	EN ISO 13016-1 (DVPE)
Water content			Max 0.05 per cent v/v Appearance at -7°C: clear and bright	EN 12937
Distillation:				
- evaporated at 70 °C	per cent v/v	18.0	46.0	EN-ISO 3405
- evaporated at 100 °C	per cent v/v	46.0	62.0	EN-ISO 3405
- evaporated at 150 °C	per cent v/v	75.0	94.0	EN-ISO 3405
- final boiling point	°C	170	210	EN-ISO 3405
Residue	per cent v/v	—	2.0	EN-ISO 3405
Hydrocarbon analysis:				
- olefins	per cent v/v	3.0	18.0	EN 14517 EN 15553
- aromatics	per cent v/v	19.5	35.0	EN 14517 EN 15553
- benzene	per cent v/v	—	1.0	EN 12177 EN 238, EN 14517
- saturates	per cent v/v	Report		EN 14517 EN 15553
Carbon/hydrogen ratio		Report		
Carbon/oxygen ratio		Report		
Induction period[4]	minutes	480		EN-ISO 7536
Oxygen content[5]	per cent m/m	3.3[8]	3.7	EN 1601 EN 13132 EN 14517
Existent gum	mg/ml	—	0.04	EN-ISO 6246
Sulphur content[6]	mg/kg	—	10	EN ISO 20846

				EN ISO 20884
Copper corrosion (3h at 50 °C)	rating	—	Class 1	EN-ISO 2160
Lead content	mg/l	—	5	EN 237
Phosphorus content[7]	mg/l	—	1.3	ASTM D 3231
Ethanol[4]	per cent v/v	9.0[8]	10.2[8]	EN 22854

Notes:

[1] The values quoted in the specifications are "true values". In establishment of their limit values the terms of ISO 4259 Petroleum products - Determination and application of precision data in relation to methods of test have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[2] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[3] A correction factor of 0.2 for MON and RON shall be subtracted for the calculation of the final result in accordance with EN 228:2008.

[4] The fuel may contain oxidation inhibitors and metal deactivators normally used to stabilise refinery gasoline streams, but detergent/dispersive additives and solvent oils shall not be added.

[5] Ethanol meeting the specification of EN 15376 is the only oxygenate that shall be intentionally added to the reference fuel.

[6] The actual sulphur content of the fuel used for the Type 1 test shall be reported.

[7] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

[8] The ethanol content and corresponding oxygen content may be zero for engines of category SMB at the choice of the manufacturer. In this case all testing of the engine family, or engine type where no family exists, shall be conducted using petrol with zero ethanol content.

2.2. TYPE: ETHANOL (E85)

Parameter	Unit	Limits[1]		Test method
		Minimum	Maximum	
Research octane number, RON		95.0	—	EN ISO 5164
Motor octane number, MON		85.0	—	EN ISO 5163
Density at 15 °C	kg/m^3	Report		ISO 3675
Vapour pressure	kPa	40.0	60.0	EN ISO 13016-1 (DVPE)
Sulphur content[2]	mg/kg	—	10	EN 15485 or EN 15486
Oxidation stability	Minutes	360		EN ISO 7536
Existent gum content (solvent washed)	mg/100ml	—	5	EN-ISO 6246
Appearance This shall be determined at ambient temperature or 15°C whichever is higher		Clear and bright, visibly free of suspended or precipitated contaminants		Visual inspection
Ethanol and higher alcohols[3]	per cent v/v	83	85	EN 1601 EN 13132 EN 14517 E DIN 51627-3
Higher alcohols (C_3-C_8)	per cent v/v	—	2.0	E DIN 51627-3
Methanol	per cent v/v		1.00	E DIN 51627-3
Petrol[4]	per cent v/v	Balance		EN 228
Phosphous	mg/l	0.20[5]		EN 15487
Water content	per cent v/v		0.300	EN 15489 or EN 15692
Inorganic chloride content	mg/l		1	EN 15492
pHe		6.5	9.0	EN 15490
Copper strip corrosion (3h at 50°C)	Rating	Class 1		EN ISO 2160
Acidity, (as acetic acid CH_3COOH)	per cent m/m (mg/l)	—	0.0050 (40)	EN 15491

Electric Conductivity	µS/cm	1.5	DIN 51627-4 or prEN 15938
Carbon/hydrogen ratio		Report	
Carbon/oxygen ration		Report	

Notes:

[1] The values quoted in the specifications are "true values". In establishment of their limit values the terms of ISO 4259 Petroleum products - Determination and application of precision data in relation to methods of test have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[2] The actual sulphur content of the fuel used for the emission tests shall be reported.

[3] Ethanol to meet specification of EN 15376 is the only oxygenate that shall be intentionally added to this reference fuel.

[4] The unleaded petrol content can be determined as 100 minus the sum of the per cent content of water, alcohols, MTBE and ETBE.

[5] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

3. TECHNICAL DATA ON GASEOUS FUELS FOR SINGLE-FUEL AND DUAL-FUEL ENGINES

3.1. Type: LPG

Parameter	Unit	Fuel A	Fuel B	Test method
Composition:				EN 27941
C_3-content	per cent v/v	30 ± 2	85 ± 2	
C_4-content	per cent v/v	Balance[1]	Balance[1]	
$< C_3$, $> C_4$	per cent v/v	Maximum 2	Maximum 2	
Olefins	per cent v/v	Maximum 12	Maximum 15	
Evaporation residue	mg/kg	Maximum 50	Maximum 50	EN 15470
Water at 0 °C		Free	Free	EN 15469
Total sulphur content including odorant	mg/kg	Maximum 10	Maximum 10	EN 24260, ASTM D 3246, ASTM 6667
Hydrogen sulphide		None	None	EN ISO 8819
Copper strip corrosion (1h at 40 °C)	Rating	Class 1	Class 1	ISO 6251[2]
Odour		Characteristic	Characteristic	
Motor octane number[3]		Minimum 89.0	Minimum 89.0	EN 589 Annex B

Notes:

[1] Balance shall be read as follows: balance = 100 - C_3 - $<C_3$ - $>C_4$.

[2] This method may not accurately determine the presence of corrosive materials if the sample contains corrosion inhibitors or other chemicals which diminish the corrosivity of the sample to the copper strip. Therefore, the addition of such compounds for the sole purpose of biasing the test method is prohibited.

[3] At the request of the engine manufacturer, a higher MON could be used to perform the type approval tests.

3.2. Type: Natural Gas/ Biomethane

3.2.1. Specification for reference fuels supplied with fixed properties (eg from a sealed container)

As an alternative to the reference fuels set out in this clause, the equivalent fuels in clause3.2.2.of this Annex may be used

Characteristics	**Units**	**Basis**	**Limits**		**Test method**
			minimum	**maximum**	
Reference fuel G_R					
Composition:					
Methane		87	84	89	
Ethane		13	11	15	
Balance[1]	per cent mole	—	—	1	ISO 6974
Sulphur content	mg/m^3 [2]	—		10	ISO 6326-5
Notes: [1] Inerts + C_{2+} [2] Value to be determined at standard conditions 293.2 K (20 °C) and 101.3 kPa.					
Reference fuel G_{23}					
Composition:					
Methane		92.5	91.5	93.5	
Balance[1]	per cent mole	—	—	1	ISO 6974
N_2	per cent mole	7.5	6.5	8.5	
Sulphur content	mg/m^3 [2]	—	—	10	ISO 6326-5
Notes: [1] Inerts (different from N_2) + C_2+ C_{2+} [2] Value to be determined at 293.2 K (20 °C) and 101.3 kPa.					
Reference fuel G_{25}					
Composition:					
Methane	per cent mole	86	84	88	
Balance[1]	per cent mole	—	—	1	ISO 6974
N_2	per cent mole	14	12	16	
Sulphur content	mg/m^3 [2]	—	—	10	ISO 6326-5
Notes: [1] Inerts (different from N_2) + C_2+ C_{2+} [2] Value to be determined at 293.2 K (20 °C) and 101.3 kPa.					

Reference fuel G_{20}					
Composition:					
Methane	per cent mole	100	99	100	ISO 6974
Balance (1)	per cent mole	—	—	1	ISO 6974
N_2	per cent mole				ISO 6974
Sulphur content	$mg/m^{3(2)}$	—	—	10	ISO 6326-5
Wobbe Index (net)	$MJ/m^{3(3)}$	48.2	47.2	49.2	
(1) Inerts (different from N_2) + C_2 + C_2+. (2) Value to be determined at 293.2 K (20 °C) and 101.3 kPa. (3) Value to be determined at 273.2 K (0 °C) and 101.3 kPa.					

3.2.2. Specification for reference fuel supplied from a pipeline with admixture of other gases with gas properties determined by on-site measurement

As an alternative to the reference fuels in this clause the equivalent reference fuels in clause 3.2.1. of this Annex may be used.

3.2.2.1. The basis of each pipeline reference fuel (G_R, G_{20}, …) shall be gas drawn from a utility gas distribution network, blended, where necessary to meet the corresponding lambda-shift (S_λ) specification in Table A.6-1, with an admixture of one or more of the following commercially (the use of calibration gas for this purpose shall not be required) available gases:

(a) Carbon dioxide;

(b) Ethane;

(c) Methane;

(d) Nitrogen;

(e) Propane.

3.2.2.2. The value of S_λ of the resulting blend of pipeline gas and admixture gas shall be within the range specified in Table A.6-1 for the specified reference fuel.

Table A.6-1

Required Range of S_λ for each Reference Fuel

Reference fuel	**Minimum S_λ**	**Maximum S_λ**
G_R[2]	0.87	0.95
G_{20}	0.97	1.03
G_{23}	1.05	1.10
G_{25}	1.12	1.20
[1] The engine shall not be required to be tested on a gas blend with a Methane Number (MN) less than 70. In the case that the required range of S_λ for G_R would result in an MN less than 70 the value of S_λ for G_R may be adjusted as necessary until a value of MN no less than 70 is attained.		

3.2.2.3. The engine test report for each test run shall include the following:

(a) The admixture gas(es) chosen from the list in clause 3.2.2.1.of this Annex;

(b) The value of S_λ for the resulting fuel blend;

(c) The Methane Number (MN) of the resulting fuel blend.

3.2.2.4. The requirements of Appendices A.1 and A.2 shall be met in respect to determination of the properties of the pipeline and admixture gases, the determination of S_λ and MN for the resulting gas blend, and the verification that the blend was maintained during the test.

3.2.2.5. In the case that one or more of the gas streams (pipeline gas or admixture gas(es)) contain CO_2 in greater than a de minimis proportion, the calculation of specific CO_2 emissions in Annex 5 shall be corrected according to Appendix A.3.

ANNEX 6 - APPENDIX A.1

SUPPLEMENTARY REQUIREMENTS FOR CONDUCTING EMISSION TESTING USING GASEOUS REFERENCE FUELS COMPRISING PIPELINE GAS WITH ADMIXTURE OF OTHER GASES

A.1.1. METHOD OF GAS ANALYSIS AND GAS FLOW MEASUREMENT

A.1.1.1. For the purpose of this Appendix, where required the composition of the gas shall be determined by analysis of the gas using gas chromatography according to EN ISO 6974, or by an alternative technique that achieves at least a similar level of accuracy and repeatability.

A.1.1.2. For the purpose of this Appendix, where required the measurement of gas flow shall be performed using a mass-based flowmeter.

A.1.2. ANALYSIS AND FLOWRATE OF INCOMING UTILITY GAS SUPPLY

A.1.2.1. The composition of the utility gas supply shall be analysed prior to the admixture blending system.

A.1.2.2. The flowrate of the utility gas entering the admixture blending system shall be measured.

A.1.3. ANALYSIS AND FLOWRATE OF ADMIXTURE

A.1.3.1. When an applicable certificate of analysis is available for an admixture (for example issued by the gas supplier) this may be used as the source of that admixture composition. In this case the on-site analysis of that admixture composition shall be permitted but shall not be required.

A.1.3.2. Where an applicable certificate of analysis is not available for an admixture the composition of that admixture shall be analysed.

A.1.3.3. The flowrate of each admixture entering the admixture blending system shall be measured.

A.1.4. ANALYSIS OF BLENDED GAS

A.1.4.1. The analysis of the composition of the gas supplied to the engine after leaving the admixture blending system shall be permitted in addition to, or as an alternative to the analysis required by clauses A.1.2.1. and A.1.3.1., but shall not be required.

A.1.5. **CALCULATION OF S_λ AND MN OF THE BLENDED GAS**

A.1.5.1. The results of the gas analysis according to clauses A.1.2.1., A.1.3.1. or A.1.3.2. and, where applicable, clause A.1.4.1., combined with the mass flowrate of gas measured according to clauses A.1.2.2. and A.1.3.3., shall be used to calculate the MN according to EN16726:2015. The same set of data shall be used to calculate S_λ according to the procedure set out in Appendix A.2 to this Annex.

A.1.6. CONTROL AND VERIFICATION OF GAS BLEND DURING THE TEST

A.1.6.1 The control and verification of the gas blend during the test shall be performed using either an open loop or closed loop control system.

A.1.6.2 Open loop blend control system

A.1.6.2.1 In this case the gas analysis, flow measurements and calculations set out in clauses A.1.1., A.1.2., A.1.3. and A.1.4. shall be performed prior to the emission test.

A.1.6.2.2 The proportion of utility gas and admixture(s) shall be set to ensure that the S_λ is within the permitted range for the relevant reference fuel in Table A.6-1.

A.1.6.2.3 When the relative proportions have been set they shall be maintained throughout the emission test. Adjustments to individual flow rates to maintain the relative proportions shall be permitted.

A.1.6.2.4 When the emission test has been completed the analysis of gas composition, flow measurements and calculations set out in clauses A.1.2., A.1.3., A.1.4. and A.1.5. shall be repeated. In order for the test to be considered valid the value of S_λ shall remain within the specified range for the respective reference fuel given in Table A.6-1.

A.1.6.3 Closed loop blend control system

A.1.6.3.1 In this case the analysis of gas composition, flow measurements and calculations set out in clauses A.1.2., A.1.3., A.1.4. and A.1.5. shall be performed at intervals during the emission test. The intervals shall be chosen taking into consideration the frequency capability of the gas chromatograph and corresponding calculation system.

A.1.6.3.2 The results from the periodic measurements and calculations shall be used to adjust the relative proportions of utility gas and admixture in order to maintain the value of S_λ within the range specified in Table A.6-1 for the respective reference fuel. The frequency of adjustment shall not exceed the frequency of measurement.

A.1.6.3.3 In order for the test to be considered valid the value of S_λ shall be within the range specified in Table A.6-1 for the respective reference fuel for at least 90 per cent of the measurement points.

ANNEX 6 - APPENDIX A.2

CALCULATION OF λ-SHIFT FACTOR (Sλ)

A.2.1. CALCULATION

The λ-shift factor (S_λ)[1] shall be calculated by means of equation (6-1):

$$S_\lambda = \frac{2}{\left(1-\frac{\text{inert\%}}{100}\right)\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}} \qquad \text{(A.6-1)}$$

Where:

S_λ = λ-shift factor;

inert per cent = per cent by volume of inert gases in the fuel (i.e. N_2, CO_2, He, etc.);

O_2^* = per cent by volume of original oxygen in the fuel;

n and m = refer to average C_nH_m representing the fuel hydrocarbons, i.e:

$$n = \frac{1\times\left[\frac{CH_4\%}{100}\right]+2\times\left[\frac{C_2\%}{100}\right]+3\times\left[\frac{C_3\%}{100}\right]+4\times\left[\frac{C_4\%}{100}\right]+5\times\left[\frac{C_5\%}{100}\right]+..}{\frac{1-\text{diluent }\%}{100}} \qquad \text{(A.6-2)}$$

$$m = \frac{4\times\left[\frac{CH_4\%}{100}\right]+4\times\left[\frac{C_2H_4\%}{100}\right]+6\times\left[\frac{C_2H_6\%}{100}\right]+...8\times\left[\frac{C_3H_8\%}{100}\right]+..}{\frac{1-\text{diluent }\%}{100}} \qquad \text{(A.6-3)}$$

Where:

CH_4% = per cent by volume of methane in the fuel;

C_2% = per cent by volume of all C_2 hydrocarbons (e.g.: C_2H_6, C_2H_4, etc.) in the fuel;

C_3% = per cent by volume of all C_3 hydrocarbons (e.g.: C_3H_8, C_3H_6, etc.) in the fuel;

C_4% = per cent by volume of all C_4 hydrocarbons (e.g.: C_4H_{10}, C_4H_8, etc.) in the fuel;

C_5% = per cent by volume of all C_5 hydrocarbons (e.g.: C_5H_{12}, C_5H_{10}, etc.) in the fuel;

diluent = per cent by volume of dilution gases in the fuel (i.e.: O_2*, N_2, CO_2, He, etc.).

A.2.2. Examples for the calculation of the λ-shift factor S_λ:

Example 1: G_{25}: CH_4 = 86 per cent, N_2 = 14 per cent (by volume)

$$n = \frac{1\times\left[\frac{CH_4\%}{100}\right]+2\times\left[\frac{C_2\%}{100}\right]+..}{\frac{1-\text{diluent}\%}{100}} = \frac{1\times 0.86}{1-\frac{14}{100}} = \frac{0.86}{0.86} = 1$$

[1]Stoichiometric Air/Fuel ratios of automotive fuels - SAE J1829, June 1987. John B. Heywood, Internal combustion engine fundamentals, McGraw-Hill, 1988, Chapter 3.4 "Combustion stoichiometry" (pp. 68 to 72).

$$m = \frac{4\times\left[\frac{CH_4\%}{100}\right] + 4\times\left[\frac{C_2H_4\%}{100}\right] + ..}{\frac{1-diluent\%}{100}} = \frac{4\times 0.86}{0.86} = 4$$

$$S_\lambda = \frac{2}{\left(1-\frac{inert\%}{100}\right)\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}} = \frac{2}{\left(1-\frac{14}{100}\right)\times\left(1+\frac{4}{4}\right)} = 1.16$$

Example 2: G_R: CH_4 = 87 per cent, C_2H_6 = 13 per cent (by vol)

$$n = \frac{1\times\left[\frac{CH_4\%}{100}\right] + 2\times\left[\frac{C_2\%}{100}\right] + ..}{\frac{1-diluent\%}{100}} = \frac{1\times 0.87 + 2\times 0.13}{1-\frac{0}{100}} = \frac{1.13}{} = 1.13$$

$$m = \frac{4\times\left[\frac{CH_4\%}{100}\right] + 4\times\left[\frac{C_2H_4\%}{100}\right] + ..}{\frac{1-diluent\%}{100}} = \frac{4\times 0.87 + 6\times 0.13}{1} = 4.26$$

$$S_\lambda = \frac{2}{\left(1-\frac{inert\%}{100}\right)\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}} = \frac{2}{\left(1-\frac{0}{100}\right)\times\left(1.13+\frac{4.26}{4}\right)} = 0.911$$

Example 3: CH_4 = 89 per cent, C_2H_6 = 4.5 per cent, C_3H_8 = 2.3 per cent, C_6H_{14} = 0,2 per cent, O_2 = 0,6 per cent, N_2 = 4 per cent

$$n = \frac{1\times\left[\frac{CH_4\%}{100}\right] + 2\times\left[\frac{C_2\%}{100}\right] + ..}{\frac{1-diluent\%}{100}} = \frac{1\times 0.89 + 2\times 0.045 + 3\times 0.023 + 4\times 0.002}{1-\frac{0.64+4}{100}} = 1.11$$

$$m = \frac{4\times\left[\frac{CH_4\%}{100}\right] + 4\times\left[\frac{C_2H_4\%}{100}\right] + 6\times\left[\frac{C_2H_6\%}{100}\right] + \;..\; + 8\times\left[\frac{C_3H_8\%}{100}\right]}{1-\frac{diluent\%}{100}} =$$

$$= \frac{4\times 0.89 + 4\times 0.045 + 8\times 0.023 + 14\times 0.002}{1-\frac{0.6+4}{100}} = 4{,}24$$

$$S_\lambda = \frac{2}{\left(1-\frac{inert\%}{100}\right)\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}} = \frac{2}{\left(1-\frac{4}{100}\right)\times\left(1.11+\frac{4.24}{4}\right)-\frac{0.6}{100}} = 0.96$$

As an alternative to the above equation, S_λ may be calculated from the ratio of the stoichiometric air demand of pure methane to the stoichiometric air demand of the fuel blend supplied to the engine, as specified below.

Lambda-shift factor (S_λ) expresses the oxygen demand of any fuel blend in relation to oxygen demand of pure methane. Oxygen demand means the amount of oxygen to oxidise methane in a stoichiometric composition of reaction partners to products of complete combustion (i.e. carbon-dioxide and water).

For the combustion of pure methane the reaction is as set out in equation (A.6-4):

$$1 \times CH_4 + 2 \times O_2 \rightarrow 1 \times CO_2 + 2 \times H_2O \quad \text{(A.6-4)}$$

In this case the ratio of molecules in stoichiometric composition of reaction partners is exactly 2:

$$\frac{n_{O2}}{n_{CH4}} = 2$$

Where:

n_{O2} = number of molecules of oxygen

n_{CH4} = number of molecules of methane

The oxygen demand for pure methane is therefore:

$n_{O2} = 2 \cdot n_{CH4}$ with a reference value of [n_{CH4}]= 1kmol

The value of S_λ may be determined from the ratio of the stoichiometric composition of oxygen and methane to the ratio of the stoichiometric composition of oxygen and the fuel blend supplied to the engine, as set out in equation (A.6-5):

$$S_\lambda = \frac{\left(\frac{n_{O2}}{n_{CH4}}\right)}{\left(\frac{n_{O2}}{n_{blend}}\right)} = \frac{2}{(n_{O2})_{blend}} \quad \text{(A.6-5)}$$

Where:

n_{blend} = number of molecules of the fuel blend

$(n_{O2})_{blend}$ = the ratio of the molecules in the stoichiometric composition of oxygen and the fuel blend supplied to the engine

Because air contains 21per cent oxygen the stoichiometric air demand L_{st} of any fuel shall be calculated by means of equation (A.6-6):

$$L_{st,fuel} = \frac{n_{O2,\ fuel}}{0.21} \quad \text{(A.6-6)}$$

Where:

$L_{st,fuel}$ = the stoichiometric air demand for the fuel

$n_{O2,\ fuel}$ = the stoichiometric oxygen demand for the fuel

Consequently the value of S_λ may also be determined from the ratio of the stoichiometric composition of air and methane to the ratio of the stoichiometric composition of air and the fuel blend supplied to the engine, i.e. the ratio of the stoichiometric air demand of methane to that of the fuel blend supplied to the engine, as set out in equation (A.6-7):

$$S_\lambda = \frac{\left(\frac{n_{O2}}{n_{CH4}}\right)/0.21}{\left(\frac{n_{O2}}{n_{blend}}\right)/0.21} = \frac{\left(\frac{n_{O2}}{0.21}\right)_{CH4}}{\left(\frac{n_{O2}}{0.21}\right)_{blend}} = \frac{L_{st,CH4}}{L_{st,blend}} \qquad \text{(A.6-7)}$$

Therefore, any calculation that specifies the stoichiometric air demand may be used to express the Lambda-shift factor.

ANNEX 6 - APPENDIX A.3

CORRECTION FOR CO_2 IN THE EXHAUST ARISING FROM CO_2 IN THE GASEOUS FUEL

A.3.1. INSTANTANEOUS MASS FLOW RATE OF CO_2 IN THE GASEOUS FUEL STREAM

A.3.1.1. Gas composition and gas flow shall be determined according to the requirements of clauses A.1.1. to A.1.4. of Appendix A.1. of this Annex.

A.3.1.2 The instantaneous mass flow rate of CO_2 in a stream of gas supplied to the engine shall be calculated by means of equation (A.6-8).

$$\dot{m}_{CO2i} = \frac{M_{CO2}}{M_{stream}} \cdot x_{CO2i} \cdot \dot{m}_{streami} \quad \text{(A.6-8)}$$

Where:

$\dot{m}_{CO2i}$ = Instantaneous mass flow rate of CO_2 from the gas stream [g/s]

$\dot{m}_{streami,}$ = Instantaneous mass flow rate of the gas stream [g/s]

x_{CO2i} = Molar fraction of CO_2 in the gaseous stream [-]

M_{CO2} = Molar mass of CO_2 [g/mol]

M_{stream} = Molar mass of gas stream [g/mol]

M_{stream} shall be calculated from all measured constituents (1, 2, … , n) by means of equation (A.6-9).

$$M_{stream} = x_1 \cdot M_1 + x_2 \cdot M_2 + ... + x_n \cdot M_n \quad \text{(A.6-9)}$$

Where:

$X_{1, 2, \ldots n}$ = Molar fraction of each measured constituent in the gas stream (CH_4, CO_2, …) [-]

$M_{1, 2, \ldots n}$ = Molar mass of each measured constituent in the gas stream [g/mol]

A.3.1.3. In order to determine the total mass flow rate of CO_2 in the gaseous fuel entering the engine the calculation in equation (A.6-8) shall be performed for each individual gas stream containing CO_2 that is entering the gas blending system and the result for each gas stream added together, or it shall be performed for the blended gas leaving the blending system and entering the engine by means of equation (A.6-10):

$$\dot{m}_{CO2i,\ fuel} = \dot{m}_{CO2i,\ a} + \dot{m}_{CO2i,\ b} + \ldots + \dot{m}_{CO2i,\ n} \quad \text{(A.6-10)}$$

Where:

$\dot{m}_{CO2i,\ fuel}$ = instantaneous combined mass flow rate of CO_2 arising from the CO_2 in the gaseous fuel entering the engine [g/s]

$\dot{m}_{CO2i,\ a,\ b,\ \ldots,\ n}$ = instantaneous mass flow rate of CO_2 arising from the CO_2 in each individual gas stream a, b, …, n [g/s]

A.3.2. CALCULATION OF SPECIFIC CO_2 EMISSIONS FOR TRANSIENT AND RAMPED MODAL CYCLES

A.3.2.1 The total mass per test of CO_2 emission from the CO_2 in the fuel $m_{CO2,\ fuel}$ [g/test] shall be calculated by summation of the instantaneous mass flow rate of CO_2 in the gaseous fuel entering the engine $\dot{m}_{CO2i,\ fuel}$[g/s] over the test cycle by means of equation (A.6-11):

$$m_{CO2,fuel} = \frac{1}{f} \cdot \sum_{i=1}^{N} \dot{m}_{CO2i,fuel} \quad \text{(A.6-11)}$$

Where:

f = data sampling rate [Hz]

N = number of measurements [-]

A.3.2.2 The total mass of CO_2 emission m_{CO2} [g/test] used in equation (A.5-61), (A.5-63), (A.5-128) or (A.5-130) of Annex 5 to calculate the specific emissions result e_{CO2} [g/kWh] shall be replaced in those equations by the corrected value $m_{CO2,\ corr}$ [g/test] calculated by means of equation (A.6-12).

$$m_{CO2,\ corr} = m_{CO2} - m_{CO2,\ fuel} \quad \text{(A.6-12)}$$

A.3.3. Calculation of specific CO_2 emissions for discrete mode cycles

A.3.3.1 The mean mass flow of CO_2 emission from the CO_2 in the fuel per hour $q_{mCO2,\ fuel}$ or $\dot{m}_{CO2,\ fuel}$[g/h] shall be calculated for each individual test mode from the measurements of instantaneous mass flow rate of CO_2 $\dot{m}_{CO2i,\ fuel}$ [g/s] given by equation (A.6-10) taken during the sampling period of the respective test mode by means of equation (A.6-13):

$$q_{mCO2,fuel} = \dot{m}_{CO2,fuel} = \frac{1}{3600 \cdot N} \cdot \sum_{i=1}^{N} \dot{m}_{CO2i,fuel} \quad \text{(A.6-13)}$$

Where:

N = number of measurements taken during the test mode [-]

A.3.3.2 The mean mass flow rate of CO_2 emission q_{mCO2} or $\dot{m}_{CO2}$ [g/h] for each individual test mode used in equation (A.5-64) or (A.5-131) of Annex 5 to calculate the specific emissions result e_{CO2} [g/kWh] shall be replaced in those equations by the corrected value $q_{mCO2,\ corr}$ or $\dot{m}_{CO2,corr}$ [g/h] for each individual test mode calculated by means of equation (A.6-14) or (A.6-15).

$$q_{mCO2,\ corr} = q_{mCO2} - q_{mCO2,\ fuel} \quad \text{(A.6-14)}$$

$$\dot{m}_{CO2,\ corr} = \dot{m}_{CO2} - \dot{m}_{CO2,\ fuel} \quad \text{(A.6-15)}$$

ANNEX 7

TECHNICAL REQUIREMENTS FOR DUAL-FUEL ENGINES

1. SCOPE

This Annex shall apply for dual-fuel engines as defined in clause 2 of this Part when they are being operated simultaneously on both a liquid and a gaseous fuel (dual-fuel mode).

This Annex shall not apply for testing engines, including dual-fuel engines, when they are being operated solely on liquid or solely on gaseous fuels (i.e. when the GER is either 1 or 0 according to the type of fuel). In this case the requirements are the same as for any single-fuel engine.

2. DEFINITIONS AND ABBREVIATIONS

For the purposes of this Annex the following definitions shall apply and for further clarification see also Appendix A.3 of this Annex:

2.1. "GER (Gas Energy Ratio)" has the meaning defined in clause 2 of this Part based on the lower heating value;

2.2. "GER_{cycle}" means the average GER when operating the engine on the applicable engine test cycle;

2.3. "Dual-fuel Type 1A engine" means either:

(a) dual-fuel engine of a sub-category of NRE $19 \leq kW \leq 560$, that operates over the hot part of the NRTC test-cycle with an average gas energy ratio that is not lower than 90 per cent ($GER_{NRTC, hot} \geq 0.9$) and that does not idle using exclusively liquid fuel, and that has no liquid-fuel mode, or;

(b) a dual-fuel engine of any (sub-) category other than a sub-category of NRE $19 \leq kW \leq 560$, that operates over the NRSC test-cycle with an average gas energy ratio that is not lower than 90 per cent ($GER_{NRSC} \geq 0.9$) and that does not idle using exclusively liquid fuel, and that has no liquid-fuel mode;

2.4. "Dual-Fuel Type 1B engine" means either:

(a) dual-fuel engine of a sub-category of NRE $19 \leq kW \leq 560$, that operates over the hot part of the NRTC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRTC, hot} \geq 0.9$) and that does not idle using exclusively liquid fuel in dual-fuel mode, and that has a liquid-fuel mode, or;

(b) dual-fuel engine of any (sub-) category other than a sub-category of NRE $19 \leq kW \leq 560$, that operates over the NRSC test-cycle with an average gas energy ratio that is not lower than 90 % ($GER_{NRSC} \geq 0.9$) and that does not idle using exclusively liquid fuel in dual-fuel mode, and that has a liquid-fuel mode;

2.5. "Dual-Fuel Type 2A engine" means either:

(a) dual-fuel engine of a sub-category of NRE $19 \leq kW \leq 560$, that operates over the hot part of the NRTC test-cycle with an average gas energy ratio between 10 per cent and 90 per cent ($0.1 < GER_{NRTC, hot} < 0.9$) and that has no liquid-fuel mode or that operates over the hot part of the NRTC test-cycle with an average gas energy ratio that is not lower than

90 per cent ($GER_{NRTC, hot} \geq 0.9$), but that idles using exclusively liquid fuel, and that has no liquid-fuel mode, or;

(b) dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC test-cycle with an average gas energy ratio between 10 per cent and 90 per cent ($0.1 < GER_{NRSC} < 0.9$), and that has no liquid-fuel mode or that operates over the NRSC test-cycle with an average gas energy ratio that is not lower than 90 per cent ($GER_{NRSC} \geq 0.9$), but that idles using exclusively liquid fuel, and that has no liquid-fuel mode;

2.6. "Dual-Fuel Type 2B engine" means either:

(a) dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot part of the NRTC test-cycle with an average gas energy ratio between 10 per cent and 90 per cent ($0.1 < GER_{NRTC, hot} < 0.9$) and that has a liquid-fuel mode or that operates over the hot part of the NRTC test-cycle with an average gas energy ratio that is not lower than 90 per cent ($GER_{NRTC, hot} \geq 0.9$), and that has a liquid-fuel mode but that can idle using exclusively liquid fuel in dual-fuel mode, or;

(b) dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC test-cycle with an average gas energy ratio between 10 per cent and 90 per cent ($0.1 < GER_{NRSC} < 0.9$), and that has no liquid-fuel mode or that operates over the NRSC test-cycle with an average gas energy ratio that is not lower than 90 per cent ($GER_{NRSC} \geq 0.9$), and that has a liquid-fuel mode but that can idle using exclusively liquid fuel in dual-fuel mode;

2.7. "Dual-Fuel Type 3B engine" means either:

(a) dual-fuel engine of a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the hot part of the NRTC test-cycle with an average gas energy ratio that does not exceed 10 per cent ($GER_{NRTC, hot} \leq 0.1$) and that has a liquid-fuel mode, or:

(b) dual-fuel engine of any (sub-) category other than a sub-category of NRE 19 ≤ kW ≤ 560, that operates over the NRSC test-cycle with an average gas energy ratio that does not exceed 10 per cent ($GER_{NRSC} \leq 0.1$) and that has a liquid-fuel mode;

3. DUAL-FUEL SPECIFIC ADDITIONAL APPROVAL REQUIREMENTS

3.1. Engines with operator-adjustable control of GER_{cycle}.

In the case for a given engine type the value of GER_{cycle} can be reduced from the maximum by an operator-adjustable control, the minimum GER_{cycle} shall not be limited but the engine shall be capable of meeting the emission limit values at any value of GER_{cycle} permitted by the manufacturer.

4. GENERAL REQUIREMENTS

4.1. Operating modes of dual-fuel engines

4.1.1. Conditions for a dual-fuel engine to operate in liquid mode

A dual-fuel engine may only operate in liquid-fuel mode if, when operating in liquid-fuel mode, it has been certified according to all the requirements of this Part concerning operation solely on the specified liquid fuel.

When a dual-fuel engine is developed from an already certified liquid-fuel engine, then a new type approval certificate is required in the liquid-fuel mode.

4.1.2. Conditions for a dual-fuel engine to idle using liquid fuel exclusively

4.1.2.1. Dual-fuel Type 1A engines shall not idle using liquid fuel exclusively except under the conditions defined in clause 4.1.3. of this Annex for warm-up and start.

4.1.2.2. Dual-fuel Type 1B engines shall not idle using liquid fuel exclusively in dual-fuel mode.

4.1.2.3. Dual-fuel Types 2A, 2B and 3B engines may idle using liquid fuel exclusively.

4.1.3. Conditions for a dual-fuel engine to warm-up or start using liquid fuel solely

4.1.3.1. A Type 1B, Type 2B, or Type 3B dual-fuel engine may warm-up or start using liquid fuel solely. In the case that the emission control strategy during warm-up or start-up in dual-fuel mode is the same as the corresponding emission control strategy in liquid-fuel mode the engine may operate in dual-fuel mode during warm-up or start-up. If this condition is not met the engine shall only warm-up or start-up using liquid fuel solely when in liquid-fuel mode.

4.1.3.2. A Type 1A or Type 2A dual-fuel engine may warm-up or start-up using liquid fuel solely. However, in that case, the strategy shall be declared as an AECS and the following additional requirements shall be met:

4.1.3.2.1. The strategy shall cease to be active when the coolant temperature has reached a temperature of 343 K (70 °C), or within 15 minutes after it has been activated, whichever occurs first; and

4.1.3.2.2. The service mode shall be activated while the strategy is active.

4.2. Service mode

4.2.1. Conditions for dual-fuel engines to operate in service mode

When an engine is operating in service mode it is subject to an operability restriction and is temporarily exempted from complying with the requirements related to exhaust emissions and NO_X control described in this Part.

4.2.2. Operability restriction in service mode

4.2.2.1. Requirement

The operability restriction applicable to agricultural tractor, construction equipment vehicle or combine harvester fitted with a dual-fuel engine operated in service mode is the one activated by the "severe inducement system" specified in clause A.1.5.4 of Appendix A.1 of Annex 9.

In order to account for safety concerns and to allow for self-healing diagnostics, use of an inducement override function for releasing full engine power is permitted according to clause A.1.5.5 of Appendix A.1 of Annex 9.

The operability restriction shall not otherwise be deactivated by either the activation or deactivation of the warning and inducement systems specified in clause A.1.5.of Appendix A.1 of Annex 9.

The activation and the deactivation of the service mode shall not activate or deactivate the warning and inducement systems specified in Annex 9.

4.2.2.2. Reserved

4.2.2.3. Activation of the operability restriction

The operability restriction shall be automatically activated when the service mode is activated.

In the case where the service mode is activated according to clause 4.2.3. of this Annex because of a malfunction of the gas supply system, the operability restriction shall become active within 30 minutes operating time after the service mode is activated.

In the case where the service mode is activated because of an empty gaseous fuel tank, the operability restriction shall become active as soon as the service mode is activated.

4.2.2.4. Deactivation of the operability restriction

The operability restriction system shall be deactivated when the engine no longer operates in service mode.

4.2.3. Unavailability of gaseous fuel when operating in a dual-fuel mode

In order to permit the agricultural tractor, construction equipment vehicle or combine harvester to move to a position of safety, upon detection of an empty gaseous fuel tank, or of a malfunctioning gas supply system:

(a) Dual-fuel engines of Types 1A and 2A shall activate the service mode;

(b) Dual-fuel engines of Types 1B, 2B and 3B shall operate in liquid mode.

4.2.3.1. Unavailability of gaseous fuel – empty gaseous fuel tank

In the case of an empty gaseous fuel tank, the service mode or, as appropriate according to clause 4.2.3. above, the liquid fuel mode shall be activated as soon as the engine system has detected that the tank is empty.

When the gas availability in the tank again reaches the level that justified the activation of the empty tank warning system specified in clause 4.3.2. below, the service mode may be deactivated, or, when appropriate, the dual-fuel mode may be reactivated.

4.2.3.2. Unavailability of gaseous fuel – malfunctioning gas supply

In the case of a malfunctioning gas supply system that causes the unavailability of gaseous fuel, the service mode or, as appropriate according to clause 4.2.3. above, the liquid fuel mode shall be activated when gaseous fuel supply is not available.

As soon as the gaseous fuel supply becomes available the service mode may be deactivated, or, when appropriate, the dual-fuel mode may be reactivated.

4.3. Dual-fuel indicators

4.3.1. Dual-fuel operating mode indicator

The agricultural tractor, construction equipment vehicle or combine harvester shall provide to the operator a visual indication of the mode under which the engine operates (dual-fuel mode, liquid mode, or service mode).

The characteristics and the location of this indicator shall be left to the discretion of the OEM and may be part of an already existing visual indication system.

This indicator may be completed by a message display. The system used for displaying the messages referred to in this clause may be the same as the ones used for NO_X control diagnostics, or other maintenance purposes.

The visual element of the dual-fuel operating mode indicator shall not be the same as the one used for the purpose of NO_X control diagnostics, or for other engine maintenance purposes.

Safety alerts always have display priority over the operating mode indication.

4.3.1.1. The dual-fuel mode indicator shall be set to service mode as soon as the service mode is activated (i.e. before it becomes actually active) and the indication shall remain as long as the service mode is active.

4.3.1.2. The dual-fuel mode indicator shall be set for at least one minute on dual-fuel mode or liquid-fuel mode as soon as the engine operating mode is changed from liquid fuel to dual-fuel mode or vice-versa. This indication is also required for at least one minute at key-on, or at the request of the manufacturer at engine cranking. The indication shall also be given upon the operator's request.

4.3.2. Empty gaseous fuel tank warning system (dual-fuel warning system)

Agricultural tractor, construction equipment vehicle or combine harvester fitted with a dual-fuel engine shall be equipped with a dual-fuel warning system that alerts the operator that the gaseous fuel tank will soon become empty.

The dual-fuel warning system shall remain active until the tank is refuelled to a level above which the warning system is activated.

The dual-fuel warning system may be temporarily interrupted by other warning signals providing important safety-related messages.

It shall not be possible to turn off the dual-fuel warning system by means of a scan-tool as long as the cause of the warning activation has not been rectified.

4.3.2.1. Characteristics of the dual-fuel warning system

The dual-fuel warning system shall consist of a visual alert system (icon, pictogram, etc.) left to the choice of the manufacturer.

It may include, at the choice of the manufacturer, an audible component. In that case, the cancelling of that component by the operator is permitted.

The visual element of the dual-fuel warning system shall not be the same as the one used for the purpose of NO_X control diagnostics, or for other engine maintenance purposes.

In addition the dual-fuel warning system may display short messages, including messages indicating clearly the remaining distance or time before the activation of the operability restriction.

The system used for displaying the warning or messages referred to in this clause may be the same as the one used for displaying the warning or messages related the NO_X control diagnostics, or warning or messages for other maintenance purposes.

A facility to permit the operator to dim the visual alarms provided by the warning system may be provided on agricultural tractors, construction equipment vehicle or combine harvester for use by the rescue services or on agricultural tractors, construction equipment vehicle or combine harvester designed and constructed for use by the armed services, civil defence, fire services and forces responsible for maintaining public order.

4.4. Communicated torque

4.4.1. Communicated torque when a dual-fuel engine operates in dual-fuel mode

When a dual-fuel engine operates in dual-fuel mode:

(a) The reference torque curve retrievable shall be the one obtained when that engine is tested on an engine test bench in the dual-fuel mode;

(b) The recorded actual torques (indicated torque and friction torque) shall be the result of the dual-fuel combustion and not the one obtained when operating with liquid fuel exclusively.

4.4.2. Communicated torque when a dual-fuel engine operates in liquid-fuel mode

When a dual-fuel engine operates in liquid-fuel mode, the reference torque curve retrievable shall be the one obtained when the engine is tested on an engine test bench in liquid-fuel mode.

4.5. Additional requirements

4.5.1. Where used for a dual-fuel engine, adaptive strategies shall, in addition to satisfying the requirements of Annex 9, additionally comply with the following requirements:

(a) The engine shall always remain within the dual-fuel engine type (that is Type 1A, Type 2B, etc.) that has been declared for the type-approval; and

(b) In case of a Type 2 engine, the resulting difference between the highest and the lowest maximum GER_{cycle} within the family shall never exceed the range set out in clause 2.4.15. of Annex 10 to this Part, except in the case of engines with an operator adjustable control of GER_{cycle} as permitted by clause 3.1. of this Annex.

4.6 The type approval shall be conditional upon providing to the OEM and end-users, in accordance with Appendices 1 and 2 of clause 6 of this Part instructions for installation and operation of the dual-fuel engine including the service mode set out in clause 4.2. and the dual-fuel indicator system set out in clause 4.3..

5. PERFORMANCE REQUIREMENTS

5.1. The performance requirements, including emission limit values, and the requirements for type-approval applicable to dual-fuel engines are identical to those of any other engine of the respective engine category as set out in this Part, except as set out in this clause 5.

5.2 The hydrocarbon (HC) limit for operation in dual-fuel mode shall be determined using the average gas energy ratio (GER) over the specified test cycle as set out in Appendix A.6 to Annex 4.

5.3 The technical requirements on emission control strategies, including documentation required to demonstrate these strategies, technical provisions to resist tampering and the prohibition of defeat devices are identical to those of any other engine of the respective engine category as set out in Annex 9.

5.4 The detailed technical requirements on the area associated with the relevant NRSC cycle, within which there is control of the amount that the emissions shall be permitted to exceed the limit values set out in Appendix 1 to clause 5 of this Part are identical to those of any other engine of the respective engine category as set out in this Annex 7.

6. DEMONSTRATION REQUIREMENTS

6.1. The demonstration requirements applicable to dual-fuel engines are identical to those of any other engine of the respective engine category as set out in this Part, except as set out in clause 6. of this Annex.

6.2. Compliance with the applicable limit values shall be demonstrated in dual-fuel mode.

6.3. For dual-fuel engine types with a liquid-fuel mode (i.e. types 1B, 2B, 3B) compliance with the applicable limit values shall additionally be demonstrated in liquid-fuel mode.

6.4. Additional demonstration requirements in case of a Type 2 engine

6.4.1 The manufacturer shall present the Test Agency with evidence showing that the GER_{cycle} span of all members of the dual-fuel engine family remains within the range specified in clause 2.4.15. of Annex 10 to this Part, or in the case of engines with an operator-adjustable GER_{cycle} satisfy the requirements of clause 6.5. (for example, through algorithms, functional analyses, calculations, simulations, results of previous tests, etc.).

6.5 Additional demonstration requirements in case of an engine with an operator-adjustable GER_{cycle}

6.5.1 Compliance with the applicable limit values shall be demonstrated at the minimum and maximum value of GER_{cycle} permitted by the manufacturer.

6.6. Requirements for demonstrating the durability of a dual-fuel engine

6.6.1 Provisions of Annex 8 shall apply.

6.7. Demonstration of the dual-fuel indicators, warning and operability restriction

6.7.1 As part of the application for type-approval under this Part, the manufacturer shall demonstrate the operation of dual-fuel indicators and of the warning and operability restriction in accordance with the provisions of Appendix A.1. to this Annex.

6.8 Documentation of the demonstration

A demonstration report shall document the demonstration conducted to comply with clause 6 of this Annex. The report shall:

(a) describe the demonstration performed, including the applicable test cycle;

(b) be included in the information folder as set out in Annex 1 of this Part.

7. REQUIREMENTS TO ENSURE THE CORRECT OPERATION OF NO_X CONTROL MEASURES

7.1. Annex 9 (on technical requirements on NO_X control measures) shall apply to dual-fuel engines, whether operating in dual-fuel or liquid mode.

7.2. Additional NO_X control requirements in case of Type 1B, Type 2B and Type 3B dual-fuel engines

7.2.1. The torque considered to apply to the severe inducement defined in clause A.1.5.4 of Appendix A.1 of Annex 9 shall be the lowest of the torques obtained in liquid-fuel mode and in dual-fuel mode.

7.2.2 A possible influence of the mode of operation on the malfunction detection shall not be used to extend the time until an inducement becomes active.

7.2.3. In the case of malfunctions the detection of which does not depend on the operation mode of the engine, the mechanisms specified in Annex 9 that are

associated with the DTC status shall not depend on the operation mode of the engine (for example, if a DTC reached the potential status in dual-fuel mode, it will get the confirmed and active status the next time the failure is detected, even in liquid-fuel mode).

7.2.4. In the case of malfunctions where the detection depends on the operation mode of the engine, DTCs shall not get a previously active status in a different mode than the mode in which they reached the confirmed and active status.

7.2.5. A change of the mode of operation (dual-fuel to liquid fuel or vice-versa) shall not stop nor reset the mechanisms implemented to comply with the specification of Annex 9 (counters, etc.). However, in the case where one of these mechanisms (for example a diagnostic system) depends on the actual operation mode the counter associated with that mechanism may, at the request of the manufacturer and upon approval of the Test Agency:

(a) Halt and, when applicable, hold their present value when the operation mode changes;

(b) Restart and, when applicable, continue counting from the point at which they have been held when the operation mode changes backs to the other operation mode.

ANNEX 7 - APPENDIX A.1

DUAL-FUEL ENGINE DUAL-FUEL INDICATOR, WARNING SYSTEM, OPERABILITY RESTRICTION - DEMONSTRATION REQUIREMENTS

A.1.1. DUAL-FUEL INDICATORS

A.1.1.1. Dual-fuel mode indicator

The ability of the engine to command the activation of the dual-fuel mode indicator when operating in dual-fuel mode shall be demonstrated at type-approval.

A.1.1.2. Liquid-fuel mode indicator

In the case of a Type 1B, Type 2B, or Type 3B dual-fuel engine the ability of the engine to command the activation of the liquid-fuel mode indicator when operating in liquid-fuel mode shall be demonstrated at type-approval.

A.1.1.3. Service mode indicator

The ability of the engine to command the activation of the service mode indicator when operating in service mode shall be demonstrated at type-approval.

A.1.1.3.1. When so-equipped it is sufficient to perform the demonstration related to the service mode indicator by activating a service mode activation switch and to present the Test Agency with evidence showing that the activation occurs when the service mode is commanded by the engine system itself (for example, through algorithms, simulations, result of in-house tests, etc. …).

A.1.2. WARNING SYSTEM

The ability of the engine to command the activation of the warning system in the case that the amount of gaseous fuel in the gaseous fuel tank is below the warning level, shall be demonstrated at type-approval. For that purpose the actual amount of gaseous fuel may be simulated.

A.1.3. OPERABILITY RESTRICTION

In the case of a Type 1A or Type 2A dual-fuel engine the ability of the engine to command the activation of the operability restriction upon detection of an empty gaseous fuel tank and of a malfunctioning gas supply system shall be demonstrated at type-approval. For that purpose the empty gaseous fuel tank and the malfunctioning of the gas supply may be simulated.

A.1.3.1. It is sufficient to perform the demonstration in a typical use-case selected with the agreement of the Test Agency and to present that Test Agency with evidence showing that the operability restriction occurs in the other possible use-cases (for example, through algorithms, simulations, result of in-house tests, etc).

ANNEX 7 - APPENDIX A.2

EMISSION TEST PROCEDURE REQUIREMENTS FOR DUAL-FUEL ENGINES

A.2.1. GENERAL

This Appendix defines the additional requirements and exceptions to enable emission testing of dual-fuel engines independent whether these emissions are solely exhaust emissions or also crankcase emissions added to the exhaust emissions according to clause 6.10. of Annex 4. In the case that no additional requirement or exception is listed, the requirements of this Part shall apply to dual-fuel engines in the same way as they apply to any other approved engine types or engine families.

Emission testing of a dual-fuel engine is complicated by the fact that the fuel used by the engine can vary between pure liquid fuel and a combination of mainly gaseous fuel with only a small amount of liquid fuel as an ignition source. The ratio between the fuels used by a dual-fuel engine can also change dynamically depending of the operating condition of the engine. As a result special precautions and restrictions are necessary to enable emission testing of these engines.

A.2.2. TEST CONDITIONS

Clause 6. of Annex 4 shall apply.

A.2.3. TEST PROCEDURES

Clause 7. of Annex 4 shall apply.

A.2.4. MEASUREMENT PROCEDURES

Clause 8. of Annex 4 shall apply except as set out in this Appendix.

A full-flow dilution measurement procedure for dual-fuel engines is illustrated in Figure A.4-5 of Annex 4 (CVS system).

This measurement procedure ensures that the variation of the fuel composition during the test will mainly influence the hydrocarbon measurement results. This shall be compensated via one of the methods described in clause A.2.7 of this Appendix.

Raw gaseous/partial flow measurement illustrated in Figure A.4-6 of Annex 4 may be used with some precautions regarding exhaust mass flow determination and calculation methods.

A.2.5. MEASUREMENT EQUIPMENT

Clause 9. of Annex 4 shall apply.

A.2.6. PARTICLE NUMBER EMISSIONS MEASUREMENT

Appendix A.1 of Annex 4 shall apply.

A.2.7. EMISSION CALCULATION

The emission calculation shall be performed according to Annex 5 except as set out in this clause. The additional requirements set out in clause A.2.7.1. shall apply for mass-based calculations and the additional requirements set out in clause A.2.7.2. shall apply for molar-based calculations.

The emission calculation requires knowledge of the composition of the fuels being used. When a gaseous fuel is supplied with a certificate confirming the properties of the fuel (e.g. gas from bottles) it is acceptable to use the composition specified by the supplier. Where the composition is not available (e.g. pipeline fuel) the fuel composition shall be analysed at least prior to and after the engine emission test is conducted. More frequent analysis shall be permitted and the results used in the calculation.

Where the gas energy ratio (GER) is used it shall be consistent with the definition in clause 2 of this Part and the specific provisions on hydrocarbon (HC) limits for fully and partially gaseous-fuelled engines in Appendix 1 to clause 5 of this Part. The average value of GER over the cycle shall be calculated by one of the following methods:

For hot-start transient cycle and RMC NRSC by dividing the sum of the GER at each measurement point by the number of measurement points;

For discrete-mode NRSC by multiplying the average GER for each test mode by the corresponding weighting factor for that mode and calculating the sum for all modes. The weighting factors shall be taken from Appendix A.6 of Annex 4 for the applicable cycle.

A.2.7.1. Mass-based emission calculation

Appendix A.1 of Annex 5 shall apply except as set out in this clause.

A.2.7.1.1. Dry/wet correction

A.2.7.1.1.1. Raw exhaust gas

Equations A.5-3 and A.5-4 of Appendix A.1 to Annex 5 shall be used to calculate the dry/wet correction.

The fuel specific parameters shall be determined in accordance with clause A.2.7.1.5..

A.2.7.1.1.2. Diluted exhaust gas

Equation (A.5-3) with either equation (A.5-25) or (A.5-26) of Appendix A.1 of Annex 5 shall be used to calculate the wet/dry correction.

The molar hydrogen ratio α of the combination of the two fuels shall be used for the dry/wet correction. This molar hydrogen ratio shall be calculated from the fuel consumption measurement values of both fuels in accordance with clause A.2.7.1.5..

A.2.7.1.2. NO_X correction for humidity

The NO_X humidity correction for compression ignition engines as specified in equation (A.5-9) of Appendix A.1 of Annex 5 shall be used.

A.2.7.1.3. Partial flow dilution (PFS) and raw gaseous measurement

A.2.7.1.3.1. Determination of exhaust gas mass flow

The exhaust mass flow shall be determined using a raw exhaust flowmeter as described in clause 9.4.5.3. of Annex 4.

Alternatively the airflow and air to fuel ratio measurement method according to equations (A.5-17) to (A.5-19) of Appendix A.1 of Annex 5 may be used only if α, γ, $\delta$and εvalues are determined according to clause A.2.7.1.5.3.. The use of a zirconia-type sensor to determine the air fuel ratio is not allowed.

In the case of testing engines subject to steady-state test cycles only the exhaust gas mass flow may be determined by the air and fuel measurement method in accordance with equation (A.5-15) of Appendix A.1 of Annex 5.

A.2.7.1.3.2. Determination of the gaseous components

Clause A.1.1. of Appendix A. 1 to Annex 5 shall apply except as set out in this paragraph.

The possible variation of fuel composition will influence all the u_{gas} factors and molar component ratios used in the emission calculations. One of the following approaches shall be used to determine u_{gas} factors and molar component ratios at the choice of the manufacturer.

(a) The exact equations in clause A.1.1.5.2. or A.1.2.3. of Appendix 1 to Annex 5 shall be applied to calculate instantaneous values of u_{gas} using the instantaneous proportions of liquid and gaseous fuel (determined from instantaneous fuel consumption measurements or calculations) and instantaneous molar component ratios determined in accordance with clause 2. 7.1.5. of this Appendix; or,

(b) When the mass-based calculation in Appendix A.1 of Annex 5 is used for the specific case of a dual-fuel engine operated on gas and diesel fuel, tabulated values may be used for the molar component ratios and u_{gas} values. These tabulated values shall be applied as follows:

i. For engines operated on the applicable test cycle with an average gas energy ratio greater than or equal to 90 per cent (GER ≥ 0.9) the required values shall be those for the gaseous fuel taken from Tables A.5-1 or A.5-2 of Annex 5.

ii. For engines operated on the applicable test cycle with an average gas energy ratio between 10 per cent and 90 per cent (0.1 < GER < 0.9) the required values shall be assumed to be represented by those for a mixture of 50 % gaseous fuel and 50 % diesel fuel taken from Tables A.7-1 and A.7-2 below.

iii. For engines operated on the applicable test cycle with an average gas energy ratio less than or equal to 10 per cent (GER ≤ 0.1) the required values shall be those for diesel fuel taken from taken from Tables A.5-1 or A.5-2 of Annex 5.

iv. For the calculation of HC emissions the u_{gas} value of the gaseous fuel shall be used in all cases irrespective of the average gas energy ratio (GER).

Table A.7-1.
Molar Component Ratios for a Mixture of 50 per cent Gaseous Fuel and 50 per cent Diesel Fuel (Mass per cent)

Gaseous fuel	α	γ	δ	ε
CH_4	2.8681	0	0	0.0040
G_R	2.7676	0	0	0.0040
G_{23}	2.7986	0	0.0703	0.0043
G_{25}	2.7377	0	0.1319	0.0045
Propane	2.2633	0	0	0.0039
Butane	2.1837	0	0	0.0038
LPG	2.1957	0	0	0.0038

Gaseous fuel	α	γ	δ	ε
LPG Fuel A	2.1740	0	0	0.0038
LPG Fuel B	2.2402	0	0	0.0039

A.2.7.1.3.2.1. Mass per test of a gaseous emission

In the case that the exact equations are applied to calculate instantaneous values of u_{gas} in accordance with clause A.2.7.1.3.2.(a) then, when calculating the mass per test of a gaseous emission for transient (NRTC and LSI-NRTC) test cycles and RMC, u_{gas} shall be included in the summation in equation (A.5-2) of clause A.1.1.2 of Appendix A.1 to Annex 5 by means of equation (A.7-1):

$$m_{gas} = \frac{1}{f} \cdot k_h \cdot k \cdot \sum_{i=1}^{N} \left(u_{gas,i} \cdot q_{mew,i} \cdot c_{gas,i} \right) \quad \text{(A.7-1)}$$

Where:

$u_{gas,i}$ is the instantaneous value of u_{gas}

The remaining terms of the equation are as set out in clause A.1.1.2 of Appendix A. 1 to Annex 5.

Table A.7-2

Raw Exhaust Gas u Gas Values and Component Densities for a Mixture of 50 per cent Gaseous Fuel and 50 per cent Diesel Fuel (Mass per cent)

Gaseous fuel	Gas						
	ρ_e	NO_X	CO	HC	CO_2	O_2	CH_4
		ρ_{gas} [kg/m³]					
		2.053	1.250	(a)	1.9636	1.4277	0.716
		u_{gas} (b)					
CNG/ LNG(c)	1.2786	0.001606	0.000978	0.000528 (c)	0.001536	0.001117	0.000560
Propane	1.2869	0.001596	0.000972	0.000510	0.001527	0.001110	0.000556
Butane	1.2883	0.001594	0.000971	0.000503	0.001525	0.001109	0.000556
LPG(e)	1.2881	0.001594	0.000971	0.000506	0.001525	0.001109	0.000556

(a) depending on fuel

(b) at λ = 2, dry air, 273 K, 101.3 kPa

(c) *u* accurate within 0.2 % for mass composition of: C = 58 - 76 per cent; H = 19 - 25 per cent; N = 0 - 14 per cent (CH_4, G_{20}, G_{23}, and G_{25})
(d) NMHC on the basis of $CH_{2.93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used)
(e) *u* accurate within 0.2 % for mass composition of: C_3 = 27 - 90 per cent; C4 = 10 - 73 per cent (LPG Fuels A and B)

A.2.7.1.3.3. Particulate determination

For the determination of particulate emissions with the partial dilution measurement method the calculation shall be performed according to the equations in clause A.1.3. of Appendix A. 1 to Annex 5.

The requirements of clause 8.2.1.2. of Annex 4 shall apply for controlling the dilution ratio. In particular, if the combined transformation time of the exhaust flow measurement and the partial flow system exceeds 0.3 s, look-ahead control based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s. Except in the case that the exhaust mass flow is measured directly the determination of exhaust mass flow shall use values of α, γ, $\delta$and εdetermined according to clause A.2.7.1.5.3..

The quality check according to clause 8.2.1.2. of Annex 4 shall be performed for each measurement.

A.2.7.1.3.4. Additional requirements regarding the exhaust gas mass flowmeter

The flowmeter referred to in clauses 9.4.5.3. and 9.4.5.4. of Annex 4 shall not be sensitive to the changes in exhaust gas composition and density. The small errors of e.g. pitot tube or orifice-type of measurement (equivalent with the square root of the exhaust density) may be neglected.

A.2.7.1.4. Full flow dilution measurement (CVS)

Clause A.1.2. of Appendix A. 1 to Annex 5 shall apply except as set out in this clause.

The possible variation of the fuel composition will mainly influence the tabulated hydrocarbon u_{gas} value. The exact equations shall be applied for the calculation of the hydrocarbon emissions using the molar component ratios determined from the fuel consumption measurements of both fuels according to clause A.2.7.1.5..

A.2.7.1.4.1. Determination of the background corrected concentrations

To determine the stoichiometric factor, the molar hydrogen ratio α of the fuel shall be calculated as the average molar hydrogen ratio of the fuel mix during the test according to clause A.2.7.1.5.3..

Alternatively the F_s value of the gaseous fuel may be used in equation (A.5-28) of Annex 5.

A.2.7.1.5. Determination of molar component ratios

A.2.7.1.5.1. General

This clause shall be used for the determination of molar component ratios when the fuel mix is known (exact method).

A.2.7.1.5.2. Calculation of the fuel mixture components

Equations (A.7-2) to (A.7-7) shall be used to calculate the elemental composition of the fuel mixture:

$$q_{mf} = q_{mf1} + q_{mf2} \quad \text{(A.7-2)}$$

$$w_{\mathrm{H}} = \frac{w_{\mathrm{H1}} \times q_{mf1} + w_{\mathrm{H2}} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad \text{(A.7-3)}$$

$$w_{\mathrm{C}} = \frac{w_{\mathrm{C1}} \times q_{mf1} + w_{\mathrm{C2}} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad \text{(A.7-4)}$$

$$w_{\mathrm{S}} = \frac{w_{\mathrm{S1}} \times q_{mf1} + w_{\mathrm{S2}} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad \text{(A.7-5)}$$

$$w_{\mathrm{N}} = \frac{w_{\mathrm{N1}} \times q_{mf1} + w_{\mathrm{N2}} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad \text{(A.7-6)}$$

$$w_{\mathrm{O}} = \frac{w_{\mathrm{O1}} \times q_{mf1} + w_{\mathrm{O2}} \times q_{mf2}}{q_{mf1} + q_{mf2}} \quad \text{(A.7-7)}$$

where:

q_{mf1} is the fuel mass flow rate of fuel 1, kg/s

q_{mf2} is the fuel mass flow rate of fuel 2, kg/s

w_{H} is the hydrogen content of fuel, per cent mass

w_{H} is the carbon content of fuel, per cent mass

w_{S} is the sulphur content of fuel, per cent mass

w_{N} is the nitrogen content of fuel, per cent mass

w_{O} is the oxygen content of fuel, per cent mass

A.2.7.1.5.3. Calculation of the molar ratios of H, C, S, N and O related to C for the fuel mixture

The calculation of the atomic ratios (especially the H/C-ratio α) is given in Annex 5 by means of equations (A.7-8) to (A.7-11):

$$\alpha = 11.9164 \cdot \frac{w_{\mathrm{H}}}{w_{\mathrm{C}}} \quad \text{(A.7-8)}$$

$$\gamma = 0.37464 \cdot \frac{w_{\mathrm{S}}}{w_{\mathrm{C}}} \quad \text{(A.7-9)}$$

$$\delta = 0.85752 \cdot \frac{w_{\mathrm{N}}}{w_{\mathrm{C}}} \quad \text{(A.7-10)}$$

$$\varepsilon = 0.75072 \cdot \frac{w_{\mathrm{O}}}{w_{\mathrm{C}}} \quad \text{(A.7-11)}$$

where:

w_{H} is the hydrogen content of fuel, mass fraction [g/g] or [per cent mass]

w_{C} is the carbon content of fuel, mass fraction [g/g] or [per cent mass]

w_S is the sulphur content of fuel, mass fraction [g/g] or [per cent mass]

w_N is the nitrogen content of fuel, mass fraction [g/g] or [per cent mass]

w_O is the oxygen content of fuel, mass fraction [g/g] or [per cent mass]

α is the molar hydrogen ratio (H/C)

γ is the molar sulphur ratio (S/C)

δ is the molar nitrogen ratio (N/C)

ε is the molar oxygen ratio (O/C)

referring to a fuel $CH\alpha O\varepsilon N\delta S\gamma$

A.2.7.2. Molar-based emission calculation

Annex 5 Appendix A.2 shall apply except as set out in this clause.

A.2.7.2.1. NO_X correction for humidity

Equation (A.5-102) of Appendix A.2 to Annex 5 (correction for compression ignition engines) shall be used.

A.2.7.2.2. Determination of exhaust gas mass flow when not using a raw exhaust flowmeter

Equation (A.5-112) of Appendix A.2 to Annex 5 (molar flow rate calculation based on intake air) shall be used. Equation (A.5-113) of Appendix A.2 to Annex 5 (molar flow rate calculation based on fuel mass flow rate) may alternatively be used only when conducting an NRSC test.

A.2.7.2.3. Molar component ratios for determination of the gaseous components

The exact approach shall be used to determine the molar component ratios using the instantaneous proportions of liquid and gaseous fuel determined from instantaneous fuel consumption measurements or calculations. The instantaneous molar component ratios shall be input in the equations (A.5-88), (A.5-90), and (A.5-91) of Appendix A.2 of Annex 5 for the continuous chemical balance.

The determination of the ratios shall be either performed according to clause A.2.7.2.3.1. or clause A.2.7.1.5.3..

Gaseous fuels, either blended or sourced from a land line, may contain significant amounts of inert constituents such as CO_2 and N_2. The manufacturer shall either include these constituents in the atomic ratio calculations described in clause A.2.7.2.3.1. or clause A.2.7.1.5.3. as applicable, or, alternatively, the manufacturer shall exclude the inert constituents from the atomic ratios and allocate them appropriately to the chemical balance intake air parameters x_{O2int}, x_{CO2int}, and x_{H2Oint} in clause A.2.4.3. of Appendix A.2 of Annex 5.

A.2.7.2.3.1. Determination of molar component ratios

Instantaneous molar component ratios of the number of hydrogen, oxygen, sulphur, and nitrogen atoms to carbons atoms in the mixed fuel for the dual-fuel engines may be calculated by means of equations (A.7-12) to (A.7-15):

$$\alpha(t) = \frac{\frac{\dot{m}_{liquid}(t)\times w_{H,liquid}}{M_H} + \frac{\dot{m}_{gas}(t)\times w_{H,gas}}{M_H}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C} + \frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}} = \frac{M_C\times[(\dot{m}_{liquid}(t)\times w_{H,liquid}) + (\dot{m}_{gas}(t)\times w_{H,gas})]}{M_H\times[(\dot{m}_{liquid}(t)\times w_{C,liquid}) + (\dot{m}_{gas}(t)\times w_{C,gas})]}$$

(A.7-12)

$$\beta(t) = \frac{\frac{\dot{m}_{liquid}(t)\times w_{O,liquid}}{M_O} + \frac{\dot{m}_{gas}(t)\times w_{O,gas}}{M_O}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C} + \frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}} = \frac{M_C\times[(\dot{m}_{liquid}(t)\times w_{O,liquid}) + (\dot{m}_{gas}(t)\times w_{O,gas})]}{M_O\times[(\dot{m}_{liquid}(t)\times w_{C,liquid}) + (\dot{m}_{gas}(t)\times w_{C,gas})]}$$

(A.7-13)

$$\gamma(t) = \frac{\frac{\dot{m}_{liquid}(t)\times w_{S,liquid}}{M_S} + \frac{\dot{m}_{gas}(t)\times w_{S,gas}}{M_S}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C} + \frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}} = \frac{M_C\times[(\dot{m}_{liquid}(t)\times w_{S,liquid}) + (\dot{m}_{gas}(t)\times w_{S,gas})]}{M_S\times[(\dot{m}_{liquid}(t)\times w_{C,liquid}) + (\dot{m}_{gas}(t)\times w_{C,gas})]}$$

(A.7-14)

$$\delta(t) = \frac{\frac{\dot{m}_{liquid}(t)\times w_{N,liquid}}{M_N} + \frac{\dot{m}_{gas}(t)\times w_{N,gas}}{M_N}}{\frac{\dot{m}_{liquid}(t)\times w_{C,liquid}}{M_C} + \frac{\dot{m}_{gas}(t)\times w_{C,gas}}{M_C}} = \frac{M_C\times[(\dot{m}_{liquid}(t)\times w_{N,liquid}) + (\dot{m}_{gas}(t)\times w_{N,gas})]}{M_N\times[(\dot{m}_{liquid}(t)\times w_{C,liquid}) + (\dot{m}_{gas}(t)\times w_{C,gas})]}$$

(A.7-15)

Where:

$w_{i,fuel}$ =the mass fraction of the element of interest, C, H, O, S, or N, of liquid or gaseous fuel;

$\dot{m}_{liquid}(t)$ = the instantaneous mass flow rate of the liquid fuel at time t,[kg/hr];

$\dot{m}_{gas}(t)$ = the instantaneous mass flow rate of the gaseous fuel at time t,[kg/hr];

In cases where exhaust mass flow rate is calculated based on the mixed fuel rate then w_C in equation (A.5-113) of Appendix A.2 to Annex 5 shall be calculated by means of equation (A.7-16):

$$w_C = \frac{\dot{m}_{liquid}\times w_{C,liquid} + \dot{m}_{gas}\times w_{C,gas}}{\dot{m}_{liquid} + \dot{m}_{gas}} \quad \text{(A.7-16)}$$

Where:

w_C = the mass fraction of the carbon in the diesel or gaseous fuel;

$\dot{m}_{liquid}$ = the mass flow rate of the liquid fuel, [kg/hr];

$\dot{m}_{gas}$ = the mass flow rate of the gaseous fuel, [kg/hr].

A.2.7.3. CO_2 determination

Annex 5 shall apply except when the engine is tested on a transient or ramped modal cycle (RMC) using raw gas sampling.

A.2.7.3.1. CO_2 determination when testing on atransient or ramped modal cycle (RMC) using raw gas sampling

Calculation of CO_2 emissions from measurement of CO_2 in the exhaust gas in accordance with Annex 5 shall not apply. Instead the following provisions shall apply:

The measured test-averaged fuel consumption shall be determined from the sum of the instantaneous values over the cycle and shall be used as the base for calculating the test averaged CO_2 emissions.

The mass of each fuel consumed shall be used to determine, in accordance with clause A.2.7.1.5, the molar hydrogen ratio and the mass fractions of the fuel mix in the test.

The total corrected fuel mass of both fuels $m_{fuel,corr}$[g/test] and CO_2 mass emission coming from the fuel $m_{CO2,\ fuel}$ [g/test] shall be determined by means of equations (A.7-17) and (A.7-18).

$$m_{\text{fuel,corr}} = m_{\text{fuel}} - (m_{\text{THC}} + \frac{A_C + a * A_H}{M_{CO}} x m_{CO} + \frac{W_{GAM} + W_{DEL} + W_{EPS}}{100} * m_{\text{fuel}}) \quad \text{(A.7-17)}$$

$$m_{CO_2,\text{fuel}} = \frac{M_{CO_2}}{A_C + a * A_H} * m_{\text{fuel,corr}} \quad \text{(A.7-18)}$$

Where:

m_{fuel} = total fuel mass of both fuels [g/test]

m_{THC} = mass of total hydrocarbon emissions in the exhaust gas [g/test]

m_{CO} = mass of carbon monoxide emissions in the exhaust gas [g/test]

w_{GAM} = sulphur content of the fuels [per cent mass]

w_{DEL} = nitrogen content of the fuels [per cent mass]

w_{EPS} = is the oxygen content of the fuels [per cent mass]

α = is the molar hydrogen ratio of the fuels (H/C) [-]

A_C = is the atomic mass of Carbon: 12.011 [g/mol]

A_H = is the atomic mass of Hydrogen: 1.0079 [g/mol]

M_{CO} = is the molecular mass of Carbon monoxide: 28.011 [g/mol]

M_{CO2} = is the molecular mass of Carbon dioxide: 44.01 [g/mol]

The CO_2 emission resulting from urea $m_{CO2,urea}$ [g/test] shall be calculated by means of equation (A.7-19):

$$m_{CO2,\text{urea}} = \frac{c_{\text{urea}}}{100} \times \frac{M_{CO_2}}{M_{CO(NH_2)_2}} \times m_{\text{urea}} \quad \text{(A.7-19)}$$

Where:

c_{urea} = urea concentration [per cent]

m_{urea} = total urea mass consumption [g/test]

$M_{CO(NH2)2}$ = Molecular mass of urea: 60.056 [g/mol]

Then the total CO_2 emission m_{CO2} [g/test] shall be calculated by means of equation (A.7-20):

$$m_{CO2} = m_{CO2,fuel} + m_{CO2,urea} \quad \text{(A.7-20)}$$

The total CO_2 emission calculated by means of equation (A.7-20) shall be used in the calculation of brake specific CO_2 emissions, e_{CO2} [g/kWh] in clause A.1.4.1.1 of Appendix A.1 or clause A.2.8.1.1 of Appendix A.2, both of Annex 5. Where applicable, the correction for CO_2 in the exhaust arising from CO_2 in the gaseous fuel shall be performed in accordance with Appendix A.3 to Annex 6.

ANNEX 7 - APPENDIX A.3

TYPES OF DUAL-FUEL ENGINES OPERATED ON NATURAL GAS/ BIOMETHANE OR LPG AND A LIQUID FUEL – ILLUSTRATION OF THE DEFINITIONS AND MAIN REQUIREMENTS

Dual-fuel type	GER_{cycle}	Idle on liquid fuel	Warm-up on liquid fuel	Operation on liquid fuel solely	Operation in absence of gas	Comments
1A	$GER_{NRTC,\ hot} \geq 0.9$ or $GER_{NRSC,} \geq 0.9$	NOT allowed	Allowed only on service mode	Allowed only on service mode	Service mode	
1B	$GER_{NRTC,\ hot} \geq 0.9$ or $GER_{NRSC} \geq 0.9$	Allowed only on liquid-fuel mode	Allowed only on liquid-fuel mode	Allowed only on liquid-fuel and service modes	Liquid-fuel mode	
2A	$0.1 < GER_{NRTC,\ hot} < 0.9$ or $0.1 < GER_{NRSC} < 0.9$	Allowed	Allowed only on service mode	Allowed only on service mode	Service mode	$GER_{NRTC,\ hot} \geq 0.9$ or $GER_{NRSC} \geq 0.9$ allowed
2B	$0.1 < GER_{NRTC,\ hot} < 0.9$ or $0.1 < GER_{NRSC} < 0.9$	Allowed	Allowed	Allowed	Liquid-fuel mode	$GER_{NRTC,\ hot} \geq 0.9$ or $GER_{NRSC} \geq 0.9$ allowed
3A	Neither defined nor allowed					
3B	$GER_{NRTC,\ hot} \leq 0.1$ or $GER_{NRSC} \leq 0.1$	Allowed	Allowed	Allowed	Liquid-fuel mode	

ANNEX 8

METHODOLOGY FOR ADAPTING THE EMISSION LABORATORY TEST RESULTS TO INCLUDE THE DETERIORATION FACTORS

1. DEFINITIONS

For the purposes of this Annex, the following definitions apply:

1.1. "Ageing cycle" means the agricultural tractor, construction equipment vehicle or combine harvester or engine operation (speed, load, power) to be executed during the service accumulation period.

1.2. "Critical emission-related components" means the exhaust after- treatment system, the electronic engine control unit and its associated sensors and actuators, and the EGR system including all related filters, coolers, control valves and tubing.

1.3. "Critical emission-related maintenance" means the maintenance to be performed on critical emission-related components of the engine.

1.4. "Emission-related maintenance" means the maintenance which substantially affects emissions or which is likely to affect emissions performance of the agricultural tractor, construction equipment vehicle or combine harvester or the engine during normal in-use operation.

1.5. "Engine-after-treatment system family" means a manufacturer's grouping of engines that comply with the definition of engine family, but which are further grouped into a family of engine families utilising a similar exhaust after-treatment system.

1.6. "Non-emission-related maintenance" means maintenance which does not substantially affect emissions and which does not have a lasting effect on the emissions performance deterioration of the agricultural tractor, construction equipment vehicle or combine harvester or the engine during normal in-use operation once the maintenance is performed.

1.7. "Service accumulation schedule" means the ageing cycle and the service accumulation period for determining the deterioration factors for the engine-after-treatment system family.

2. GENERAL

2.1. This Annex details the procedures for selecting engines to be tested over a service accumulation schedule for the purpose of determining deterioration factors for engine type approval and conformity of production assessments. The deterioration factors shall be applied to the emissions measured in accordance with Annex 4 and calculated in accordance with Annex 5 in accordance with the procedure set out in clause 3.2.7. or clause 4.3. of this Annex, respectively.

2.2. The service accumulation tests or the emissions tests performed to determine deterioration need not be witnessed by the Test Agency.

2.3. This Annex also details the emission-related and non-emission-related maintenance that should be or may be carried out on engines undergoing a service accumulation schedule. Such maintenance shall conform to the maintenance performed on in-service engines and communicated to the end-users of new engines.

3. ENGINE CATEGORIES NRE

3.1. Selection of engines for establishing emission durability period deterioration factors

3.1.1. Engines shall be selected from the engine family defined in clause 2 of Annex 10 to establish emission durability period deterioration factors.

3.1.2. Engines from different engine families may be further combined into families based on the type of exhaust after-treatment system utilised , or where no after-treatment is used, based upon the similarity of the technical characteristics of the emission control system. Engines of different bore and stroke, different configuration, different air management systems, different fuel systems may be considered as equivalent in respect to emissions deterioration characteristics if the manufacturer provides data to the Test Agency that there is a reasonable technical basis for such determination. In order to place engine families having similar technical specifications and installation for the exhaust after-treatment systems into the same engine after-treatment system family, the manufacturer shall provide data to the Test Agency that demonstrates that the emissions reduction performance of such engines is similar.

3.1.3. The test engine shall represent the emission deterioration characteristics of the engine families that will apply the resulting deterioration factors for type approval. The engine manufacturer shall select one engine representing the engine family, group of engine families or engine-after-treatment system family, as determined in accordance with clause 3.1.2. of this Annex, for testing over the service accumulation schedule referred to in clause 3.2.2. of this Annex, which shall be reported to the Test Agency before any testing commences.

3.1.4. If the Test Agency decides that the worst case emissions of the engine family, group of engine families or engine-after-treatment system family can be better characterised by another test engine, the test engine to be used shall be selected jointly by the Test Agency and the engine manufacturer.

3.2. Determination of emission durability period deterioration factors

3.2.1. General

Deterioration factors applicable to an engine family, group of engine families or engine-after-treatment system family shall be developed from the selected engines based on a service accumulation schedule that includes periodic testing for gaseous and particulate emissions over each test cycle applicable to the engine category, as given in Appendix 2 to clause 5 to this Part . In the case of the NRTC, only the hot-start cycle shall be used.

3.2.1.1. At the request of the manufacturer, the Test Agency may allow the use of deterioration factors that have been established using alternative procedures to those specified in clauses 3.2.2. to 3.2.5. of this Annex. In that case, the manufacturer shall demonstrate to the satisfaction of the Test Agency that the alternative procedures used are not less rigorous than those set out in clauses 3.2.2. to 3.2.5. of this Annex.

3.2.2. Service accumulation schedule

Service accumulation schedules may be carried out at the choice of the manufacturer by running a agricultural tractor, construction equipment vehicle or combine harvester equipped with the selected engine over an "in-service" accumulation schedule or by running the selected engine over a "dynamometer

service" accumulation schedule. The manufacturer shall not be required to use reference fuel for the service accumulation in-between emission measurement test points.

3.2.2.1. In-service and dynamometer service accumulation

3.2.2.1.1. The manufacturer shall determine the form and duration of the service accumulation and the ageing cycle for engines in a manner consistent with good engineering judgment.

3.2.2.1.2. The manufacturer shall determine the test points where gaseous and particulate emissions will be measured over the applicable cycles, as follows:

3.2.2.1.2.1. When running a service accumulation schedule shorter than the emission durability period in accordance with clause 3.2.2.1.7. of this Annex, the minimum number of test points shall be three, one at the beginning, one approximately in the middle and one at the end of the service accumulation schedule.

3.2.2.1.2.2. When completing the service accumulation up to the end of the emission durability period, the minimum number of test points shall be two, one at the beginning and one at the end of the service accumulation.

3.2.2.1.2.3. The manufacturer may additionally test at evenly spaced intermediate points.

3.2.2.1.3. The emission values at the start point and at the emission durability period endpoint either calculated in accordance with clause 3.2.5.1. of this Annex or measured directly in accordance with clause 3.2.2.1.2.2. of this Annex, shall be within the limit values applicable to the engine family. However individual emission results from the intermediate test points may exceed those limit values.

3.2.2.1.4. For engine categories or sub-categories to which a transient cycle applies, the manufacturer may request the agreement of the Test Agency to run only one test cycle (either the hot NRTC or LSI-NRTC, as applicable, or NRSC cycle) at each test point, and to run the other test cycle only at the beginning and at the end of the service accumulation schedule.

3.2.2.1.5. In the case of engine categories or sub-categories for which there is no applicable non-road transient cycle set out in Appendix A.6 to Annex 4, only the NRSC cycle shall be run at each test point.

3.2.2.1.6. Service accumulation schedules may be different for different engine-after-treatment system families.

3.2.2.1.7. Service accumulation schedules may be shorter than the emission durability period, but shall not be shorter than the equivalent of at least one quarter of the relevant emission durability period specified in Appendix 2 to clause 5 of this Part.

3.2.2.1.8. Accelerated ageing by adjusting the service accumulation schedule on a fuel consumption basis is permitted. The adjustment shall be based on the ratio between the typical in-use fuel consumption and the fuel consumption on the ageing cycle, but fuel consumption on the ageing cycle shall not exceed typical in-use fuel consumption by more than 30 per cent.

3.2.2.1.9. At the request of the manufacturer and with the agreement of the Test Agency, alternative methods of accelerated ageing may be permitted.

3.2.2.1.10. The service accumulation schedule shall be fully described in the application for type-approval and reported to the Test Agency before the start of any testing.

3.2.2.2. If the Test Agency decides that additional measurements need to be performed between the points selected by the manufacturer it shall notify the manufacturer. The revised service accumulation schedule shall be prepared by the manufacturer and agreed by the Test Agency.

3.2.3. Engine testing

3.2.3.1. Engine stabilisation

3.2.3.1.1. For each engine-after-treatment system family, the manufacturer shall determine the number of hours of agricultural tractor, construction equipment vehicle or combine harvester or engine running after which the operation of the engine-after-treatment system has stabilised. If requested by the Test Agency the manufacturer shall make available the data and analysis used to make this determination. As an alternative, the manufacturer may run the engine or agricultural tractor, construction equipment vehicle or combine harvester between 60 and 125 hours or the equivalent time on the ageing cycle to stabilise the engine-after-treatment system.

3.2.3.1.2. The end of the stabilisation period determined in clause 3.2.3.1.1. of this Annex shall be deemed to be the start of the service accumulation schedule.

3.2.3.2. Service accumulation testing

3.2.3.2.1. After stabilisation, the engine shall be run over the service accumulation schedule selected by the manufacturer, as described in clause 3.2.2. of this Annex. At the periodic intervals in the service accumulation schedule determined by the manufacturer, and, where applicable, decided by the Test Agency in accordance with clause 3.2.2.2. of this Annex, the engine shall be tested for gaseous and particulate emissions over the hot NRTC and NRSC cycles, or LSI-NRTC and NRSC cycles applicable to the engine category, as set out in Appendix 2 to clause 5.

The manufacturer may select to measure the pollutant emissions before any exhaust after-treatment system separately from the pollutant emissions after any exhaust after-treatment system.

In accordance with clause 2.2.1.4. of this Annex, if it has been agreed that only one test cycle (hot NRTC, LSI-NRTC or NRSC) be run at each test point, the other test cycle (hot NRTC, LSI-NRTC or NRSC) shall be run at the beginning and at the end of the service accumulation schedule.

In accordance with clause 3.2.2.1.5. of this Annex, in the case of engine categories or sub-categories for which there is no applicable non-road transient cycle given in Appendix A.6 to Annex 4, only the NRSC cycle shall be run at each test point.

3.2.3.2.2. During the service accumulation schedule, maintenance shall be carried out on the engine in accordance with clause 3.4. of this Annex.

3.2.3.2.3. During the service accumulation schedule, unscheduled maintenance on the engine or agricultural tractor, construction equipment vehicle or combine harvester may be performed, for example if the manufacturer's normal diagnostic system has detected a problem that would have indicated to the agricultural tractor, construction equipment vehicle or combine harvester operator that a fault had arisen.

3.2.4. Reporting

3.2.4.1. The results of all emission tests (hot NRTC, LSI-NRTC and NRSC) conducted during the service accumulation schedule shall be made available to the Test Agency. If an emission test is declared to be void, the manufacturer shall provide reasons why the test has been declared void. In such a case, another series of emission tests shall be carried out within the following 100 hours of service accumulation.

3.2.4.2. The manufacturer shall retain records of all information concerning all the emission tests and maintenance carried out on the engine during the service accumulation schedule. This information shall be submitted to the Test Agency along with the results of the emission tests conducted over the service accumulation schedule.

3.2.5. Determination of deterioration factors

3.2.5.1. When running a service accumulation schedule in accordance with clause 3.2.2.1.2.1. or clause 3.2.2.1.2.3. of this Annex, for each pollutant measured over the hot NRTC, LSI-NRTC and NRSC cycles at each test point during the service accumulation schedule, a "best fit" linear regression analysis shall be made on the basis of all test results. The results of each test for each pollutant shall be expressed to the same number of decimal places as the limit value for that pollutant, as applicable to the engine family, plus one additional decimal place.

Where in accordance with clause 3.2.2.1.4. or clause 3.2.2.1.5. of this Annex, only one test cycle (hot NRTC, LSI-NRTC or NRSC) has been run at each test point, the regression analysis shall be made only on the basis of the test results from the test cycle run at each test point.

The manufacturer may request the prior approval of the Test Agency for a non-linear regression.

3.2.5.2. The emission values for each pollutant at the start of the service accumulation schedule and at the emission durability period end point that is applicable for the engine under test shall be either:

(a) determined by extrapolation of the regression equation in clause 3.2.5.1. of this Annex, when running a service accumulation schedule in accordance with clause 3.2.2.1.2.1. or clause 3.2.2.1.2.3. of this Annex, or

(b) measured directly, when running a service accumulation schedule in accordance with clause 3.2.2.1.2.2. of this Annex.

Where emission values are used for engine families in the same engine-after-treatment family or group of engine families but with different emission durability periods, then the emission values at the emission durability period end point shall be recalculated for each emission durability period by extrapolation or interpolation of the regression equation as determined in clause 3.2.5.1. of this Annex.

3.2.5.3. The deterioration factor (DF) for each pollutant is defined as the ratio of the applied emission values at the emission durability period end point and at the start of the service accumulation schedule (multiplicative deterioration factor).

The manufacturer may request the prior approval of the Test Agency for the application of an additive DF for each pollutant may be applied. The additive DF is defined as the difference between the calculated emission values at the

emission durability period end point and at the start of the service accumulation schedule.

An example for determination of DFs by using linear regression is shown in Figure A.8-1. for NO_X emission.

Mixing of multiplicative and additive DFs within one set of pollutants is not permitted.

If the calculation results in a value of less than 1.00 for a multiplicative DF, or less than 0.00 for an additive DF, then the deterioration factor shall be 1.0 or 0.00, respectively.

In accordance with clause 3.2.2.1.4. of this Annex, if it has been agreed that only one test cycle (hot NRTC, LSI-NRTC or NRSC) be run at each test point and the other test cycle (hot NRTC, LSI-NRTC or NRSC) run only at the beginning and end of the service accumulation schedule, the deterioration factor calculated for the test cycle that has been run at each test point shall be applicable also for the other test cycle.

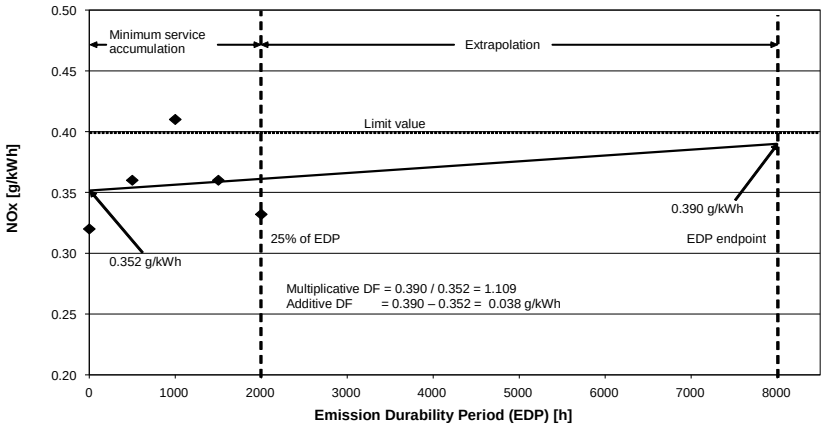


Figure A.8-1.

Example of DF Determination

3.2.6. Assigned deterioration factors

3.2.6.1. As an alternative to using a service accumulation schedule to determine DFs, engine manufacturers may select to use assigned multiplicative DFs, as given in Table A.8-1..

Table A.8-1.

Assigned Deterioration Factors

Test cycle	CO	HC	NO_X	PM	PN
NRTC and LSI-NRTC	1.3	1.3	1.15	1.05	1.0
NRSC	1.3	1.3	1.15	1.05	1.0

Assigned additive DFs shall not be given. The assigned multiplicative DFs shall not be transformed into additive DFs.

3.2.6.1.1. Nothwithstanding clause 3.2.6.1. of this Annex, for PN, either an additive DF of 0.0 or a multiplicative DF of 1.0 may be used, in conjunction with the results of previous DF testing that did not establish a value for PN if both of the following conditions are fulfilled:

(a) the previous DF test was conducted on engine technology that would have qualified for inclusion in the same engine after-treatment system family, as set out in clause 3.1.2. of this Annex, as the engine family to which it is intended to apply the DFs; and,

(b) the test results were used in a previous type approval granted before the official date of entry into force of this Part

3.2.6.2. Where assigned DFs are used, the manufacturer shall present to the Test Agency robust evidence that the emission control components can reasonably be expected to have the emission durability associated with those assigned factors. This evidence may be based upon design analysis, or tests, or a combination of both.

3.2.7. Application of deterioration factors

3.2.7.1. The engines shall meet the respective emission limits for each pollutant, as applicable to the engine family, after application of the deterioration factors to the test result as measured in accordance with Annex 4 (cycle-weighted specific emission for particulate and each individual gas). Depending on the type of DF, the following provisions apply:

(a) Multiplicative: (cycle weighted specific emission) * DF ≤ emission limit

(b) Additive: (cycle weighted specific emission) + DF ≤ emission limit

Cycle weighted specific emission may include the adjustment for infrequent regeneration, where applicable.

3.2.7.2. For a multiplicative NO_X + HC DF, separate HC and NO_X DFs shall be determined and applied separately when calculating the deteriorated emission levels from an emissions test result before combining the resultant deteriorated NO_X and HC values to establish compliance with the emission limit.

3.2.7.3. The manufacturer may carry across the DFs determined for an engine-after-treatment system family to an engine that does not fall into the same engine-after-treatment system family. In such cases, the manufacturer shall demonstrate to the Test Agency that the engine for which the engine-after-treatment system family was originally tested and the engine for which the DFs are being carried across have similar technical specifications and installation

requirements on the agricultural tractor, construction equipment vehicle or combine harvester and that the emissions of such engine are similar.

Where DFs are carried across to an engine with a different emission durability period, the DFs shall be recalculated for the applicable emission durability period by extrapolation or interpolation of the regression equation as determined in clause 3.2.5.1. of this Annex.

3.2.7.4. The DF for each pollutant for each applicable test cycle shall be recorded in the test report set out in Appendix A.1 to Annex 2.

3.3. Checking of conformity of production

3.3.1. Conformity of production for emissions compliance is checked on the basis of clause 8 of this Part.

3.3.2. The manufacturer may measure the pollutant emissions before any exhaust after-treatment system at the same time as the type-approval test is being performed. For that purpose, the manufacturer may develop informal DFs separately for the engine without after-treatment system and for the after-treatment system that may be used by the manufacturer as an aid to end of production line auditing.

3.3.3. For the purposes of approval, only the DFs determined in accordance with clause 3.2.5. or 3.2.6. of this Annex shall be recorded in the test report set out in Appendix A.1 to Annex 2.

3.4. Maintenance

For the purpose of the service accumulation schedule, maintenance shall be performed in accordance with the manufacturer's manual for service and maintenance.

3.4.1. Scheduled emission-related maintenance

3.4.1.1. Scheduled emission-related maintenance during engine running, undertaken for the purpose of conducting a service accumulation schedule, shall occur at equivalent intervals to those that are specified in the manufacturer's maintenance instructions to the end-user of the agricultural tractor, construction equipment vehicle or combine harvester or engine. This schedule maintenance may be updated as necessary throughout the service accumulation schedule provided that no maintenance operation is deleted from the maintenance schedule after the operation has been performed on the test engine.

3.4.1.2. Any adjustment, disassembly, cleaning or exchange of critical emission-related components which is performed on a periodic basis within the emission durability period to prevent malfunction of the engine, shall only be done to the extent that is technologically necessary to ensure proper functioning of the emission control system. The need for scheduled exchange, within the service accumulation schedule and after a certain running time of the engine, of critical emission-related components other than those qualifying as routine exchange items shall be avoided. In this context, consumable maintenance items for regular renewal or items that require cleaning after a certain running time of the engine, shall qualify as routine exchange items.

3.4.1.3. Any scheduled maintenance requirements shall be subject to approval by the Test Agency before type-approval is granted and shall be included in the “owner’s manual“ and “service station manual “. The Test Agency shall not refuse to approve maintenance requirements that are reasonable and

technically necessary, including but not limited to those identified in clause 3.4.1.4. of this Annex.

3.4.1.4. The engine manufacturer shall specify for the service accumulation schedules any adjustment, cleaning, maintenance (where necessary) and scheduled exchange of the following items:

- filters and coolers in the exhaust gas re-circulation system
- positive crankcase ventilation valve, if applicable
- fuel injector tips (only cleaning is permitted)
- fuel injectors
- turbocharger
- electronic engine control unit and its associated sensors and actuators
- particulate after-treatment system (including related components)
- NO_X after-treatment system (including related components)
- exhaust gas re-circulation system, including all related control valves and tubing
- any other exhaust after-treatment system.

3.4.1.5. Scheduled critical emission-related maintenance shall only be performed if it is required to be performed in-use and that requirement is communicated to the end-user of the engine or agricultural tractor, construction equipment vehicle or combine harvester.

3.4.2. Changes to scheduled maintenance

The manufacturer shall submit a request to the Test Agency for approval of any new scheduled maintenance that it wishes to perform during the service accumulation schedule and subsequently to recommend to end-users of agricultural tractor, construction equipment vehicle or combine harvester and engines. The request shall be accompanied by data supporting the need for the new scheduled maintenance and the maintenance interval.

3.4.3. Non-emission-related scheduled maintenance

Non-emission-related scheduled maintenance which is reasonable and technically necessary (for example oil change, oil filter change, fuel filter change, air filter change, cooling system maintenance, idle speed adjustment, governor, engine bolt torque, valve lash, injector lash, adjustment of the tension of any drive-belt, etc.) may be performed on engines or agricultural tractor, construction equipment vehicle or combine harvester selected for the service accumulation schedule at the least frequent intervals recommended by the manufacturer to the end-user (for example not at the intervals recommended for severe service).

3.5. Repair

3.5.1. Repairs to the components of an engine selected for testing over a service accumulation schedule shall be performed only as a result of component failure or engine malfunction. Repair of the engine itself, the emission control system or the fuel system is not permitted except to the extent defined in clause 3.5.2. of this Annex.

3.5.2. If the engine, its emission control system or its fuel system fails during the service accumulation schedule, the service accumulation shall be considered void, and a new service accumulation shall be started with a new engine.

The previous clause shall not apply when the failed components are replaced with equivalent components that have been subject to a similar number of hours of service accumulation.

ANNEX 9

REQUIREMENTS WITH REGARD TO EMISSION CONTROL STRATEGIES, NO_X CONTROL MEASURES AND PARTICULATE CONTROL MEASURES

1. DEFINITIONS ABBREVIATIONS AND GENERAL REQUIREMENTS

1.1. For the purposes of this Annex, the following definitions and abbreviations apply:

(a) "diagnostic trouble code ("DTC")" means a numeric or alphanumeric identifier which identifies or labels a NCM and/ PCM;

(b) "confirmed and active DTC" means a DTC that is stored during the time the NCD and/or PCD system concludes that a malfunction exists;

(c) "NCD engine family" means a manufacturer's grouping of engines having common methods of monitoring/diagnosing NCMs;

(d) "NO_X Control Diagnostic system (NCD)" means a system on-board the engine which has the capability of

(i) detecting a NO_X Control Malfunction,

(ii) identifying the likely cause of NO_X control malfunctions by means of information stored in computer memory and/or communicating that information off-board;

(e) "NO_X Control Malfunction (NCM)" means an attempt to tamper with the NO_X control system of an engine or a malfunction affecting that system that might be due to tampering, that is considered by this Part as requiring the activation of a warning or an inducement system once detected;

(f) “Particulate Control Diagnostic system (PCD)” means a system on-board the engine which has a capability of:

(i) detecting a Particulate Control Malfunction,

(ii) identifying the likely cause of particulate control malfunctions by means of information stored in computer memory and/or communicating that information off-board;

(g) "Particulate Control Malfunction (PCM)" means an attempt to tamper with the particulate after-treatment system of an engine or a malfunction affecting the particulate after-treatment system that might be due to tampering, that is considered by this Part as requiring the activation of a warning once detected;

(h) “PCD engine family” means a manufacturer’s grouping of engines having common methods of monitoring/diagnosing PCMs;

(i) "Scan-tool" means an external test equipment used for off-board communication with the NCD and/or PCD system.

1.2. Ambient temperature

Where reference is made to ambient temperature in relation to environments other than a laboratory environment, the following provisions shall apply:

1.2.1. For an engine installed in a test-bed, ambient temperature shall be the temperature of the combustion air supplied to the engine, upstream of any part of the engine being tested.

1.2.2. For an engine installed in agricultural tractor, construction equipment vehicle or combine harvester, ambient temperature shall be the air temperature immediately outside the perimeter of the agricultural tractor, construction equipment vehicle or combine harvester.

2. TECHNICAL REQUIREMENTS RELATING TO EMISSION CONTROL STRATEGIES

2.1. This clause 2. shall apply for electronically controlled engines of categories NRE, , complying with the emission limits set out in Appendix 1 to clause 5 of this Part and using electronic control to determine both the quantity and timing of injecting fuel or using electronic control to activate, de-activate or modulate the emission control system used to reduce NO_X.

2.2. Requirements for base emission control strategy

2.2.1 The base emission control strategy shall be designed as to enable the engine, in normal use, to comply with the provisions of this Part. Normal use is not restricted to the control conditions as specified in clause 4.

2.2.2. Base emission control strategies are, but not limited to, maps or algorithms for controlling:

(a) timing of fuel injection or ignition (engine timing);

(b) exhaust gas recirculation (EGR);

(c) SCR catalyst reagent dosing.

2.2.3. Any base emission control strategy that can distinguish engine operation between a standardised approval test and other operating conditions and subsequently reduce the level of emission control when not operating under conditions substantially included in the approval procedure is prohibited.

2.2.3.1. Notwithstanding clause 2.2.3. of this Annex, in the case of engine (sub-) categories that are not subject to a non-road transient test cycle at type-approval the base emission control strategy may distinguish transient operating conditions and apply the corresponding emission control strategy. In this case transient operation shall be included in the overview of the base emission control strategy required by clause 1.4. of Appendix A.1 of Annex 1 and in the confidential information on emission control strategy set out in Appendix A.2 to Annex 1.

2.2.4 The manufacturer shall demonstrate to the Test Agency at the time of the type-approval test that the operation of the base emission control strategy complies with the provisions of this section. The demonstration shall consist of an evaluation of the documentation referred to in clause 2.6. of this Annex.

2.3. Requirements for auxiliary emission control strategy

2.3.1 An auxiliary emission control strategy may be activated by an engine or agricultural tractor, construction equipment vehicle or combine harvester, provided that the auxiliary emission control strategy:

2.3.1.1. Does not permanently reduce the effectiveness of the emission control system;

2.3.1.2. Operates only outside the control conditions specified in clauses 2.4.1., 2.4.2. or 2.4.3. of this Annex for the purposes defined in clause 2.3.5. of this Annex and only as long as is needed for those purposes, except as permitted by clauses 2.3.1.3., 2.3.2. and 2.3.4. of this Annex;

2.3.1.3. is activated only exceptionally within the control conditions in clauses 2.4.1., 2.4.2. or 2.4.3. of this Annex, respectively, has been demonstrated to be necessary for the purposes identified in clause 2.3.5. of this Annex has been approved by the Test Agency, and is not activated for longer than is needed for those purposes;

2.3.1.4. ensures a level of performance of the emission control system that is as close as possible to that provided by the base emission control strategy.

2.3.2. Where the auxiliary emission control strategy is activated during the type-approval test, activation shall not be limited to occur outside the control conditions set out in clause 2.4. of this Annex, and the purpose shall not be limited to the criteria set out in clause 2.3.5. of this Annex.

2.3.3. Where the auxiliary emission control strategy is not activated during the type-approval test, it must be demonstrated that the auxiliary emission control strategy is active only for as long as required for the purposes set out in clause 2.3.5. of this Annex.

2.3.4. Cold temperature operation

An auxiliary emission control strategy may be activated on an engine equipped with exhaust gas recirculation (EGR) irrespective of the control conditions in clause 2.4. of this Annex if the ambient temperature is below 275 K (2 °C) and one of the two following criteria is met:

(a) intake manifold temperature is less than or equal to the temperature defined by the following equation: $IMT_c = P_{IM} / 15.75 + 304.4$, where: IMT_c is the calculated intake manifold temperature, K and P_{IM} is the absolute intake manifold pressure in kPa;

(b) engine coolant temperature is less than or equal to the temperature defined by the following equation: $ECT_c = P_{IM} / 14.004 + 325.8$, where: ECT_c is the calculated engine coolant temperature, K and P_{IM} is the absolute intake manifold pressure, kPa.

2.3.5. Except as permitted by clause 2.3.2. of this Annex, an auxiliary emission control strategy may solely be activated for the following purposes:

(a) By on-board signals, for protecting the engine (including air-handling device protection) and/or agricultural tractor, construction equipment vehicle or combine harvester into which the engine is installed from damage;

(b) For operational safety reasons;

(c) For prevention of excessive emissions, during cold start or warming-up, during shut-down;

(d) If used to trade-off the control of one regulated pollutant under specific ambient or operating conditions, for maintaining control of all other regulated pollutants, within the emission limit values that are appropriate for the engine concerned. The purpose is to compensate for

naturally occurring phenomena in a manner that provides acceptable control of all emission constituents.

2.3.6. The manufacturer shall demonstrate to the Test Agency at the time of the type-approval test that the operation of any auxiliary emission strategy complies with the provisions of this clause. The demonstration shall consist of an evaluation of the documentation referred to in clause 2.6. of this Annex.

2.3.7. Any operation of an auxiliary emission control strategy non-compliant with clauses 2.3.1. to 2.3.5. of this Annex is prohibited.

2.4. Control conditions

The control conditions specify an altitude, ambient temperature and engine coolant range that determines whether auxiliary emission control strategies may generally or only exceptionally be activated in accordance with clause 2.3. of this Annex.

The control conditions specify an atmospheric pressure which is measured as absolute atmospheric static pressure (wet or dry) ("Atmospheric pressure")

2.4.1. Reserved

2.4.2. Reserved

2.4.3. Control conditions for engines of categories NRE:

(a) the atmospheric pressure greater than or equal to 82.5 kPa;

(b) the ambient temperature within the following range:

(i) equal to or above 273 K (0 °C),

(ii) less than or equal to 42 °C;

(c) the engine coolant temperature above 343 K (70 °C).

2.5. Where the engine inlet air temperature sensor is being used to estimate ambient air temperature the nominal offset between the two measurement points shall be evaluated for an engine type or engine family. Where used, the measured intake air temperature shall be adjusted by an amount equal to the nominal offset to estimate ambient temperature for an installation using the specified engine type or engine family.

The evaluation of the offset shall be made using good engineering judgement based on technical elements (calculations, simulations, experimental results, data etc.) including:

(a) the typical types of agricultural tractors, construction equipment vehicles or combine harvesters into which the engine type or engine family will be installed; and,

(b) the installation instructions provided to the OEM by the manufacturer.

A copy of the evaluation shall be made available to the Test Agency upon request.

2.6. Documentation requirements

2.6.1 The manufacturer shall comply with the documentation requirements laid down in clause 1.4. of Appendix A.1 of Annex 1 and Appendix A.2 to that Annex.

2.6.2 The manufacturer shall ensure all documents used for this purpose are marked with an identification number and date. Whenever particulars recorded are changed the relevant pages shall be marked to clearly show the date of revision and the nature of the amendment. A consolidated, updated version, accompanied by a detailed description of the amendments, shall be deemed to fulfil the requirement of this clause.

3. TECHNICAL REQUIREMENTS RELATING TO NO_X CONTROL MEASURES

3.1. Clause 3. of this Annex shall apply to electronically controlled engines of categories NRE , complying with the emission limits set out in Appendix 1 to clause 5 of this Part and using electronic control to determine both the quantity and timing of injecting fuel or using electronic control to activate, de-activate or modulate the emission control system used to reduce NO_X.

3.2. The manufacturer shall provide complete information on the functional operational characteristics of the NO_X control measures using the documents set out in Annex 1.

3.3. The NO_X control strategy shall be operational under all environmental conditions regularly occurring in India, especially at low ambient temperatures.

3.4. The manufacturer shall demonstrate that the emission of ammonia during the applicable emission test cycle of the type approval procedure, when a reagent is used, does not exceed a mean value of 10 ppm for all engine categories.

3.5. If reagent containers are installed on or connected to a agricultural tractor, construction equipment vehicle or combine harvester, means for taking a sample of the reagent inside the containers must be included. The sampling point must be easily accessible without requiring the use of any specialised tool or device.

3.6. In addition to the requirements set out in clauses 3.2. to 3.5. of this Annex, the technical requirements set out in Appendix A.1 of this Annex shall apply for engines of category NRE.

4. TECHNICAL REQUIREMENTS RELATING TO PARTICULATE POLLUTANT CONTROL MEASURES

4.1. This clause shall apply to engines of sub-categories subject to a PN limit in accordance with the emission limits set out in Appendix 1 to clause 5 of this Part fitted with a particulate after-treatment system. In cases where the NO_X control system and the particulate control system share the same physical components (e.g. same substrate (SCR on filter), same exhaust temperature sensor) the requirements of this clause shall not apply to any component or malfunction where, after consideration of a reasoned assessment provided by the manufacturer, the Test Agency concludes that a particulate control malfunction within the scope of this clause would lead to a corresponding NO_X control malfunction within the scope of clause 3. of this Annex.

4.2. The detailed technical requirements relating to particulate pollutant control measures are specified in Appendix A.2 of this Annex.

ANNEX 9 - APPENDIX A.1

ADDITIONAL TECHNICAL REQUIREMENTS ON NO_X CONTROL MEASURES FOR ENGINES OF CATEGORTY NRE , INCLUDING THE METHOD TO DEMONSTRATE THESE STRATEGIES

A.1.1. INTRODUCTION

This Appendix sets out the additional requirements to ensure the correct operation of NO_X control measures. It includes requirements for engines that rely on the use of a reagent in order to reduce emissions. The type approval shall be made conditional upon the application of the relevant provisions on operator instruction, installation documents, operator warning system, inducement system and reagent freeze protection that are set out in this Appendix.

A.1.2. GENERAL REQUIREMENTS

The engine shall be equipped with a NO_X Control Diagnostic system (NCD) able to identify the NO_X control malfunctions (NCMs). Any engine covered by this clause shall be designed, constructed and installed so as to be capable of meeting these requirements throughout the normal life of the engine under normal conditions of use. In achieving this objective it is acceptable that engines which have been used in excess of the emission durability period as specified in Appendix 2 to clause 5 of this Part show some deterioration in the performance and the sensitivity of the NO_X Control Diagnostic system (NCD), such that the thresholds specified in this Annex may be exceeded before the warning and/or inducement systems are activated.

A.1.2.1. Required information

A.1.2.1.1. If the emission control system requires a reagent, the type of reagent, information on concentration when the reagent is in solution, its operational temperature conditions a reference to international standards for composition and quality and other characteristics of that reagent shall be specified by the manufacturer in accordance with Appendix A.3 of Annex 1.

A.1.2.1.2. Detailed written information fully describing the functional operation characteristics of the operator warning system set out in clause A.1.4. of this Annex and of the operator inducement system set out in clause A.1.5. of this Annex shall be provided to the Test Agency at the time of approval.

A.1.2.1.3. The manufacturer shall provide the OEM with documents with instructions on how to install the engine in the agricultural tractor, construction equipment vehicle or combine harvester in such manner that the engine, its emission control system and the agricultural tractor, construction equipment vehicle or combine harvester or parts, operate in conformity with the requirements of this Appendix. This documentation shall include the detailed technical requirements of the engine (software, hardware, and communication) needed for the correct installation of the engine in the agricultural tractor, construction equipment vehicle or combine harvester.

A.1.2.2. Operating conditions

A.1.2.2.1. Monitoring for reagent level in the storage tank shall be conducted under all conditions where measurement is technically feasible (for instance, under all conditions when a liquid reagent is not frozen).

A.1.2.2.2. Reagent freeze protection shall apply at ambient temperatures at or below 273K (0 °C).

A.1.2.2.3. All elements of the NO_X control diagnostic system other than those listed in clauses A.1.2.2.1. and A.1.2.2.2. of this Annex shall, at a minimum be operational at the applicable control conditions set out in clause 2.4 of this Annex for each engine category. The diagnostic system shall remain operational outside of this range where technically possible.

A.1.2.3. Reagent freeze protection

A.1.2.3.1. It is permitted to use a heated or a non-heated reagent tank and dosing system. A heated system shall meet the requirements of clause A.1.2.3.2.2. of this Annex. A non-heated system shall meet the requirements of clause A.1.2.3.2.3. of this Annex.

A.1.2.3.1.1. The use of a non-heated reagent tank and dosing system shall be indicated in the written instructions to the end-user of the agricultural tractor, construction equipment vehicle or combine harvester.

A.1.2.3.2. Reagent tank and dosing system

A.1.2.3.2.1. If the reagent has frozen, the reagent shall be available for use within a maximum of 70 minutes after the start of the engine at 273 K (0 °C) ambient temperature.

A.1.2.3.2.2. Design criteria for a heated system

A heated system shall be so designed that it meets the performance requirements set out in this clause A.1.2.3.2. when tested using the procedure defined.

Demonstration: Demonstration test at the time of type approval is not mandatory.

A.1.2.3.2.2.1. The reagent tank and dosing system shall be soaked at 255 K (- 18°C) for 72 hours or until the reagent becomes solid, whichever occurs first.

A.1.2.3.2.2.2. After the soak period set out in clause A.1.2.3.2.2.1. of this Annex, the agricultural tractor, construction equipment vehicle or combine harvester vehicle /engine shall be started and operated at 266 K (- 7 °C) ambient temperature or lower as follows:

(a) 10 to 20 minutes idling, followed by

(b) up to 50 minutes at no more than 40 per cent of rated torque.

A.1.2.3.2.2.3. At the conclusion of the test procedure set out in clause A.1.2.3.2.2.2. of this Annex, the reagent dosing system shall be fully functional.

A.1.2.3.2.2.4. Evaluation of the design criteria may be performed in a cold chamber test cell using an entire agricultural tractor, construction equipment vehicle or combine harvester or parts representative of those to be installed on such vehicle or based on field tests.

A.1.2.3.2.3. Activation of the operator warning and inducement system for a non-heated system

A.1.2.3.2.3.1. The operator warning system described in clause 4. of this Annex shall be activated if no reagent dosing occurs at an ambient temperature ≥ 273 K (0°C).

A.1.2.3.2.3.2. The driver inducement system described in clause A.1.8 of this Appendix shall be activated if no reagent dosing occurs within a maximum of 70 minutes after engine start at an ambient temperature $\geq$ 273 K (0°C).

A.1.2.4. Diagnostic requirements

A.1.2.4.1 The NO_X Control Diagnostic system (NCD) shall be able to identify the NO_X control malfunctions (NCMs) by means of Diagnostic Trouble Codes (DTCs) stored in the computer memory and to communicate that information off-board upon request.

A.1.2.4.2 Requirements for recording Diagnostic Trouble Codes (DTCs)

A.1.2.4.2.1 The NCD system shall record a DTC for each distinct NO_X Control Malfunction (NCM).

A.1.2.4.2.2 The NCD system shall conclude within 60 minutes of engine operation whether a detectable malfunction is present. At this time, a "confirmed and active" DTC shall be stored and the warning system be activated according to clause A.1.4. of this Appendix

A.1.2.4.2.3 In cases where more than 60 minutes running time is required for the monitors to accurately detect and confirm a NCM (e.g. monitors using statistical models or with respect to fluid consumption on the agricultural tractor, construction equipment vehicle or combine harvester), the Test Agency may permit a longer period for monitoring provided the manufacturer justifies the need for the longer period (for example by technical rationale, experimental results, in house experience, etc.).

A.1.2.4.3. Requirements for erasing Diagnostic trouble codes (DTCs)

(a) DTCs shall not be erased by the NCD system itself from the computer memory until the failure related to that DTC has been remedied.

(b) The NCD system may erase all the DTCs upon request of a proprietary scan or maintenance tool that is provided by the engine manufacturer upon request, or using a pass code provided by the engine manufacturer.

A.1.2.4.4. An NCD system shall not be programmed or otherwise designed to partially or totally deactivate based on age of the agricultural tractor, construction equipment vehicle or combine harvester during the actual life of the engine, nor shall the system contain any algorithm or strategy designed to reduce the effectiveness of the NCD system over time.

A.1.2.4.5. Any reprogrammable computer codes or operating parameters of the NCD system shall be resistant to tampering.

A.1.2.4.6. NCD engine family

The manufacturer is responsible for determining the composition of an NCD engine family. Grouping engines within an NCD engine family shall be based on good engineering judgment and be subject to approval by the Test Agency.

Engines that do not belong to the same engine family may still belong to the same NCD engine family.

A.1.2.4.6.1. Parameters defining an NCD engine family

An NCD engine family is characterized by basic design parameters that shall be common to engines within the family.

In order that engines are considered to belong to the same NCD engine family, the following list of basic parameters shall be similar:

(a) emission control systems;

(b) methods of NCD monitoring;

(c) criteria for NCD monitoring;

(d) monitoring parameters (e.g. frequency).

These similarities shall be demonstrated by the manufacturer by means of relevant engineering demonstration or other appropriate procedures and subject to the approval of the Test Agency.

The manufacturer may request approval by the Test Agency of minor differences in the methods of monitoring/diagnosing the NCD system due to engine configuration variation, when these methods are considered similar by the manufacturer and they differ only in order to match specific characteristics of the components under consideration (for example size, exhaust gas flow, etc.); or their similarities are based on good engineering judgment.

A.1.3. MAINTENANCE REQUIREMENTS

A.1.3.1. The OEM shall provide to all end-users of agricultural tractors, construction equipment vehicles or combine harvesters written instructions about the emission control system and its correct operation in accordance with Appendix 2 of clause 6 of this Annex.

A.1.4. OPERATOR WARNING SYSTEM

A.1.4.1. The agricultural tractors, construction equipment vehicles or combine harvesters shall include an operator warning system using visual alarms that informs the operator when a low reagent level, incorrect reagent quality, interruption of dosing or a malfunction specified in clause A.1.9. of this Appendix has been detected that will lead to activation of the operator inducement system if not rectified in a timely manner. The warning system shall remain active when the operator inducement system described in clause A.1.5. of this Appendix has been activated.

A.1.4.2. The warning shall not be the same as the warning used for the purposes of malfunction or other engine maintenance, though it may use the same warning system.

A.1.4.3. The operator warning system may consist of one or more lamps, or display short messages, which may include, for example, messages indicating clearly:

(c) the remaining time before activation of the low-level and/or severe inducements,

(d) the amount of low-level and/or severe inducement, for example the amount of torque reduction,

(e) the conditions under which agricultural tractor, construction equipment vehicle or combine harvester disablement can be cleared.

Where messages are displayed, the system used for displaying these messages may be the same as the one used for other maintenance purposes.

A.1.4.4. At the choice of the manufacturer, the warning system may include an audible component to alert the operator. The cancelling of audible warnings by the operator is permitted.

A.1.4.5. The operator warning system shall be activated as specified in clauses A.1.2.3.2.3.1., A.1.6.2., A.1.7.2., A.1.8.4., and A.1.9.3. of this Appendix respectively.

A.1.4.6. The operator warning system shall be deactivated when the conditions for its activation have ceased to exist. The operator warning system shall not be automatically deactivated without the reason for its activation having been remedied.

A.1.4.7. The warning system may be temporarily interrupted by other warning signals providing important safety related messages.

A.1.4.8. Details of the operator warning system activation and deactivation procedures are described in clause A.1.11. of this Appendix.

A.1.4.9. As part of the application for approval under this Part, the manufacturer shall demonstrate the operation of the operator warning system, as specified in clause A.1.10. of this Annex.

A.1.5. OPERATOR INDUCEMENT SYSTEM

A.1.5.1. The engine shall incorporate an operator inducement system based on one of the following principles:

A.1.5.1.1. a two-stage inducement system starting with a low-level inducement (performance restriction) followed by a severe inducement (effective disablement of agricultural tractor, construction equipment vehicle or combine harvester operation);

A.1.5.1.2. a one-stage severe inducement system (effective disablement of agricultural tractor, construction equipment vehicle or combine harvester operation) activated under the conditions of a low-level inducement system as specified in clauses A.1.6.3.1., A.1.7.3.1., A.1.8.4.1., and A.1.9.4.1. of this Appendix.

Where the manufacturer elects to shut down the engine to fulfil the requirement for one-stage severe inducement then the inducement for reagent level may, at the choice of the manufacturer, be activated under the conditions of clause A.1.6.3.2. of this Annex instead of the conditions of clause A.1.6.3.1. of this Appendix.

A.1.5.2. The engine may be fitted with a means to disable the operator inducement on condition that it complies with the requirements of clause A.1.5.2.1. of this Appendix.

A.1.5.2.1 The engine may be fitted with a means to temporarily disable the operator inducement during an emergency declared by a national or regional government, their emergency services or their armed services.

A.1.5.2.1.1 All of the following conditions shall apply when a means to temporarily disable the operator inducement in an emergency is fitted to an engine:

(a) The maximum operating period for which the inducement may be disabled by the operator shall be 120 hours;

(b) The method of activation shall be designed to prevent accidental operation by requiring a double voluntary action and shall be clearly marked, at a miminum, with the warning “EMERGENCY USE ONLY”;

(c) The disablement shall de-activate automatically after the 120 hours has expired, and there shall be a means for the operator to manually de-activate the disablement if the emergency has ended;

(d) After the 120 hours of operation has expired it shall no longer be possible to disable the inducement unless the means to disable has been re-armed by the input of a manufacturer's temporary security code, or re-configuration of the engine's ECU by a qualified service technician, or an equivalent security feature that is unique to each engine;

(e) The total number and duration of activations of the disablement must be stored in non-volatile electronic memory or counters in a manner to ensure that the information cannot be intentionally deleted. It shall be possible for national inspection authorities to read these records with a scan tool;

(f) A description of the connection for, and method to read, the records at point (e) is included in the information folder as set out in Appendix A.1 of Annex 1;

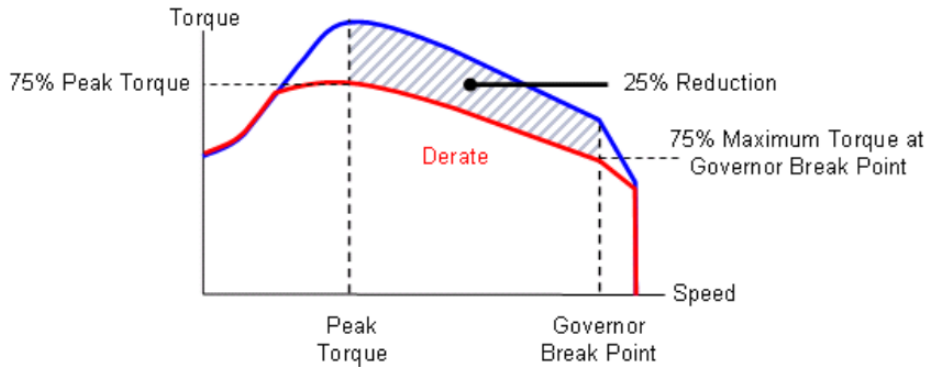
(g) The manufacturer shall maintain a record of each request to re-arm the means to temporarily disable the operator inducement and shall make those records available to Test Agency upon request.

A.1.5.3. Low-level inducement system

A.1.5.3.1. The low-level inducement system shall be activated after any of the conditions specified in clauses A.1.6.3.1., A.1.7.3.1., A.1.8.4.1., and A.1.9.4.1. of this Appendix has occurred.

A.1.5.3.2. The low-level inducement system shall gradually reduce the maximum available engine torque across the engine speed range by at least 25 per cent between the peak torque speed and the governor breakpoint as shown in Figure A.9-1.. The rate of torque reduction shall be a minimum of 1 per cent per minute.

A.1.5.3.3. Other inducement measures that are demonstrated to the Test Agency as having the same or greater level of severity may be used.



Figurea.9-1.

Low-Level Inducement Torque Reduction Scheme

A.1.5.4. Severe inducement system

A.1.5.4.1. The severe inducement system shall be activated after any of the conditions specified in clauses A.1.2.3.2.3.2., A.1.6.3.2., A.1.7.3.2., A.1.8.4.2., and A.1.9.4.2. of this Appendix has occurred.

A.1.5.4.2. The severe inducement system shall reduce the agricultural tractor's construction equipment vehicle's or combine harvester's utility to a level that is sufficiently onerous as to cause the operator to remedy any problems related to clauses A.1.6. to A.1.9. of this Appendix. The following strategies are acceptable:

A.1.5.4.2.1. Engine torque between the peak torque speed and the governor breakpoint shall be gradually reduced from the low-level inducement torque in Figure A.9-1. by a minimum of 1 per cent per minute to 50 per cent of maximum torque or lower and for variable speed engines the engine speed shall be gradually reduced to 60 per cent of rated speed or lower within the same time period as the torque reduction, as shown in Figure A.9-2..

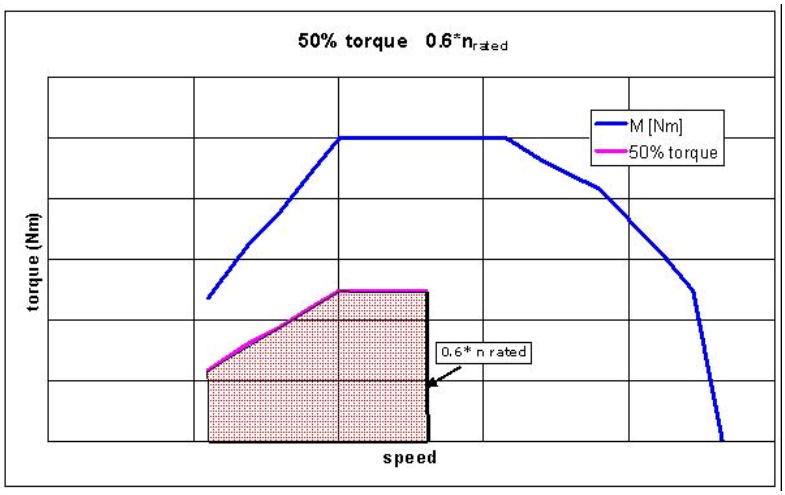


Figure A.9-2.

Severe Inducement Torque Reduction Scheme

A.1.5.4.2.2. Other inducement measures that are demonstrated to the Test Agency as having the same or greater level of severity may be used.

A.1.5.5. In order to account for safety concerns and to allow for self-healing diagnostics, use of an inducement override function for releasing full engine power is permitted provided it

(a) is active for no longer than 30 minutes, and

(b) is limited to 3 activations during each period that the operator inducement system is active.

A.1.5.6. The operator inducement system shall be deactivated when the conditions for its activation have ceased to exist. The operator inducement system shall not be automatically deactivated without the reason for its activation having been remedied.

A.1.5.7. Details of the operator inducement system activation and deactivation procedures are described in clause A.1.11. of this Appendix.

A.1.5.8. As part of the application for approval under this Part, the manufacturer shall demonstrate the operation of the operator inducement system, as specified in clause A.1.10. of this Appendix.

A.1.6. REAGENT AVAILABILITY

A.1.6.1. Reagent level indicator

The agricultural tractor, construction equipment vehicle or combine harvester shall include an indicator that clearly informs the operator of the level of reagent in the reagent storage tank. The minimum acceptable performance level for the reagent indicator is that it shall continuously indicate the reagent level whilst the operator warning system referred to in clause A.1.4. of this Appendix is activated. The reagent indicator may be in the form of an analogue

or digital display, and may show the level as a proportion of the full tank capacity, the amount of remaining reagent, or the estimated operating hours remaining.

A.1.6.2. Activation of the operator warning system

A.1.6.2.1. The operator warning system specified in clause A.1.4. of this Appendix shall be activated when the level of reagent goes below 10 per cent of the capacity of the reagent tank or a higher percentage at the choice of the manufacturer.

A.1.6.2.2. The warning provided shall be sufficiently clear, in conjunction with the reagent indicator, for the operator to understand that the reagent level is low. When the warning system includes a message display system, the visual warning shall display a message indicating a low level of reagent. (for example "urea level low", "AdBlue level low", or "reagent low").

A.1.6.2.3. The operator warning system does not initially need to be continuously activated (for example a message does not need to be continuously displayed), however activation shall escalate in intensity so that it becomes continuous as the level of the reagent approaches empty and the point where the operator inducement system will come into effect is approached (for example frequency at which a lamp flashes). It shall culminate in an operator notification at a level that is at the choice of the manufacturer, but sufficiently more noticeable at the point where the operator inducement system in clause A.1.6.3. of this Appendix comes into effect than when it was first activated.

A.1.6.2.4. The continuous warning shall not be easily disabled or ignored. When the warning system includes a message display system, an explicit message shall be displayed (for example "fill up urea", "fill up AdBlue", or "fill up reagent"). The continuous warning may be temporarily interrupted by other warning signals providing important safety related messages.

A.1.6.2.5. It shall not be possible to turn off the operating warning system until the reagent has been replenished to a level not requiring its activation.

A.1.6.3 Activation of the operator inducement system

A.1.6.3.1 The low-level inducement system described in clause A.1.5.3. of this Appendix shall be activated if the reagent tank level goes below 2.5 per cent of its nominally full capacity or a higher percentage at the choice of the manufacturer.

A.1.6.3.2. The severe inducement system described in clause A.1.5.4. of this Appendix shall be activated if the reagent tank is empty, that is, when the dosing system is unable to draw further reagent from the tank, or at any level below 2.5 per cent of its nominally full capacity at the discretion of the manufacturer.

A.1.6.3.3. Except to the extent permitted by clause A.1.5.5. of this Appendix it shall not be possible to turn off the low-level or severe inducement system until the reagent has been replenished to a level not requiring their respective activation.

A.1.7. REAGENT QUALITY MONITORING

A.1.7.1. The engine, or agricultural tractors, construction equipment vehicles or combine harvesters shall include a means of determining the presence of an incorrect reagent on board a agricultural tractors, construction equipment vehicles or combine harvesters.

A.1.7.1.1. The manufacturer shall specify a minimum acceptable reagent concentration CD_{min}, which results in tailpipe NO_X emissions not exceeding the lower of

either the applicable NO_X limit multiplied by 2.25 or the applicable NO_X limit plus 1.5 g/kWh. For engine sub-categories with a combined HC and NO_X limit, the applicable NO_X limit value for the purpose of this clause shall be the combined limit value for HC and NO_X reduced by 0.19 g/kWh.

A.1.7.1.1.1. The value of CD_{min} specified by the manufacturer shall be used during the demonstration set out in clause A.1.13. of this Appendix and recorded in the extended documentation package as specified in Appendix A.3 to Annex 1.

A.1.7.1.2. Any reagent concentration lower than CD_{min} shall be detected and be regarded, for the purpose of clause A.1.7.1. of this Appendix, as being incorrect reagent.

A.1.7.1.3. A specific counter ("the reagent quality counter") shall be attributed to the reagent quality. The reagent quality counter shall count the number of engine operating hours with an incorrect reagent.

A.1.7.1.3.1. Optionally, the manufacturer may group the reagent quality failure together with one or more of the failures listed in clauses A.1.8. of this Appendix and A.1.9. of this Appendix into a single counter.

A.1.7.1.4. Details of the reagent quality counter activation and deactivation criteria and mechanisms are described in clause A.1.11. of this Appendix.

A.1.7.2. Activation of the operator warning system

When the monitoring system confirms that the reagent quality is incorrect, the operator warning system described in clause A.1.4 of this Appendix shall be activated. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (for example “incorrect urea detected”, “incorrect AdBlue detected”, or “incorrect reagent detected”).

A.1.7.3 Activation of the operator inducement system

A.1.7.3.1. The low-level inducement system described in clause A.1.5.3. of this Appendix shall be activated if the reagent quality is not rectified within a maximum of 10 engine operating hours after the activation of the operator warning system as described in clause A.1.7.2. of this Appendix.

A.1.7.3.2. The severe inducement system described in clause A.1.5.4. of this Appendix shall be activated if the reagent quality is not rectified within a maximum of 20 engine operating hours after the activation of the operator warning system as described in clause A.1.7.2. of this Appendix.

A.1.7.3.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in clause A.1.11. of this Appendix.

A.1.8. REAGENT DOSING ACTIVITY

A.1.8.1 The engine shall include a means of determining interruption of dosing.

A.1.8.2. Reagent dosing activity counter

A.1.8.2.1. A specific counter shall be attributed to the dosing activity (the "dosing activity counter"). The counter shall count the number of engine operating hours which occur with an interruption of the reagent dosing activity. This is not required where such interruption is demanded by the engine ECU because the agricultural tractor, construction equipment vehicle or combine harvester operating conditions are such that their emission performance does not require reagent dosing.

A.1.8.2.1.1. Optionally, the manufacturer may group the reagent dosing failure together with one or more of the failures listed in clauses A.1.7. and A.1.9. of this Appendix into a single counter.

A.1.8.2.2. Details of the reagent dosing activity counter activation and deactivation criteria and mechanisms are described in clause A.1.11. of this Appendix.

A.1.8.3. Activation of the operator warning system

The operator warning system described in clause A.1.4. of this Appendix shall be activated in the case of interruption of dosing which sets the dosing activity counter in accordance with clause A.1.8.2.1. of this Appendix. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (e.g. "urea dosing malfunction", "AdBlue dosing malfunction", or "reagent dosing malfunction").

A.1.8.4. Activation of the operator inducement system

A.1.8.4.1. The low-level inducement system described in clause A.1.5.3. of this Appendix shall be activated if an interruption in reagent dosing is not rectified within a maximum of 10 engine operating hours after the activation of the operator warning system in accordance with clause A.1.8.3. of this Appendix.

A.1.8.4.2. The severe inducement system described in clause A.1.5.4. of this Appendix shall be activated if an interruption in reagent dosing is not rectified within a maximum of 20 engine operating hours after the activation of the operator warning system in accordance with clause A.1.8.3. of this Appendix.

A.1.8.4.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in clause A.1.11. of this Appendix.

A.1.9. OTHER FAILURES THAT MAY BE ATTRIBUTED TO TAMPERING

A.1.9.1. In addition to the level of reagent in the reagent tank, the reagent quality, and the interruption of dosing, the following failures shall be monitored because they may be attributed to tampering:

(a) failures of the NO_X Control Diagnostic (NCD) system as described in clause A.1.9.2.1.of this Appendix;

(b) failures of the exhaust gas recirculation (EGR) valve as described in clause A.1.9.2.2. of this Appendix.

A.1.9.2. Monitoring requirements and counters

A.1.9.2.1. NCD system

A.1.9.2.1.1. The NO_X Control Diagnostic (NCD) system shall be monitored for electrical failures and for removal or deactivation of any sensor that prevents it from diagnosing any other failures set out in clauses A.1.6. to A.1.8. (component monitoring) of this Appendix.

A non-exhaustive list of sensors that affect the diagnostic capability are those directly measuring NO_X concentration, urea quality sensors, ambient sensors and sensors used for monitoring reagent dosing activity, reagent level, or reagent consumption.

A.1.9.2.1.2. A counter shall be attributed to each of the monitoring failures. The NCD system counters shall count the number of engine operating hours when the DTC associated to a malfunction of the NCD system is confirmed to be active. Different NCD system failures may be grouped into a single counter.

A.1.9.2.1.2.1. The manufacturer may group the NCD system failure together with one or more of the failures listed in clauses A.1.7., A.1.8. and clause A.1.9.2.2 of this Appendix into a single counter.

A.1.9.2.1.3. Details of the NCD system counter(s) activation and deactivation criteria and mechanisms are described in clause A.1.11. of this Appendix.

A.1.9.2.2. EGR valve

A.1.9.2.2.1. The EGR system shall be monitored for an impeded EGR valve.

A.1.9.2.2.2. A counter shall be attributed to an impeded EGR valve. The EGR valve counter shall count the number of engine operating hours when the DTC associated to an impeded EGR valve is confirmed to be active.

A.1.9.2.2.2.1. The manufacturer may group the impeded EGR valve failure together with one or more of the failures listed in clauses A.1.7., A.1.8. and A.1.9.2.1 of this Appendix. into a single counter.

A.1.9.2.2.3. Details of the EGR valve counter activation and deactivation criteria and mechanisms are described in clause A.1.11. of this Appendix.

A.1.9.3. Activation of the operator warning system

The operator warning system set out in clause 4. shall be activated in case any of the failures specified in clause A.1.9.1. of this Appendix occur, and shall indicate that an urgent repair is required. When the warning system includes a message display system, it shall display a message indicating either the reason of the warning (for example “reagent dosing valve disconnected”, or "critical emission failure").

A.1.9.4. Activation of the operator inducement system

A.1.9.4.1. The low-level inducement system described in clause A.1.5.3. of this Appendix shall be activated if a failure specified in clause A.1.9.1. of this Appendix is not rectified within a maximum of 36 engine operating hours after the activation of the operator warning system set out in clause A.1.9.3. of this Appendix.

A.1.9.4.2. The severe inducement system described in clause A.1.5.4. of this Appendix shall be activated if a failure specified in clause A.1.9.1. of this Appendix is not rectified within a maximum of 100 engine operating hours after the activation of the operator warning system set out in clause A.1.9.3. of this Annex.

A.1.9.4.3. The number of hours prior to activation of the inducement systems shall be reduced in case of a repetitive occurrence of the malfunction according to the mechanism described in clause A.1.11. of this Appendix.

A.1.9.5. As an alternative to the monitoring requirements set out in clause A.1.9.2. of this Appendix, the manufacturer may monitor for failures using a NO_X sensor located in the exhaust system. In this case,

(a) the NO_X value at which the NCM shall be detected shall not exceed the lower of either the applicable NO_X limit multiplied by 2.25 or the applicable NO_X limit plus 1.5 g/kWh. For engine sub-categories with a combined HC and NO_X limit, the applicable NO_X limit value for the purpose of this clause shall be the combined limit value for HC and NO_X reduced by 0.19 g/kWh.

(b) a single warning may be used, including, where messages are used, the statement 'high NO_X – root cause unknown',

(c) in clause A.1.9.4.1. of this Appendix the maximum number of engine operating hours between the activation of the operator warning system and the activation of the low-level inducement system shall be reduced to 10,

(d) in clause A.1.9.4.2. of this Appendix the maximum number of engine operating hours between the activation of the operator warning system and the activation of the severe inducement system shall be reduced to 20.

A.1.10. DEMONSTRATION REQUIREMENTS

A.1.10.1. General

The compliance to the requirements of this Appendix shall be demonstrated during type-approval by performing, as illustrated in Table A.9-1. and specified in clause A.1.10. of this Appendix:

(a) a demonstration of the warning system activation

(b) a demonstration of the low level inducement system activation, if applicable

(c) a demonstration of the severe inducement system activation

A.1.10.2. Engine families and NCD engine families

The compliance of an engine family or an NCD engine family with the requirements of clause A.1.10. of this Appendix may be demonstrated by testing one of the members of the considered family, provided the manufacturer demonstrates to the Test Agency that the monitoring systems necessary for complying with the requirements of this Appendix are similar within the family.

A.1.10.2.1. The demonstration that the monitoring systems for other members of the NCD engine family are similar may be performed by presenting to the approval authorities such elements as algorithms, functional analyses, etc.

A.1.10.2.2. The test engine is selected by the manufacturer in agreement with the Test Agency. It may or may not be the parent engine of the considered family.

A.1.10.2.3. In the case where engines of an engine family belong to an NCD engine family that has already been type-approved, according to clause A.1.10.2.1. (Figure A.9-3.) of this Appendix the compliance of that engine family is deemed to be demonstrated without further testing, provided the manufacturer demonstrates to the Test Agency that the monitoring systems necessary for complying with the requirements of this Appendix are similar within the considered engine and NCD engine families.

Table A.9-1.

Illustration of the Content of the Demonstration Process in Accordance with the Provisions in clauses A.1.10.3. And A.1.10.4.

Mechanism	Demonstration elements
Warning system activation specified in clause A.1.10.3. of this Appendix	- 2 activation tests (incl. lack of reagent) - Supplementary demonstration elements, as appropriate
Low-level inducement activation specified in clause A.1.10.4. of this Appendix	- 2 activation tests (incl. lack of reagent) - Supplementary demonstration elements, as appropriate - 1 torque reduction test
Severe inducement activation specified in clause A.1.10.4. of this Appendix	- 2 activation tests (incl. lack of reagent) - Supplementary demonstration elements, as appropriate

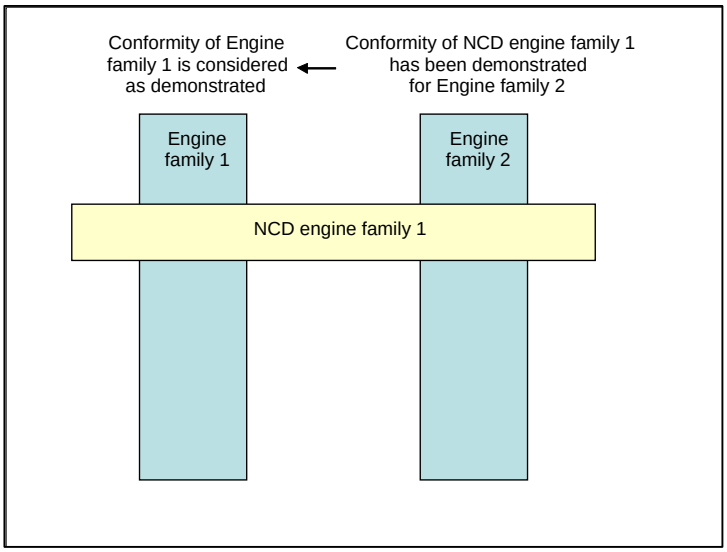


Figure A.9-3.

Previously Demonstrated Conformity of an NCD Engine Family

A.1.10.3. Demonstration of the warning system activation

A.1.10.3.1. The compliance of the warning system activation shall be demonstrated by performing two tests: lack of reagent, and one failure category identified in clauses A.1.7, A.1.8. or A.1.9. of this Appendix.

A.1.10.3.2. Selection of the failure to be tested from clauses A.1.7., A.1.8., or A.1.9. of this Appendix.

A.1.10.3.2.1. The Test Agency shall select one failure category. In the case that a failure is selected from points A.1.7. or A.1.9. of this Appendix the additional requirements set out in points A.1.10.3.2.2. or A.1.10.3.2.3. of this Appendix respectively shall apply.

A.1.10.3.2.2 For the purpose of demonstrating the activation of the warning system in case of a wrong reagent quality, a reagent shall be selected with a dilution of the active ingredient at least as dilute as that communicated by the manufacturer according to the requirements set out in clause A.1.7. of this Appendix.

A.1.10.3.2.3. For the purpose of demonstrating the activation of the warning system in case of failures that may be attributed to tampering, and are defined in clause A.1.9. of this Appendix the selection shall be performed according to the following requirements:

A.1.10.3.2.3.1. The manufacturer shall provide the Test Agency with a list of such potential failures.

A.1.10.3.2.3.2. The failure to be considered in the test shall be selected by the Test Agency from this list referred to in clause A.1.10.3.2.3.1. of this Appendix.

A.1.10.3.3. Demonstration

A.1.10.3.3.1. For the purpose of this demonstration, a separate test shall be performed for the lack of reagent and the failure selected in clause A.1.10.3.2. of this Appendix.

A.1.10.3.3.2. During a test, no failure shall be present other than the one addressed by the test.

A.1.10.3.3.3. Prior to starting a test, all DTC shall have been erased.

A.1.10.3.3.4. At the request of the manufacturer, and with the agreement of the Test Agency, the failures subject to testing may be simulated.

A.1.10.3.3.5. Detection of failures other than lack of reagent.

For failures other than lack of reagent, once the failure installed or simulated, the detection of that failure shall be performed as follows:

A.1.10.3.3.5.1. The NCD system shall respond to the introduction of a failure selected as appropriate by the Test Agency in accordance to the provisions of this Appendix. This is considered to be demonstrated if activation occurs within two consecutive NCD test-cycles according to clause A.1.10.3.3.7. of this Appendix.

When it has been specified in the monitoring description and agreed by the Test Agency that a specific monitor needs more than two NCD test-cycles to complete its monitoring, the number of NCD test-cycles may be increased to 3 NCD test-cycles.

Each individual NCD test-cycle in the demonstration test may be separated by an engine shut-off. The time until the next start-up shall take into consideration any monitoring that may occur after engine shut-off and any necessary condition that must exist for monitoring to occur at the next start up.

A.1.10.3.3.5.2. The demonstration of the warning system activation is deemed to be accomplished if, at the end of each demonstration test performed according to clause A.1.10.3.3. of this Appendix, the warning system has been properly

activated and the DTC for the selected failure has got the “confirmed and active” status.

A.1.10.3.3.6. Detection in case of lack of reagent availability

For the purpose of demonstrating the activation of the warning system in case of lack of reagent availability, the engine shall be operated over one or more NCD test cycles at the discretion of the manufacturer.

A.1.10.3.3.6.1. The demonstration shall start with a level of reagent in the tank to be agreed between the manufacturer and the Test Agency but representing not less than 10 per cent of the nominal capacity of the tank.

A.1.10.3.3.6.2. The warning system is deemed to have performed in the correct manner if the following conditions are met simultaneously:

(a) the warning system has been activated with a reagent availability greater or equal to 10 per cent of the capacity of the reagent tank, and

(b) the "continuous" warning system has been activated with a reagent availability greater or equal to the value declared by the manufacturer in accordance with the provisions of clause A.1.6. of this Appendix.

A.1.10.3.3.7. NCD test cycle

A.1.10.3.3.7.1 The NCD test cycle considered in clause A.1.10. of this Annex for demonstrating the correct performance of the NCD system is the hot NRTC cycle for engines of sub-category NRE-v-3, NRE-v-4, NRE-v-5 NRE-v-6 and the applicable NRSC for all other categories.

A.1.10.3.3.7.2 On request of the manufacturer and with approval of the Test Agency, an alternative NCD test-cycle can be used (e.g. other than the NTRC or the NRSC) for a specific monitor. The request shall contain elements (technical considerations, simulation, test results, etc.) demonstrating:

(a) the requested test-cycle results in a monitor that will run in real world operations, and;

(b) the applicable NCD test-cycle specified in clause A.1.10.3.3.7.1. of this Appendix is shown to be less appropriate for the considered monitoring.

A.1.10.3.4. The demonstration of the warning system activation is deemed to be accomplished if, at the end of each demonstration test performed according to clause A.1.10.3.3. of this Appendix, the warning system has been properly activated.

A.1.10.4. Demonstration of the inducement system

A.1.10.4.1. The demonstration of the inducement system shall be done by tests performed on an engine test bench.

A.1.10.4.1.1. Any components or sub-systems not physically mounted on the engine, such as, but not limited to, ambient temperature sensors, level sensors, and operator warning and information systems, that are required in order to perform the demonstrations shall be connected to the engine for that purpose, or shall be simulated, to the satisfaction of the Test Agency.

A.1.10.4.1.2. If the manufacturer chooses, and subject to the agreement of the Test Agency, the demonstration tests may be performed on a complete agricultural tractor, construction equipment vehicle or combine harvester either by mounting the agricultural tractor, construction equipment vehicle or

combine harvester on a suitable test bed or, notwithstanding clause A.1.10.4.1. of this Appendix, by running it on a test track under controlled conditions.

A.1.10.4.2. The test sequence shall demonstrate the activation of the inducement system in case of lack of reagent and in case of the failure selected by the Test Agency according to clause A.1.10.3.2.1. of this Appendix for the test of the warning system.

A.1.10.4.3. For the purpose of this demonstration,

(a) the manufacturer shall, in agreement with the Test Agency, be permitted to accelerate the test by simulating the achievement of a certain number of operating hours,

(b) the achievement of the torque reduction required for low-level inducement may be demonstrated at the same time as the general engine performance approval process performed in accordance with this Part. Separate torque measurement during the inducement system demonstration is not required in this case,

(c) the low-level inducement, if applicable, shall be demonstrated according to the requirements of clause A.1.10.4.5. of this Appendix.

(d) the severe inducement shall be demonstrated according to the requirements of clause A.1.10.4.6. of this Appendix.

A.1.10.4.4. The manufacturer shall, in addition, demonstrate the operation of the inducement system under those failure conditions defined in clauses A.1.7., A.1.8. or A.1.9. of this Annex which have not been chosen for use in demonstration tests described in clauses A.1.10.4.1. to A.1.10.4.3. of this Appendix.

These additional demonstrations may be performed by presentation to the Test Agency of a technical case using evidence such as algorithms, functional analyses, and the result of previous tests.

A.1.10.4.4.1. These additional demonstrations shall in particular demonstrate to the satisfaction of the Test Agency the inclusion of the correct torque reduction mechanism in the engine ECU.

A.1.10.4.5. Demonstration test of the low level inducement system

A.1.10.4.5.1. This demonstration starts when the warning system or when appropriate "continuous" warning system has been activated as a result of the detection of a failure selected by the Test Agency.

A.1.10.4.5.2. When the system is being checked for its reaction to the case of lack of reagent in the tank, the engine shall be run until the reagent availability has reached a value of 2.5 per cent of the tank nominal full capacity of the tank or the value declared by the manufacturer in accordance with clause A.1.6.3.1. of this Appendix at which the low-level inducement system is intended to operate.

A.1.10.4.5.2.1. The manufacturer may, with the agreement of the Test Agency, simulate continuous running by extracting reagent from the tank, either whilst the engine is running or is stopped.

A.1.10.4.5.3. When the system is checked for its reaction in the case of a failure other than a lack of reagent in the tank, the engine shall be run for the relevant number of operating hours indicated in Table A.9-3. or, at the choice of the manufacturer, until the relevant counter has reached the value at which the low-level inducement system is activated.

A.1.10.4.5.4. The demonstration of the low level inducement system shall be deemed to be accomplished if, at the end of each demonstration test performed according to clauses A.1.10.4.5.2. and A.1.10.4.5.3. of this Appendix, the manufacturer has demonstrated to the Test Agency that the engine ECU has activated the torque reduction mechanism.

A.1.10.4.6. Demonstration test of the severe inducement system

A.1.10.4.6.1. This demonstration shall start from a condition where the low-level inducement system, where applicable, has been previously activated and may be performed as a continuation of the tests undertaken to demonstrate the low-level inducement system.

A.1.10.4.6.2. When the system is checked for its reaction in the case of lack of reagent in the tank, the engine shall be run until the reagent tank is empty, or has reached the level below 2.5 per cent of nominal full capacity of the tank at which the manufacturer has declared to activate the severe inducement system.

A.1.10.4.6.2.1. The manufacturer may, with the agreement of the Test Agency, simulate continuous running by extracting reagent from the tank, either whilst the engine is running or is stopped.

A.1.10.4.6.3. When the system is checked for its reaction in the case of a failure that is not a lack of reagent in the tank, the engine shall then be run for the relevant number of operating hours indicated in Table A.9-4. or, at the choice of the manufacturer, until the relevant counter has reached the value at which the severe inducement system is activated.

A.1.10.4.6.4. The demonstration of the severe inducement system shall be deemed to be accomplished if, at the end of each demonstration test performed according to clauses A.1.10.4.6.2. and A.1.10.4.6.3. of this Appendix, the manufacturer has demonstrated to the Test Agency that the severe inducement mechanism considered in this Appendix has been activated.

A.1.10.4.7. Alternatively, if the manufacturer chooses, and subject to the agreement of the Test Agency, the demonstration of the inducement mechanisms may be performed on a complete agricultural tractor, construction equipment vehicle or combine harvester in accordance with the requirements of clauses A.1.5.4. and A.1.10.4.1.2. of this Appendix, either by mounting the agricultural tractor, construction equipment vehicle or combine harvester on a suitable test bed or by running it on a test track under controlled conditions.

A.1.10.4.7.1. The construction equipment vehicle, agricultural tractors or combine harvester shall be operated until the counter associated with the selected failure has reached the relevant number of operating hours indicated in Table A.9-4. or, as appropriate, until either the reagent tank is empty or, has reached the level below 2.5 per cent of nominal full capacity of the tank at which the manufacturer has chosen to activate the severe inducement system.

A.1.10.5. Documentation of the demonstration

A.1.10.5.1 A demonstration report shall be created that documents the demonstration of the NCD system. The report shall:

(a) identify the failures examined;

(b) describe the demonstration performed including the applicable test cycle;

(c) confirm that the applicable warnings and inducements were activated as required by this Part;

(d) be included in the information folder as set out in Appendix A.1 of Annex 1.

A.1.11. DESCRIPTION OF THE OPERATOR WARNING AND INDUCEMENT ACTIVATION AND DEACTIVATION MECHANISMS

A.1.11.1 To complement the requirements specified in this Appendix concerning the warning and inducement activation and deactivation mechanisms, clause A.1.11. of this Appendix specifies the technical requirements for an implementation of those activation and deactivation mechanisms.

A.1.11.2. Activation and deactivation mechanisms of the warning system

A.1.11.2.1. The operator warning system shall be activated when the diagnostic trouble code (DTC) associated with a NCM justifying its activation has the status defined in Table A.9-2..

Table A.9-2.

Activation of the Operator Warning System

Failure type	DTC status for activation of the warning system
Poor reagent quality	confirmed and active
Interruption of dosing	confirmed and active
Impeded EGR valve	confirmed and active
Malfunction of the monitoring system	confirmed and active
NO_X threshold, if applicable	confirmed and active

A.1.11.2.2. The operator warning system shall be deactivated when the diagnosis system concludes that the malfunction relevant to that warning is no longer present or when the information including DTCs relative to the failures justifying its activation is erased by a scan tool.

A.1.11.2.2.1 Requirements for erasing " NO_X control information"

A.1.11.2.2.1.1. Erasing / resetting " NO_X control information" by a scan-tool

On request of the scan tool, the following data shall be erased or reset to the value specified in this Appendix from the computer memory (see Table A.9-3.).

Table A.9-3.

Erasing / Rsetting "NO_X Control Information" by a Scan-tool

NO_X control information	Erasable	Resetable
All DTCs	X	
The value of the counter with the highest number of engine operating hours		X
The number of engine operating hours from the NCD counter(s)		X

A.1.11.2.2.1.2. NO_X control information shall not be erased by disconnection of the battery(ies) of the agricultural tractor, construction equipment vehicle or combine harvester.

A.1.11.2.2.1.3. The erasing of " NO_X control information" shall only be possible under “engine-off” conditions.

A.1.11.2.2.1.4. When "NO_X control information" including DTCs are erased, any counter associated with these failures and which is specified in this Appendix shall not be erased, but reset to the value specified in the appropriate clause of this Appendix.

A.1.11.3. Activation and deactivation mechanism of the operator inducement system

A.1.11.3.1. The operator inducement system shall be activated when the warning system is active and the counter relevant to the type of NCM justifying their activation have reached the value specified in Table A.9-4..

A.1.11.3.2. The operator inducement system shall be deactivated when the system no longer detects a malfunction justifying its activation, or if the information including the DTCs relative to the NCMs justifying its activation has been erased by a scan tool or maintenance tool.

A.1.11.3.3. The operator warning and inducement systems shall be immediately activated or deactivated as appropriate according to the provisions of clause A.1.6. of this Appendix after assessment of the reagent quantity in the reagent tank. In that case, the activation or deactivation mechanisms shall not depend upon the status of any associated DTC.

A.1.11.4. Counter mechanism

A.1.11.4.1. General

A.1.11.4.1.1. To comply with the requirements of this Appendix, the system shall contain counters to record the number of hours during which the engine has been operated while the system has detected any of the following NCM:

(a) an incorrect reagent quality;

(b) an interruption of reagent dosing activity;

(c) an impeded EGR valve;

(d) a failure of the NCD system.

A.1.11.4.1.1.1. The manufacturer may use one or more counters for grouping the NCMs indicated in clause A.1.11.4.1.1. of this Appendix.

A.1.11.4.1.2. Each of the counters shall count up to the maximum value provided in a 2 byte counter with 1 hour resolution and hold that value unless the conditions allowing the counter to be reset to zero are met.

A.1.11.4.1.3. A manufacturer may use a single or multiple NCD system counters. A single counter may accumulate the number of hours of 2 or more different malfunctions relevant to that type of counter, none of them having reached the time the single counter indicates.

A.1.11.4.1.3.1. When the manufacturer decides to use multiple NCD system counters, the system shall be capable of assigning a specific monitoring system counter to each malfunction relevant according to this Appendix to that type of counters.

A.1.11.4.2. Principle of counters mechanism

A.1.11.4.2.1. Each of the counters shall operate as follows:

A.1.11.4.2.1.1. If starting from zero, the counter shall begin counting as soon as a malfunction relevant to that counter is detected and the corresponding diagnostic trouble code (DTC) has the status defined in Table A.9-2..

A.1.11.4.2.1.2. In case of repeated failures, one of the following provisions shall apply at the choice of the manufacturer.

(a) If a single monitoring event occurs and the malfunction that originally activated the counter is no longer detected or if the failure has been erased by a scan tool or a maintenance tool, the counter shall halt and hold its current value. If the counter stops counting when the severe inducement system is active, the counter shall be kept frozen at the value defined in Table A.9-4. or a value of greater than or equal to the counter value for severe inducement minus 30 minutes.

(b) The counter shall be kept frozen at the value defined in Table A.9-4. or a value of greater than or equal to the counter value for severe inducement minus 30 minutes.

A.1.11.4.2.1.3. In the case of a single monitoring system counter, that counter shall continue counting if a NCM relevant to that counter has been detected and its corresponding Diagnostic trouble code (DTC) has the status "confirmed and active". It shall halt and hold one of the values specified in clause A.1.11.4.2.1.2. of this Appendix, if no NCM that would justify the counter activation is detected or if all the failures relevant to that counter have been erased by a scan tool or a maintenance tool.

Table A.9-4.

Counters and Inducement

	DTC status for first activation of the counter	Counter value for low-level inducement	Counter value for severe inducement	Frozen value held by the counter
Reagent quality counter	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90 per cent of counter value for severe inducement
Dosing counter	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90 per cent of counter value for severe inducement
EGR valve counter	confirmed and active	≤ 36 hours	≤ 100 hours	≥ 95 per cent of counter value for severe inducement
Monitoring system counter	confirmed and active	≤ 36 hours	≤ 100 hours	≥ 95 per cent of counter value for severe inducement
NO_X threshold, if applicable	confirmed and active	≤ 10 hours	≤ 20 hours	≥ 90 per cent of counter value for severe inducement

A.1.11.4.2.1.4. Once frozen, the counter shall be reset to zero when the monitors relevant to that counter have run at least once to completion of their monitoring cycle without having detected a malfunction and no malfunction relevant to that counter has been detected during 40 engine operating hours since the counter was last held (see Figure A.9-4.).

A.1.11.4.2.1.5. The counter shall continue counting from the point at which it had been held if a malfunction relevant to that counter is detected during a period when the counter is frozen (see Figure A.9-4.).

A.1.12. ILLUSTRATION OF THE ACTIVATION AND DEACTIVATION AND COUNTER MECHANISMS

A.1.12.1. This clause A.1.12. of this Appendix illustrates the activation and deactivation and counter mechanisms for some typical cases. The Figures and descriptions given in clauses A.1.12.2., A.1.12.3. and A.1.12.4. of this Appendix are provided solely for the purposes of illustration in this Appendix and should not be referenced as examples of either the requirements of this Part or as definitive statements of the processes involved. The counter hours in Figures A.9-6. and A.9-7. refer to the maximum severe inducement values in Table A.9-4.. For simplification purposes, for example, the fact that the warning system will also be active when the inducement system is active has not been mentioned in the illustrations given.

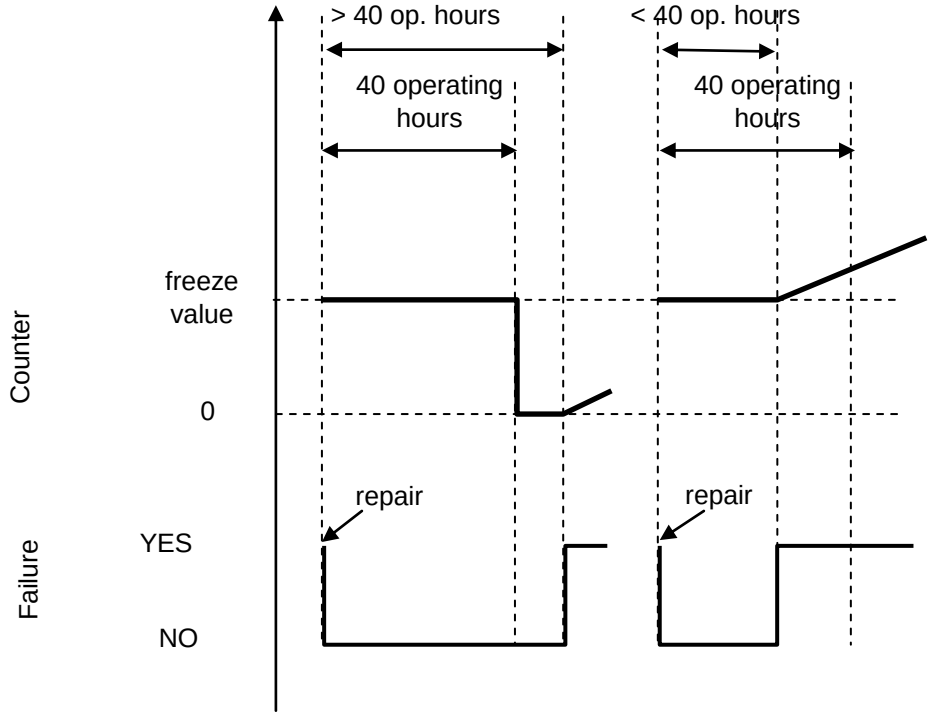


Figure A.9-4.
Reactivation and Resetting to Zero of a Counter after a period when its Value has been frozen

A.1.12.2. Figure A.9-5. illustrates the operation of the activation and deactivation mechanisms when monitoring the reagent availability for four cases:

(a) use case 1: the operator continues operating the agricultural tractor, construction equipment vehicle or combine harvester in spite of the warning until construction equipment vehicle, agricultural tractors or combine harvester operation is disabled;

(b) refilling case 1 ("adequate" refilling): the operator refills the reagent tank so that a level above the 10 per cent threshold is reached. Warning and inducement are de-activated;

(c) refilling cases 2 and 3 ("inadequate" refilling): The warning system is activated. The level of warning depends on the amount of available reagent;

(d) refilling case 4 ("very inadequate" refilling): The low level inducement is activated immediately.

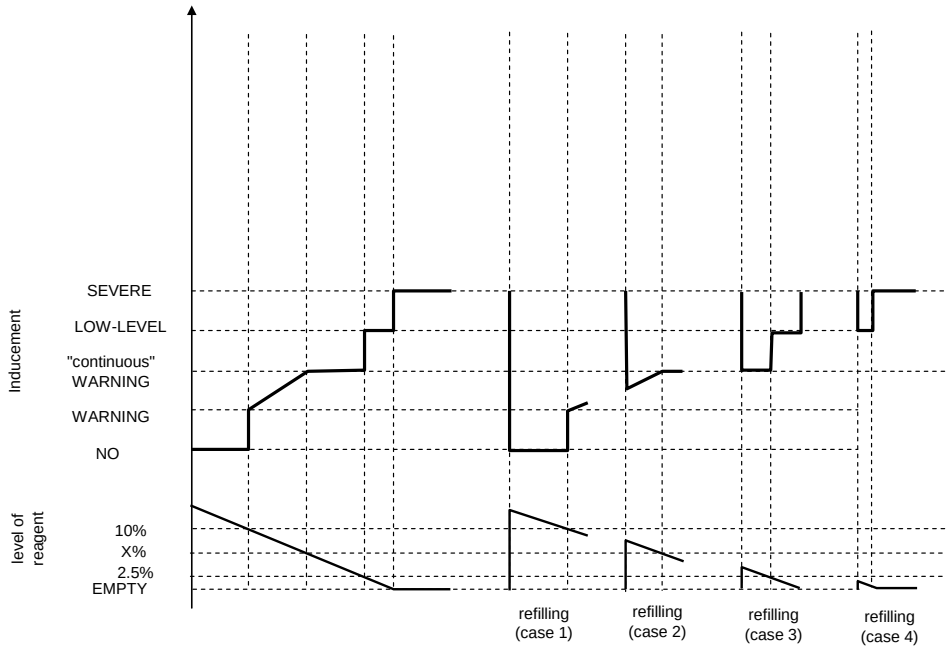


Figure A.9-5.

Reagent Availability

A.1.12.3. Figure A.9-6. illustrates three cases of wrong reagent quality:

(a) use case 1: the operator continues operating the agricultural tractor, construction equipment vehicle or combine harvester in spite of the warning until agricultural tractor, construction equipment vehicle or combine harvester operation is disabled.

(b) repair case 1 ("bad" or "dishonest" repair): after disablement of the agricultural tractor, construction equipment vehicle or combine harvester, the operator changes the quality of the reagent, but soon after, changes it again for a poor quality one. The inducement system is immediately reactivated and agricultural tractor, construction equipment vehicle or combine harvester operation is disabled after 2 engine operating hours.

(c) repair case 2 ("good" repair): after disablement of the agricultural tractor, construction equipment vehicle or combine harvester, the operator rectifies the quality of the reagent. However some time afterwards, he refills again with a poor quality reagent. The warning, inducement and counting processes restart from zero.

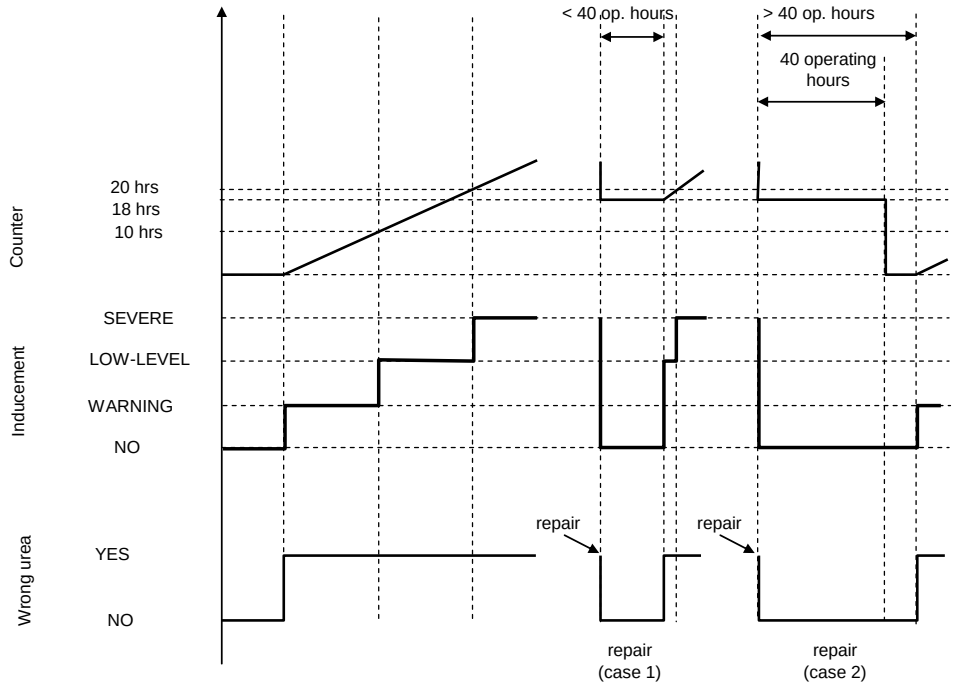


Figure A.9-6.
Filling with Poor Reagent Quality

A.1.12.4. Figure A.9-7. illustrates three cases of failure of the urea dosing system. This figure also illustrates the process that applies in the case of the monitoring failures described in clause A.1.9. of this Appendix.

(a) use case 1: the operator continues operating the agricultural tractor, construction equipment vehicle or combine harvester in spite of the warning until agricultural tractor, construction equipment vehicle or combine harvester operation is disabled.

(b) repair case 1 ("good" repair): after disablement of the agricultural tractor, construction equipment vehicle or combine harvester, the operator repairs the dosing system. However some time afterwards, the dosing system fails again. The warning, inducement and counting processes restart from zero.

(c) repair case 2 ("bad" repair): during the low-level inducement time (torque reduction), the operator repairs the dosing system. Soon after, however, the dosing system fails again. The low-level inducement system is immediately reactivated and the counter restarts from the value it had at the time of repair.

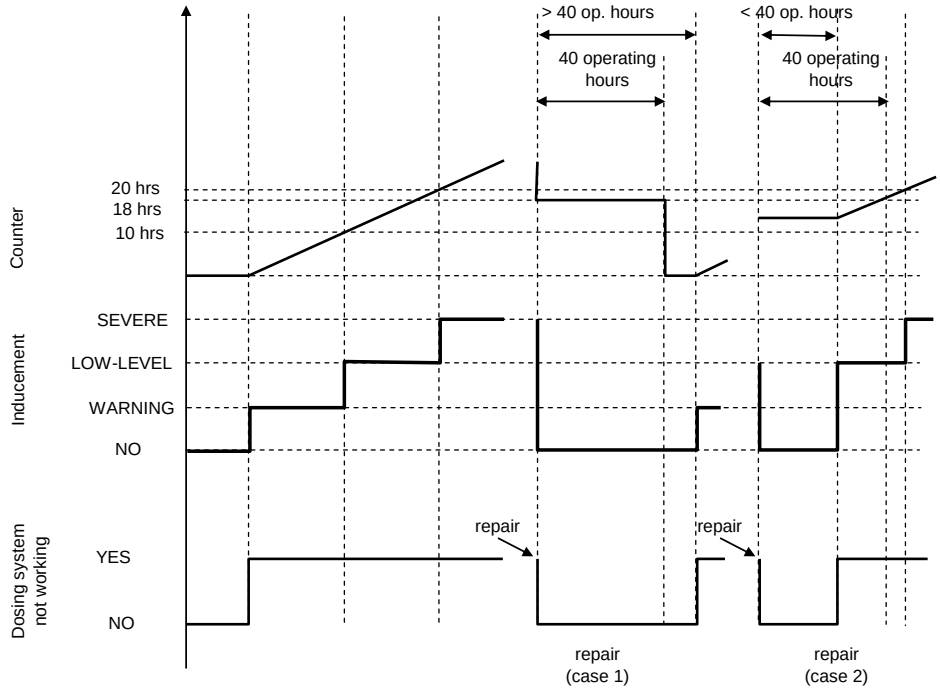


Figure A.9-7.
Failure of the Reagent Dosing System

A.1.13. DEMONSTRATION OF THE MINIMUM ACCEPTABLE REAGENT CONCENTRATION CD_{MIN}

A.1.13.1. The manufacturer shall demonstrate the correct value of CD_{min} during type approval by performing the hot part of the NRTC cycle for engines of sub-category NRE-v-3, NRE-v-4, NRE-v-5 NRE-v-6 and the applicable NRSC for all other categories using a reagent with the concentration CD_{min}.

A.1.13.2. The test shall follow the appropriate NCD cycle(s) or manufacturer defined pre-conditioning cycle, permitting a closed loop NO_X control system to perform adaptation to the quality of the reagent with the concentration CD_{min}.

A.1.13.3. The pollutant emissions resulting from this test shall not exceed the NO_X threshold specified in clause A.1.7.1.1. of this Appendix.

A.1.13.4. Documentation of the demonstration

A.1.13.4.1 A demonstration report shall be created that documents the demonstration of the minimum acceptable reagent concentration. The report shall:

(a) identify the failures examined;

(b) describe the demonstration performed including the applicable test cycle;

(c) confirm that the pollutant emissions arising from this demonstration did not exceed the NO_X threshold specified in point A.1.7.1.1 of this Appendix ;

(d) be included in the information folder as set out in Appendix A.1 of Annex 1.

ANNEX 9 - APPENDIX A.2

TECHNICAL REQUIREMENTS ON PARTICULATE POLLUTANT CONTROL MEASURES, INCLUDING THE METHOD TO DEMONSTRATE THESE MEASURES

A.2.1. INTRODUCTION

This Appendix sets out the requirements to ensure the correct operation of particulate control measures.

A.2.2. GENERAL REQUIREMENTS

The engine shall be equipped with a Particulate Control Diagnostic system (PCD) able to identify the particulate after-treatment system malfunctions considered by this Appendix. Any engine covered by this clause shall be designed, constructed and installed so as to be capable of meeting these requirements throughout the normal life of the engine under normal conditions of use. In achieving this objective it is acceptable that engines which have been used in excess of the emission durability period as specified in Appendix 2 to clause 5 of this Part show some deterioration in the performance and the sensitivity of the PCD.

A.2.2.1. Required information

A.2.2.1.1. If the emission control system requires a reagent e.g. fuel borne catalyst, the characteristics of that reagent, including the type of reagent, information on concentration when the reagent is in solution, operational temperature conditions and reference to international standards for composition and quality must be specified by the manufacturer, in the information document set out in Appendix A.1 of Annex 1.

A.2.2.1.2. Detailed written information fully describing the functional operation characteristics of the operator warning system in clause A.2.4. of this Appendix shall be provided to the Test Agency at the time of type-approval.

A.2.2.1.3. The manufacturer shall provide installation documents that, when used by the OEM, will ensure that the engine, inclusive of the emission control system that is part of the approved engine type or engine family, when installed in the agricultural tractor, construction equipment vehicle or combine harvester will operate, in conjunction with the necessary machinery parts, in a manner that will comply with the requirements of this Annex. This documentation shall include the detailed technical requirements and the provisions of the engine (software, hardware, and communication) needed for the correct installation of the engine in the agricultural tractor, construction equipment vehicle or combine harvester.

A.2.2.2. Operating conditions

A.2.2.2.1. The PCD system shall at a minimum be operational at the applicable control conditions set out in clause 2.4 of this Annex for each engine category. The diagnostic system shall remain operational outside of this range where technically possible.

A.2.2.3. Diagnostic requirements

A.2.2.3.1. The PCD system shall be able to identify the particulate control malfunctions (PCM) considered by this Appendix by means of Diagnostic Trouble Codes (DTCs) stored in the computer memory and to communicate that information off-board upon request.

A.2.2.3.2. Requirements for recording Diagnostic Trouble Codes (DTCs)

A.2.2.3.2.1. The PCD system shall record a DTC for each distinct PCM.

A.2.2.3.2.2. The PCD system shall conclude within the periods of engine operation indicated in Table A9-5. whether a detectable malfunction is present. At this time, a "confirmed and active" DTC shall be stored and the warning system specified in clause A.2.4. of this Appendix shall be activated.

A.2.2.3.2.3. In cases where more than the period of running time indicated in Table A.9-5. is required for the monitors to accurately detect and confirm a PCM (e.g. monitors using statistical models or with respect to fluid consumption on the agricultural tractor, construction equipment vehicle or combine harvester), the Test Agency may permit a longer period for monitoring provided the manufacturer justifies the need for the longer period (for example by technical rationale, experimental results, in-house experience, etc.).

Table A.9-5.

Monitor Types and corresponding period within which a "Confirmed and Active" DTC shall be stored

Monitor type	Period of accumulated running time within which a "confirmed and active" DTC shall be stored
Removal of the particulate after-treatment system	60 minutes of non-idle engine operation
Loss of function of the particulate after-treatment system	240 minutes of non-idle engine operation
Failures of the PCD system	60 minutes of engine operation

A.2.2.3.3. Requirements for erasing Diagnostic trouble codes (DTCs):

(a) DTCs shall not be erased by the PCD system itself from the computer memory until the failure related to that DTC has been remedied;

(b) the PCD system may erase all the DTCs upon request of a proprietary scan or maintenance tool that is provided by the engine manufacturer upon request, or using a pass code provided by the engine manufacturer.

(c) the record of incidents of operation with a DTC confirmed and active that are stored in non-volatile memory as required by clause A.2.5.2. of this Appendix shall not be erased.

A.2.2.3.4. A PCD system shall not be programmed or otherwise designed to partially or totally deactivate based on age of the agricultural tractor, construction equipment vehicle or combine harvester during the actual life of the engine, nor shall the system contain any algorithm or strategy designed to reduce the effectiveness of the PCD system over time.

A.2.2.3.5. Any reprogrammable computer codes or operating parameters of the PCD system shall be resistant to tampering.

A.2.2.3.6. PCD engine family

The manufacturer is responsible for determining the composition of a PCD engine family. Grouping engines within a PCD engine family shall be based on good engineering judgment and be subject to approval by the Test Agency.

Engines that do not belong to the same engine family may still belong to the same PCD engine family.

A.2.2.3.6.1. Parameters defining a PCD engine family

A PCD engine family is characterised by basic design parameters that shall be common to engines within the family.

In order that engines are considered to belong to the same PCD engine family, the following list of basic parameters shall be similar:

(a) working principle of particulate after-treatment system (e.g. mechanical, aerodynamic, diffusional, inertial, periodically regenerating, continuously regenerating, etc.)

(b) methods of PCD monitoring;

(c) criteria for PCD monitoring;

(d) monitoring parameters (e.g. frequency).

These similarities shall be demonstrated by the manufacturer by means of relevant engineering demonstration or other appropriate procedures and subject to the approval of the Test Agency.

The manufacturer may request approval by the Test Agency of minor differences in the methods of monitoring/diagnosing the PCD monitoring system due to engine configuration variation, when these methods are considered similar by the manufacturer and they differ only in order to match specific characteristics of the components under consideration (for example size, exhaust flow, etc.); or their similarities are based on good engineering judgment.

A.2.3. MAINTENANCE REQUIREMENTS

A.2.3.1. The OEM shall provide to all end-users of agricultural tractor, construction equipment vehicle or combine harvester written instructions about the emission control system and its correct operation as required in Appendix 2 to clause 6 of this Part.

A.2.4. OPERATOR WARNING SYSTEM

A.2.4.1. The agricultural tractor, construction equipment vehicle or combine harvester shall include an operator warning system using visual alarms.

A.2.4.2. The operator warning system may consist of one or more lamps, or display short messages.

The system used for displaying these messages may be the same as the one used for other maintenance or NCD purposes

The warning system shall indicate that an urgent repair is required. When the warning system includes a message display system, it shall display a message indicating the reason of the warning (for example “sensor disconnected”, or “critical emission failure”)

A.2.4.3. At the choice of the manufacturer, the warning system may include an audible component to alert the operator. The cancelling of audible warnings by the operator is permitted.

A.2.4.4. The operator warning system shall be activated as specified in clause A.2.2.3.2.2. of this Annex.

A.2.4.5. The operator warning system shall be deactivated when the conditions for its activation have ceased to exist. The operator warning system shall not be automatically deactivated without the reason for its activation having been remedied.

A.2.4.6. The warning system may be temporarily interrupted by other warning signals providing important safety related messages.

A.2.4.7. In the application for type-approval under this Part, the manufacturer shall demonstrate the operation of the operator warning system, as specified in clause A.2.9. of this Appendix.

A.2.5. SYSTEM TO STORE INFORMATION ON OPERATOR WARNING SYSTEM ACTIVATION

A.2.5.1. The PCD system shall include a non-volatile computer memory or counters to store incidents of engine operation with a DTC confirmed and active in a manner to ensure that the information cannot be intentionally deleted.

A.2.5.2. The PCD shall store in the non-volatile memory the total number and duration of all incidents of engine operation with a DTC confirmed and active where the operator warning system has been active for 20 hours of engine operation, or a shorter period at the choice of the manufacturer.

A.2.5.3. It shall be possible for national authorities to read these records with a scan tool.

A.2.5.4. A description of the connection for, and method to read, these records shall be included in the information folder as set out in Appendix A.1 of Annex 1.

A.2.6. MONITORING FOR REMOVAL OF THE PARTICULATE AFTER-TREATMENT SYSTEM

A.2.6.1. The PCD system shall detect the complete removal of the particulate after-treatment system inclusive of the removal of any sensors used to monitor, activate, de-activate or modulate its operation.

A.2.7. ADDITIONAL REQUIREMENTS IN THE CASE OF A PARTICULATE AFTER-TREATMENT SYSTEM THAT USES A REAGENT (EG FUEL BORNE CATALYST)

A.2.7.1. In the case of a confirmed and active DTC for either removal of the particulate after-treatment system or loss of the particulate after-treatment system function the reagent dosing shall be immediately interrupted. Dosing shall re-commence when the DTC is no longer active.

A.2.7.2. The warning system shall be activated if the reagent level in the additive tank falls below the minimum value specified by the manufacturer.

A.2.8. MONITORING FAILURES THAT MAY BE ATTRIBUTED TO TAMPERING

A.2.8.1. In addition to monitoring for removal of the particulate after-treatment system the following failures shall be monitored because they may be attributed to tampering:

(a) loss of the particulate after-treatment system function,

(b) failures of the PCD system, as described in clause A.2.8.3. of this Appendix.

A.2.8.2. Monitoring of loss of the particulate after-treatment system function

The PCD shall detect the complete removal of the particulate after-treatment system substrate ("empty can"). In this case the particulate after-treatment system housing and sensors used to monitor, activate, de-activate or modulate its operation are still present.

A.2.8.3. Monitoring of failures of the PCD system

A.2.8.3.1. The PCD system shall be monitored for electrical failures and for removal or deactivation of any sensor or actuator that prevents it from diagnosing any other failures mentioned in clauses A.2.6.1. and A.2.8.1(a) (component monitoring) of this Appendix.

A non-exhaustive list of sensors that affect the diagnostic capability are those directly measuring differential pressures over the particulate after-treatment system and exhaust temperature sensors for controlling the particulate after-treatment system regeneration.

A.2.8.3.2. Where the failure, removal or deactivation of a single sensor or actuator of the PCD system does not prevent the diagnosis within the required time period of the failures mentioned in clauses A.2.6.1. and A.2.8.1(a) (redundant system) of this Appendix, the activation of the warning system and storage of information on operator warning system activation shall not be required unless additional sensor or actuator failures are confirmed and active.

A.2.9. DEMONSTRATION REQUIREMENTS

A.2.9.1. General

The compliance to the requirements of this Appendix shall be demonstrated during type-approval by performing, as illustrated in Table A.9-6. and specified in clause A.2.9. of this Appendix a demonstration of the warning system activation.

Table A.9-6.

Illustration of the Content of the Demonstration process in accordance with the Provisions in clause A.2.9.3 of this Appendix.

Mechanism	Demonstration elements
Warning system activation specified in clause A.2.4.4. of this Appendix	- 2 activation tests (incl. loss of the particulate after-treatment system function) - Supplementary demonstration elements, as appropriate

A.2.9.2. Engine families and PCD engine families

A.2.9.2.1. In the case where engines of an engine family belong to a PCD engine family that has already been type-approved in accordance with clause A.2.2.3.6. of this Appendix (Figure A.9-8), the compliance of that engine family is deemed to be demonstrated without further testing, provided the manufacturer demonstrates to the Test Agency that the monitoring systems necessary for complying with the requirements of this Appendix are similar within the considered engine and PCD engine families.

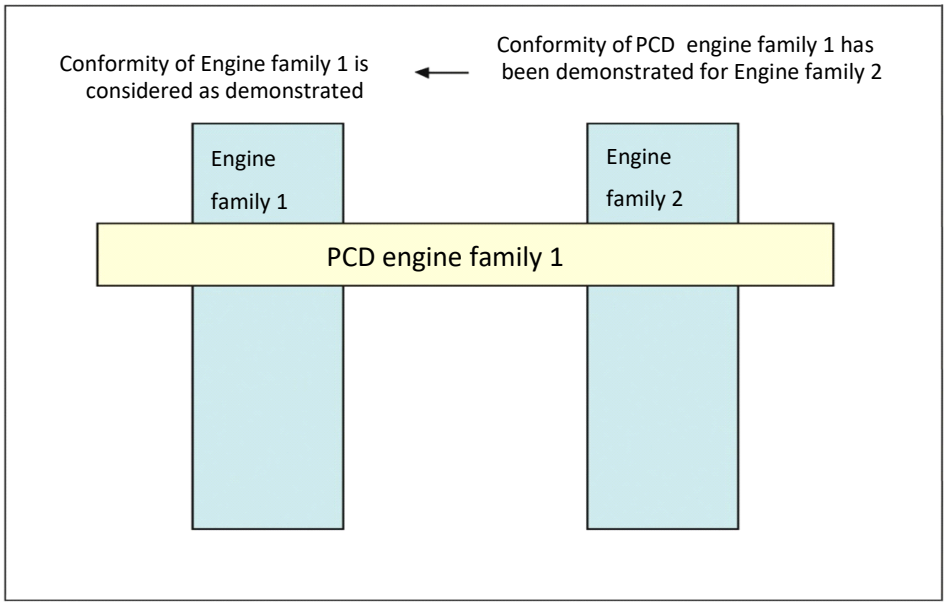


Figure A.9-7.
Failure of the Reagent Dosing System

A.2.9.3. Demonstration of the warning system activation

A.2.9.3.1. The compliance of the warning system activation shall be demonstrated by performing two tests: loss of the particulate after-treatment system function and one failure category considered in clause A.2.6. or clause A.2.8.3. of this Appendix.

A.2.9.3.2. Selection of the failures to be tested

A.2.9.3.2.1. The manufacturer shall provide the Test Agency with a list of such potential failures.

A.2.9.3.2.2. The failure to be considered in the test shall be selected by the Test Agency from this list referred to in clause A.2.9.3.2.1. of this Appendix.

A.2.9.3.3. Demonstration

A.2.9.3.3.1. For the purpose of this demonstration, a separate test shall be performed for the loss of the particulate after-treatment system function set out in clause A.2.8.2. of this Appendix and for the failures laid down in clauses A.2.6. and A.2.8.3. of this Appendix. The loss of the particulate after-treatment system

function shall be created by a complete removal of the substrate from the particulate after-treatment system housing.

A.2.9.3.3.2. During a test, no failure shall be present other than the one addressed by the test.

A.2.9.3.3.3. Prior to starting a test, all DTC shall have been erased.

A.2.9.3.3.4. At the request of the manufacturer, and with the agreement of the Test Agency, the failures subject to testing may be simulated.

A.2.9.3.3.5. Detection of failures

A.2.9.3.3.5.1. The PCD system shall respond to the introduction of a failure selected as appropriate by the Test Agency in accordance to the provisions of this Appendix. This is considered to be demonstrated if activation occurs within the number of consecutive PCD test-cycles given in Table A.9-7..

When it has been specified in the monitoring description and agreed by the Test Agency that a specific monitor needs more PCD test-cycles to complete its monitoring than indicated in Table A.9-7., the number of PCD test-cycles may be increased by up to 50 per cent.

Each individual PCD test-cycle in the demonstration test may be separated by an engine shut-off. The time until the next start-up shall take into consideration any monitoring that may occur after engine shut- off and any necessary condition that must exist for monitoring to occur at the next start-up.

Table A.9-7.

Monitor Types and corresponding number of PCD Test Cycles within which a "Confirmed and Active" DTC shall be stored

Monitor type	Number of PCD test cycles within which a "confirmed and active" DTC shall be stored
Removal of the particulate after-treatment system	2
Loss of function of the particulate after-treatment system	8
Failures of the PCD system	2

A.2.9.3.3.6. PCD test cycle

A.2.9.3.3.6.1. The PCD test cycle considered in this clause A.2.9. of this Appendix for demonstrating the correct performance of the particulate after-treatment system monitoring system is the hot NRTC cycle for engines of sub-category NRE-v-3, NRE-v-4, NRE-v-5, NRE-v-6 and the applicable NRSC for all other categories.

A.2.9.3.3.6.2. On request of the manufacturer and with approval of the Test Agency, an alternative PCD test- cycle (e.g. other than the NRTC or the NRSC) can be

used for a specific monitor. The request shall contain elements (technical considerations, simulation, test results, etc.) demonstrating:

(a) the requested test-cycle results in a monitor that will run in real world operation, and

(b) the applicable PCD test-cycle specified in clause A.2.9.3.3.6.1. of this Appendix is less appropriate for the considered monitoring.

A.2.9.3.3.7 Configuration for demonstration of the warning system activation

A.2.9.3.3.7.1. The demonstration of the warning system activation shall be done by tests performed on an engine test bench.

A.2.9.3.3.7.2. Any components or subsystems not physically mounted on the engine, such as, but not limited to, ambient temperature sensors, level sensors, and operator warning and information systems, that are required in order to perform the demonstrations shall be connected to the engine for that purpose, or shall be simulated, to the satisfaction of the Test Agency.

A.2.9.3.3.7.3. If the manufacturer chooses, and subject to the agreement of the Test Agency, the demonstration tests may be performed, notwithstanding clause A.2.9.3.3.7.1. of this Appendix, on a complete agricultural tractor, construction equipment vehicle or combine harvester either by mounting the agricultural tractor, construction equipment vehicle or combine harvester on a suitable test bed or by running it on a test track under controlled conditions.

A.2.9.3.4. The demonstration of the warning system activation is deemed to be accomplished if, at the end of each demonstration test performed in accordance with to clause A.2.9.3.3. of this Appendix the warning system has been properly activated and the DTC for the selected failure has a "confirmed and active" status.

A.2.9.3.5 Where a particulate after-treatment system that uses a reagent is subjected to a demonstration test for loss of the particulate after-treatment system function or removal of the particulate after-treatment system it shall also be confirmed that reagent dosing has been interrupted.

A.2.9.3.6. Documentation of the demonstration

A.2.9.3.6.1 A demonstration report shall be created that documents the demonstration of the PCD system. The report shall:

(a) identify the failures examined;

(b) describe the demonstration performed including the applicable test cycle;

(c) confirm that the applicable warnings were activated as required by this Part;

(d) be included in the information folder as set out in Appendix A.1 of Annex 1.

ANNEX 9 - APPENDIX A.3

TECHNICAL DETAILS FOR PREVENTION OF TAMPERING

A.3.1. For engine types and engine families that use an ECU as part of the emission control system the manufacturer shall provide to the Test Agency a description of the provisions taken to prevent tampering with and modification of the ECU including the facility for updating using a manufacturer-approved programme or calibration;

A.3.2. For engine types and engine families that use mechanical devices as part of the emission control system the manufacturer shall provide to the Test Agency a description of the provisions taken to prevent tampering with and modification of the adjustable parameters of the emission control system. This shall include the tamper resistant components such as carburettor limiter caps or sealing of carburettor screws or special screws not adjustable by user.

A.3.2.1. The manufacturer shall demonstrate to the Test Agency that the adjustable parameters of the emission control system cannot be easily tampered by applying reasonable forces, either:

(a) using the tools supplied together with the engine; or,

(b) using ordinary tools such as screwdriver, pliers (including cutting pliers) or wrenches.

Ordinary tools do not include: most cutting or grinding tools, drills and rotary cutters, or tools that generate excessive heat or flame.

A.3.3. For the purpose of this Appendix, engines from different engine families may be further combined into families based upon the type and design of tamper prevention measures utilised. In order to place engines from different engine families into the same tamper prevention engine family the manufacturer shall provide confirmation to the Test Agency that the measures used to prevent tampering are similar. In this case the requirements of clauses A.3.1. and A.3.2. of this Appendix may be performed for one representative engine and the corresponding documentation used during the type approval of all engines in the same tamper prevention engine family.

A.3.4. Manufacturers shall provide a warning in the operator's manual stating that tampering with the engine voids the type-approval of that particular engine.

ANNEX 10

PARAMETERS FOR THE DEFINITION OF ENGINE TYPES AND ENGINE FAMILIES, AND THEIR OPERATION MODES

1. ENGINE TYPE

The technical features of an engine type shall be those defined in its information document drafted in accordance with the template set out in Appendix A.1 of Annex 1.

1.1. Operating mode (speed operation)

An engine type may be type-approved as a constant speed engine or as a variable speed engine, as defined respectively in clauses 2.1 10. and 2.1.89 of this Part.

1.1.1. Variable speed engines

1.1.1.1. In the case that, as allowed by clause 1.1.2 of this Part, a variable-speed engine of a particular category is used in place of a constant-speed engine of the same category, the parent engine (for the purposes of type-approval) and all engine types within the engine family (for the purposes of conformity of production), shall be tested using the applicable variable speed NRSC and additionally, where required, the applicable transient cycle. A variable speed engine of a particular category used in a constant speed operation of the same category need not be additionally tested using the applicable constant speed NRSC.

1.1.2. Constant speed engines

1.1.2.1. The constant speed governor function shall be engaged during constant speed operation. The governors of constant speed engines may not be required to continuously maintain speed exactly constant. The speed may decrease below the speed at zero load, so that the minimum speed occurs near the engine's point of maximum power. This is typically in the region of 0.1 to 10 per cent.

1.1.2.2. In the case that the engine type is equipped with an idle speed for start-up and shut-down, the engine shall be installed in a manner to ensure that the constant speed governor function is engaged prior to increasing the load-demand to the engine from the no- load setting.

1.1.2.3. Constant speed engine types equipped with alternative speeds

A constant speed engine shall not be designed to operate with variable speed. In the case that the engine type is equipped with alternative speeds the requirements of this clause shall additionally be met.

1.1.2.3.1. In the case that the engine type is the parent engine, the engine shall meet the applicable limit values when tested using the applicable NRSC test cycle at each constant speed applicable to the engine type. Separate test reports shall be produced and included in the information package for each NRSC.

1.1.2.3.2. In the case of all engine types within the engine family, when subject to a conformity of production emissions test the engine shall meet the applicable limit values using the applicable NRSC test cycle at each constant speed applicable to the engine type.

1.1.2.3.3. Each constant speed applicable to the engine type that is permitted by the manufacturer shall be listed in item number 3.2.1. of Appendix A.3 to Annex 1.

1.1.2.3.4. The engine shall be installed in a manner to ensure that:

(a) the engine is stopped prior to resetting the constant speed governor to an alternative speed; and,

(b) the constant speed governor is only set to the alternative speeds permitted by the engine manufacturer.

1.1.2.3.5. The instructions to the OEM and end-users set out in Appendices 1 and 2 to clause 6 of this Part shall include information on the correct installation and operation of the engine according to the requirements of clauses 1.1.2.2. and 1.1.2.3. of this Annex.

2. ENGINE FAMILY CRITERIA

2.1. General

An engine family is characterised by design parameters. These shall be common to all engines within the engine family. The engine manufacturer may decide, which engines belong to an engine family, as long as the membership criteria listed in clause 2.4 of this Annex are respected. The engine family shall be approved by the Test Agency. The manufacturer shall provide to the Test Agency the appropriate information relating to the emissions levels of the members of the engine family.

2.2. Engine categories, operating mode (speed operation) and power range.

2.2.1. An engine family shall only comprise engine types within the same engine category as set out in clause 1.1. of this Part.

2.2.2. The engine family shall comprise only engine types of the same speed operation as set out in Appendix 1. to clause 1. of this Part.

2.2.3. Engine families covering more than one power range

2.2.3.1. An engine family may cover more than one power range for the same speed operation within the same engine (sub-)category. Consistent with clause 5.1.1. of this Part, in this case the parent engine (for the purposes of type-approval) and all engine types within the same engine family (for the purposes of conformity of production) shall, with respect to the applicable power ranges:

(a) meet the most stringent emissions limit values;

(b) be tested using the test cycles that correspond to the most stringent emissions limit values;

(c) be subject to the earliest applicable dates for type-approval and placing on the market set out in clause 12. of this Part.

In order to maintain, when the engine is installed in the agricultural tractor, construction equipment vehicle or combine harvester, the principle of clause 5.1.1. of this Part, the instructions for OEMs set out in Appendices 1 and 2 to clause 6. of this Part shall include the statement that the installation shall not permanently constrain an engine to only deliver power within the power range of a sub-category with a more stringent emissions limit than the sub-category in which the engine is type-approved.

2.2.3.2. For the purpose of allocating a type-approval sub-category to an engine family covering more than one power range the manufacturer and Test Agency shall decide the sub-category that most closely reflects the criteria in clause 2.2.3.1. of this Annex.

2.3. Special cases

2.3.1. Interactions between parameters

In some cases there may be interaction between parameters, which may cause emissions to change. This shall be taken into consideration to ensure that only engines with similar exhaust emissions characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.3.2. Devices or features having a strong influence on emissions In case of devices or features, which are not listed in clause 2.4. of this Annex and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer using good engineering judgment, and shall be notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.3.3. Additional criteria

In addition to the parameters listed in clause 2.4. of this Annex, the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

2.4. Parameters defining the engine family

2.4.1. Combustion cycle

(a) 2-stroke cycle;

(b) 4-stroke cycle;

(c) Rotary engine;

(d) Others.

2.4.2. Configuration of the cylinders

2.4.2.1. Position of the cylinders in the block

(a) Single

(b) V;

(c) In-line;

(d) Opposed;

(e) Radial;

(f) Others (F, W, etc.).

2.4.2.2. Relative position of the cylinders

Engines with the same block may belong to the same engine family as long as their bore centre-to-centre dimensions are the same.

2.4.3. Main cooling medium

(a) Air;

(b) Water;

(c) Oil.

2.4.4. Swept volume per cylinder

2.4.4.1. Engine with a swept volume per cylinder ≥ 750 cm^3

In order for engines with a swept volume per cylinder of ≥ 750 cm^3 to be considered to belong to the same engine family, the spread of the swept volume

per cylinder shall not exceed 15 per cent of the largest swept volume per cylinder within the engine family.

2.4.4.2. Engine with a swept volume per cylinder < 750 cm^3

In order for engines with a swept volume per cylinder of < 750 cm^3 to be considered to belong to the same engine family, the spread of the swept volume per cylinder shall not exceed 30 per cent of the largest swept volume per cylinder within the engine family.

2.4.4.3. Engines with greater spread in swept volume per cylinder

Notwithstanding clauses 2.4.4.1. and 2.4.4.2. of this Annex, engines with a swept volume per cylinder that exceeds the spread defined in those clauses may be considered to belong to the same engine family with the approval of the Test Agency. The approval shall be based on technical elements (calculations, simulations, experimental results etc.) showing that exceeding the spread does not have a significant influence on the exhaust emissions.

2.4.5. Method of air aspiration

(a) Naturally aspirated;

(b) Pressure charged;

(c) Pressure charged with charge cooler.

2.4.6. Fuel type

(a) Diesel (non-road gas-oil);

(b) Ethanol for dedicated compression ignition engines (ED95);

(c) Petrol (E10);

(d) Ethanol (E85);

(e) Natural gas/Biomethane:

(1) Universal fuel — high calorific fuel (H-gas) and low calorific fuel (L-gas);

(2) Restricted fuel — high calorific fuel (H-gas);

(3) Restricted fuel — low calorific fuel (L-gas);

(4) Fuel specific (LNG);

(f) Liquid Petroleum Gas (LPG);

2.4.7. Fuelling arrangement

(a) Liquid-fuel only;

(b) Gaseous-fuel only;

(c) Dual-fuel type 1A;

(d) Dual-fuel type 1B;

(e) Dual-fuel type 2A;

(f) Dual-fuel type 2B;

(g) Dual-fuel type 3B.

2.4.8. Combustion chamber type/design

(a) Open chamber;

(b) Divided chamber;

(c) Other types.

2.4.9. Ignition Type

(a) Spark ignition;

(b) Compression ignition.

2.4.10. Valves and porting

(a) Configuration;

(b) Number of valves per cylinder.

2.4.11. Fuel supply type

(a) Pump, (high pressure) line and injector;

(b) In-line pump or distributor pump;

(c) Unit injector;

(d) Common rail;

(e) Carburettor;

(f) Port injector;

(g) Direct injector;

(h) Mixing unit;

(i) Other.

2.4.12. Miscellaneous devices

(a) Exhaust gas recirculation (EGR);

(b) Water injection;

(c) Air injection;

(d) Others.

2.4.13. Electronic control strategy

The presence or absence of an ECU on the engine is regarded as a basic parameter of the engine family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same engine family, i.e. the reasons why these engines can be expected to satisfy the same emissions requirements.

The electronic governing of speed does not need to be in a different engine family from those with mechanical governing. The need to separate electronic engines from mechanical engines should only apply to the fuel injection characteristics, such as timing, pressure, rate shape, etc.

2.4.14. Exhaust after-treatment systems

The function and combination of the following devices are regarded as membership criteria for an engine family:

(a) Oxidation catalyst;

(b) DeNO_X system with selective reduction of NO_X (addition of reducing agent);

(c) Other $DeNO_X$ systems;

(d) Particulate after-treatment system with passive regeneration:

(1) wall-flow,

(2) non-wall-flow;

(e) Particulate after-treatment system with active regeneration:

(1) wall-flow,

(2) non-wall-flow;

(f) Other particulate after-treatment systems;

(g) Other devices.

When an engine has been certified without exhaust after-treatment system, whether as parent engine or as member of the engine family, then this engine, when equipped with an oxidation catalyst (not with particulate after-treatment system), may be included in the same engine family, if it does not require different fuel characteristics.

If it requires specific fuel characteristics (e.g. particulate after-treatment systems requiring special additives in the fuel to ensure the regeneration process), the decision to include it in the same engine family shall be based on technical elements provided by the manufacturer. These elements shall indicate that the expected emissions level of the equipped engine complies with the same limit value as the non-equipped engine.

When an engine has been certified with exhaust after-treatment system, whether as parent engine or as member of an engine family, whose parent engine is equipped with the same exhaust after-treatment system, then this engine, when equipped without exhaust after-treatment system, shall not be added to the same engine family.

2.4.15. Dual-fuel engines

All engine types within a dual-fuel engine family shall belong to the same type of dual-fuel engines defined in clause 2 of Annex 7 of this Part (for example type 1A, type 2B, etc.), and operate with the same types of fuel or when appropriate with fuels declared according to this Part as being of the same range(s).

In addition to belonging to the same dual-fuel type, they shall have a maximum gas energy ratio on the applicable test cycle (GER_{cycle}) within the range 70 to 100 per cent of that of the engine type with the highest GER_{cycle}.

2.4.16. Reserved

2.4.17. Reserved.

3. CHOICE OF THE PARENT ENGINE

3.1. General

3.1.1. Once the engine family has been agreed by the Test Agency, the parent engine of the engine family shall be selected using the primary criterion of the highest fuel delivery per stroke per cylinder at the declared maximum torque speed. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion of highest fuel delivery per stroke at rated speed.

3.1.2. The Test Agency may conclude that the worst-case emissions rate of the engine family can best be characterised by testing an alternative or an additional engine. In this case, the parties involved shall have the appropriate information to determine the engines within the engine family likely to have the highest emissions level.

3.1.3. If engines within the engine family incorporate other variable features which may be considered to affect exhaust emissions, these features shall also be identified and taken into account in the selection of the parent engine.

3.1.4. If engines within the engine family meet the same emissions values over different emissions durability periods, this shall be taken into account in the selection of the parent engine.

3.2. Special case

In order to select the parent engine in the case of any constant speed engine family containing one or more engine types with alternative constant speeds as set out in clause 1.1.2.3. of this Annex, the evaluation of the requirements of clause 3.1. of this Annex shall be applied to each constant speed of each engine type.

ANNEX 11

COP ADMINISTRATIVE PROCEDURE

Administrtative procedure for CoP shall be as per AIS-137 (Part 6) COP Administrative Procedure titled "Administrative Procedure for Type Approval and Conformity of Production for M and N Category Vehicles, Two and Three Wheelers and Agricultural Tractors/Construction Equipment Vehicles (CEVs) / Power Tillers/ Combine Harvesters Engines as per CMV Rules 115, 116 and 126"

"

ANNEX 12

POWER MEASUREMENT PROCEDURE

1. SCOPE

1.1. This Annex applies to the representation of the curves as a function of engine speed of the power and torque at full load, indicated by the manufacturer for internal combustion engines to be used:

1.1.1. In agricultural tractors, construction equipment vehicles and combine harvesters.

1.2. The internal combustion engines belong to one of the following categories:

1.2.1. Reciprocating internal combustion engines (positive-ignition or compression-ignition), but excluding free piston engines;

1.2.2. Rotary piston engines (positive-ignition or compression-ignition).

2. DEFINITIONS

2.1. "*Approval of an engine*" means the approval of an engine type with regard to its gross power measured in accordance with the procedure specified in Apeendix 1 to this annex;

2.2. "*Approval of an engine family*" means the approval of the members of an engine family with regard to their gross power in accordance with the procedure specified in Appendix 3 or 4 of this Annex

2.3. "*Engine type*" means a category of engines which do not differ in such essential engine characteristics as defined in AIS-007;

2.4. "*Engine family*" means a manufacturer's grouping of engines which, through their design, fulfil the grouping criteria laid down in Appendix 3 to this annex;

2.5. "*Parent engine*" means an engine selected from an engine family in such a way that it complies with requirements set out in Appendix 3 of this annxure;

2.6. "~~*Net*~~ *Gross power*" means the power obtained on a test bench at the end of the crankshaft or its equivalent at the corresponding engine speed with the auxiliaries and equipment listed in Table 1 of Apeendix 1 to this annex, determined under reference atmospheric conditions;

2.7. "*Rated Gross power*" means engine Gross power as declared by the manufacturer at rated speed;

2.8. "*Maximum Gross power*" means the maximum value of the Gross power measured at full engine load;

2.9. "*Rated speed*" means the maximum full load speed allowed by the governor, as designed by the manufacturer, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer;

2.10. "*Maximum Gross power speed*" means the engine speed at which the maximum Gross power is obtained, as specified by the manufacturer;

2.11. "*Maximum torque speed*" means the engine speed at which the maximum torque is obtained, as specified by the manufacturer;

2.12. "*Maximum torque*" means the maximum value of the gross torque measured at full engine load.

3. APPLICATION FOR APPROVAL

3.1. The application for approval of an engine type or an engine family with regard to the measurement of the gross power shall be submitted by the manufacturer or by his duly accredited representative.

3.2. It shall be accompanied by the following documents in triplicate: description of the engine type or engine family comprising all the relevant particulars referred to in AIS007.

3.3. An engine representative of the engine type to be approved, or the parent engine, in case of an engine family, fitted with the equipment prescribed in Apeendix 1 to this annex, shall be submitted to the Test Agency conducting the approval tests.

4. APPROVAL

4.1. If the power of the engine submitted for approval pursuant to this Part was measured according to the specifications of clause 5. below, approval of the engine type or family shall be granted.

5. SPECIFICATIONS AND TESTS

5.1. General

The components liable to affect the power of the engine shall be so designed, constructed and assembled as to enable the engine in normal use, despite the vibrations to which it may be subjected, to comply with the provisions of this Part.

5.2. Description of tests for internal combustion engines

5.2.1. The gross power test shall consist of a run at full throttle for positive-ignition engines and at fixed full-load fuel injection pump setting for compression-ignition engines, the engine being equipped as specified in Table 1 of Apeendix 1 to this annex.

5.2.2. Measurements shall be taken at a sufficient number of engine speeds to define correctly the power, torque and specific fuel consumption curves between the lowest and the highest engine speeds recommended by the manufacturer. This range of speeds must include the rotational speeds at which the engine produces its rated gross power, its maximum power and its maximum torque.

5.2.3. The fuel used shall be as specified in gazette Notification

.

5.2.4. Measurements shall be carried out according to the provisions of Appendix 1 to this Annex.

5.2.5. The test report shall contain the results and all the calculations required to determine the gross power, as listed in the Appendix 2 to this Annex together with the characteristics of the engine, as listed in AIS 007.

5.3. Interpretation of Results

5.3.1. Gorss power

The gross power declared by the manufacturer for the type of engine (or parent engine) shall be accepted if it does not differ by more than the values indicated in the table below, from the corrected values measured by the Test Agency on the engine submitted for testing.

Engine Type	**Rated gross power [%]**	**Other measurement points on the curve [%]**	**Tolerance for engine speed [%]**
General	±2	±4	±1.5
Petrol fuelled spark ignited engines with governor	±4	±6	±4
Petrol fuelled spark ignited engines without governor	±4	±10	±4

5.3.2. Rated speed

The rated speed declared by the manufacturer shall not deviate by more than 100 min^{-1} from the value measured by the Test Agency on the engine submitted for testing. For spark ignited petrol fuelled engines, the rated speed declared by the manufacturer shall not deviate from the value measured by the Test Agency on the engine submitted for testing by more than 150 min^{-1} for engines provided with governor and for engines without governor 350 min^{-1} or 4 per cent, whichever is smaller.

5.3.3 Reserved

5.3.4. Engine family

In case of compliance of the parent engine to the conditions in clauses 5.3.1. and 5.3.2., the acceptance is automatically extended to all the declared curves of the family members.

6. CONFORMITY OF PRODUCTION

6.1. Engines approved under this Part shall be so manufactured as to conform to the type approved.

6.2. The minimum requirements for conformity of production control procedures set forth in Appendix 4 to this annex shall be complied with.

7. PENALTIES FOR NON-CONFORMITY OF PRODUCTION

7.1. The approval granted in respect of an engine type or an engine family pursuant to this Part may be withdrawn if the requirements set forth in clause 6.1. above

are not met or if an engine or an engine family bearing the approval mark does not conform to the type approved.

8. MODIFICATION AND EXTENSION OF APPROVAL OF AN ENGINE TYPE OR ENGINE FAMILY

8.1. Every modification of an engine type or an engine family with regard to the characteristics in AIS-007, as amdeded form time to time , shall be notified to the Test Agency which approved the engine type or engine family. The Test Agency may then either:

8.1.1. Consider that the modifications made are unlikely to have any appreciable adverse effect and that in any case the engine still complies with the requirements; or

8.1.2. Require a further test report from the Test Agency responsible for conducting the tests.

8.2. Confirmation or refusal of approval, specifying the alterations shall be communicated to the applicant.

ANNEX 12 - APPENDIX 1

METHOD FOR MEASURING INTERNAL COMBUSTION ENGINE GROSS POWER

1. These provisions apply to the method for determining the power curve at full load of an internal combustion engine operated under intermittent speed as a function of engine speed and the rated speed and rated gross power of an internal combustion engine under constant speed.

2. TEST CONDITIONS

2.1. The engine shall have been run-in according to the manufacturer's recommendations.

2.2. If the power measurement can be carried out only on an engine with the gearbox mounted, the efficiency of the gearbox shall be taken into account.

2.3. Auxiliaries and equipment

2.3.1. Auxiliaries and equipment to be fitted

During the test, the auxiliaries necessary for the engine operation in the intended application (as listed in Table 1) shall be installed on the test bench as far as possible in the same position as in the intended application.

2.3.2. Auxiliaries and equipment to be removed

Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test. The following non-exhaustive list is given as a sample:

(i) Air compressor for brakes

(ii) Power steering compressor

(iii) Suspension compressor

(iv) Air-conditioning system

Where auxiliaries cannot be removed, the power they absorb in the unloaded condition may be determined and added to the measured engine power (see note h of Table 1). If this value is greater than 3 per cent of the maximum power at the test speed it may verified by the Test Agency.

Table 1

Equipment and Auxiliaries to be Installed for the Test to Determine Engine Power

Num-ber	Equipment and auxiliaries	Fitted for emission test
1	Inlet system	
	Inlet manifold	Yes
	Crankcase emission control system	Yes
	Air flow meter	Yes
	Air filter	Yes[a]
	Inlet silencer	Yes[a]
	Induction-heating device of inlet manifold	Yes, standard production equipment. If possible to be set in the most favourable condition
2	Exhaust system	
	Exhaust aftertreatment	Yes, standard production equipment
	Exhaust manifold	Yes, standard production equipment
	Connecting pipes	Yes[b]
	Silencer	Yes[b]
	Tail pipe	Yes[b]
	Exhaust brake	No[c]
	Pressure charging device	Yes
3	Fuel supply pump	Yes

4	Carburation equipment	
	Carburettor	Yes
	Electronic control system, air flow meter, etc.	Yes
	Equipment for gas engines	
	Pressure reducer	Yes
	Evaporator	Yes
	Mixer	Yes
5	Fuel injection equipment (petrol and diesel)	
	Pre-filter	Yes
	Filter	Yes
	Pump	Yes
	High-pressure pipe	Yes
	Injector	Yes
	Electronic control system, sensors, etc.	Yes
	Governor/control system	Yes
	Automatic full-load stop for the control rack depending on atmospheric conditions	Yes
6	Liquid-cooling equipment	
	Radiator	No
	Fan	No
	Fan cowl	No
	Water pump	Yes[e]
	Thermostat	Yes[f]
7	Air cooling	
	Cowl	No[g]

	Fan or Blower	No[g]
	Temperature-regulating device	No
8	Electrical equipment	
	Generator	Yes[h]
	Spark distribution system	Yes
	Coil or coils	Yes
	Wiring	Yes
	Spark plugs	Yes
	Electronic control system including knock sensor/spark retard system	Yes
9	Pressure charging equipment	
	Compressor driven either directly by the engine and/or by the exhaust gases	Yes
	Charge air cooler	Yes[g, i]
	Coolant pump or fan (engine-driven)	No[g]
	Coolant flow control device	Yes
10	Auxiliary test-bed fan	Yes, if necessary
11	Anti-pollution device	Yes, standard production equipment[j]
12	Starting equipment	Yes or test bed equipment[k]
13	Lubricating oil pump	Yes

[a] The complete inlet system shall be fitted as provided for the intended application:

(i) Where there is a risk of an appreciable effect on the engine power;
(ii) In the case of naturally aspirated spark ignition engines;

(iii) When the manufacturer requests that this should be done.

In other cases, an equivalent system may be used and a check should be made to ascertain that the intake pressure does not differ by more than 100 Pa from the upper limit specified by the manufacturer for a clean air filter.

[b] The complete exhaust system shall be fitted as provided for the intended application:

(i) Where there is a risk of an appreciable effect on the engine power;
(ii) In the case of naturally aspirated spark ignition engines;

(iii) When the manufacturer requests that this should be done.

In other cases, an equivalent system may be installed provided the pressure measured does not differ by more than 1,000 Pa from the upper limit specified by the manufacturer.

[c] If an exhaust brake is incorporated in the engine, the throttle valve shall be fixed in the fully open position.

[d] The fuel feed pressure may be adjusted, if necessary, to reproduce the pressure existing in the particular engine application (particularly when a "fuel return" system is used).

[e] The cooling-liquid circulation shall be operated by the engine water pump only. Cooling of the liquid may be produced by an external circuit, such that the pressure loss of this circuit and the pressure at the pump inlet remain substantially the same as those of the engine cooling system.

[f] The thermostat may be fixed in the fully open position.

[g] When the cooling fan or blower is fitted for the test, the power absorbed shall be added to the results, except for engines where such auxiliaries are an integral part of the engine (i.e.: cooling fans of air cooled engines directly fitted on the crankshaft). The fan or blower power shall be determined at the speeds used for the test either by calculation from standard characteristics or by practical tests.

[h] Minimum power of the generator: the electrical power of the generator shall be limited to that necessary for operation of auxiliaries which are indispensable for engine operation. If the connection of a battery is necessary, a fully charged battery in good condition shall be used.

[i] Charge air-cooled engines shall be tested with charge air cooling, whether liquid - or air-cooled, but if the manufacturer prefers, a test bench system may replace the air cooler. In either case, the measurement of power at each speed shall be made with the maximum pressure drop and the minimum temperature drop of the engine air across the charge air cooler on the test bench system as those specified by the manufacturer.

[j] These may include, for example, exhaust-gas recirculation (EGR system), catalytic converter, thermal reactor, secondary air-supply system and fuel evaporation protecting system.

[k] The power for electrical or other starting systems shall be provided from the test bed.

2.4. Setting conditions

The setting conditions for the test to determine the gross power are indicated in Table 2.

Table 2

Setting Conditions

1.	Setting of carburettor(s), evaporator/pressure regulator	In accordance with the manufacturer's production specifications, and used without further alteration for the particular application.
2.	Setting of injection pump delivery system	
3.	Ignition or injection timing (timing curve)	
4.	Governor setting	
5.	Emission control devices	
6.	Boost Control	

3. DATA TO BE RECORDED

3.1. Data to be recorded are those indicated in clause 4 of the Appendix 2 to this Annex. Performance data shall be obtained under stabilised operating conditions with an adequate fresh air supply to the engine. Combustion chambers may contain deposits, but in limited quantity. Test conditions, such as inlet air temperature, shall be selected as near to reference conditions (see clause 5.2. of this Annex) as possible in order to minimise the magnitude of the correction factor.

3.2. The temperature of the inlet air to the engine shall be measured within the inlet ductwork. The inlet depression measurement shall be made at the same point. The thermometer or thermocouple shall be shielded from fuel spray-back and radiant heat and located directly in the air stream. A sufficient number of locations shall be used to give a representative average of the inlet temperature.

3.3. The inlet depression shall be measured downstream of the entry ducts, air filter, inlet silencer or speed-limiting device (if fitted).

3.4. The absolute pressure at the entry to the engine downstream of the compressor and heat exchanger, if fitted, shall be measured in the inlet manifold and at any other point where pressure has to be measured to calculate correction factors.

3.5. The exhaust back pressure shall be measured at a point at least three pipe diameters downstream from the outlet flange(s) of the exhaust manifold(s) and downstream at the turbocharger(s), if fitted. The location shall be specified.

3.6. No data shall be taken until torque, speed and temperatures have been maintained substantially constant for at least one minute.

3.7. The engine speed during a run or reading shall not deviate from the selected speed by more than ±1 per cent or ±10 min, whichever is greater.

3.8. Observed brake load, fuel consumption and inlet air temperature data shall be taken simultaneously and shall be the average of two stabilised consecutive values which do not vary more than 2 per cent for the brake load.

3.9. The temperature of the coolant at the outlet from the engine shall be kept at the value specified by the manufacturer.

If no temperature is specified by the manufacturer, the temperature shall be 353 K ± 5 K. For air-cooled engines, the temperature at a point indicated by the manufacturer shall be kept within +0/-20 K of the maximum value specified by the manufacturer in the reference conditions.

3.10. For C.I. engines, the fuel temperature shall be measured at the inlet of the fuel injection pump and maintained within 306 - 316 K (33-43 °C) for positive-ignition engines the fuel temperature shall be measured as near as possible to the inlet of the carburettor or assemby of fuel injectors and maintained within 293–303 K (20-30 °C).

3.11. The temperature of the lubricating oil measured in the oil pump or at the outlet from the coil cooler, if fitted, shall be maintained within the limits established by the engine manufacturer.

3.12. An auxiliary regulating system may be used if necessary to maintain the temperatures within the limits specified in clauses 3.9., 3.10. and 3.11. above of this Appendix.

4. ACCURACY OF MEASUREMENTS

4.1. Torque: ±1 per cent of measured torque. The torque measuring system shall be calibrated to take friction losses into account. The accuracy in the lower half of the measuring range of the dynamometer bench may be ±2 per cent of measured torque.

4.2. Engine speed: 0.5 per cent of measured speed.

4.3. Fuel consumption: ±1 per cent of measured consumption.

4.4. Fuel temperature: ±2 K.

4.5. Engine inlet air temperature: ±2 K.

4.6. Barometric pressure: ±100 Pa.

4.7. Depression in inlet system: ±50 Pa.

4.8. Back-pressure in exhaust system: ±200 Pa.

5. POWER CORRECTION FACTORS

5.1. Definition

The power correction factor is the coefficient to determine the engine power under the reference atmospheric conditions specified in 5.2. below.

$$P_o = \alpha P$$

where:

P_o is the corrected power (i.e. power under reference atmospheric conditions)

α is the correction factor (α_a or α_d)

P is the measured power (test power)

5.2. Reference atmospheric conditions

5.2.1. Temperature (T_o): 298 K (25 °C)

5.2.2. Dry pressure (P_{so}): 99 kPa

The dry pressure is based on a total pressure of 100 kPa and a water vapour pressure of 1 kPa.

5.3. Test atmospheric conditions

The atmospheric conditions during the test shall be the following:

5.3.1. Temperature (T)

For positive-ignition engines: 288 K < T < 308 K

For compression-ignition engines: 283 K < T < 313 K

5.3.2. Pressure (p_s)

$$90 \text{ kPa} < p_s < 110 \text{ kPa}$$

5.4. Determination of correction factor α_a and α_d [1]

5.4.1. Naturally aspirated or pressure-charged positive-ignition engine

The correction factor α_a is obtained by applying the formula:

$$\alpha_a = \left(\frac{99}{p_s}\right)^{1.2} * \left(\frac{T}{298}\right)^{0.6}$$

where:

p_s is the total dry atmospheric pressure in kilopascals (kPa); i.e. the total barometric pressure minus water vapour pressure,

T is the absolute temperature in kelvins (K) of the air drawn in by the engine.

Conditions to be complied with in the laboratory

For a test to be valid, the correction factor must be such that

$$0.93 < \alpha_a < 1.07$$

If these limits are exceeded, the corrected value obtained shall be given and the test conditions (temperature and pressure) precisely stated in the test report.

5.4.2. Compression-ignition engines - factor α_d

The power correction factor (α_d) for compression-ignition engines at constant fuel rate is obtained by applying the formula:

$$\alpha_d = (f_a)^{fm}$$

where:

f_a is the atmospheric factor

f_m the characteristic parameter for each type of engine and adjustment

---

1. The test may be carried out in air-conditioned test room where the atmospheric conditions may be controlled

In the case of engines fitted with automatic air temperature control, if the device is such that at full load at 25 °C no heated air is added, the test shall be carried out with the device fully closed. If the device is still operating at 25 °C then the test is made with the device operatingnormally and the exponent of the temperature term in the correction factor shall be taken as zero (no temperature correction).

5.4.2.1. Atmospheric factor f_a

This factor indicates the effects of environmental conditions (pressure, temperature and humidity) on the air drawn in by the engine. The atmospheric factor formula differs according to the type of engine.

5.4.2.1.1. Naturally aspirated and mechanically pressure charged engines

$$f_a = \left(\frac{99}{p_s}\right) * \left(\frac{T}{298}\right)^{0.7}$$

5.4.2.1.2. Turbocharged engines with or without charge air cooling

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} * \left(\frac{T}{298}\right)^{1.5}$$

5.4.2.2. Engine factor f_m

f_m is a function of qc (fuel flow corrected) as follows:

$f_m = 0.036\ q_c - 1.14$

and

$q_c = q/r$

Where:

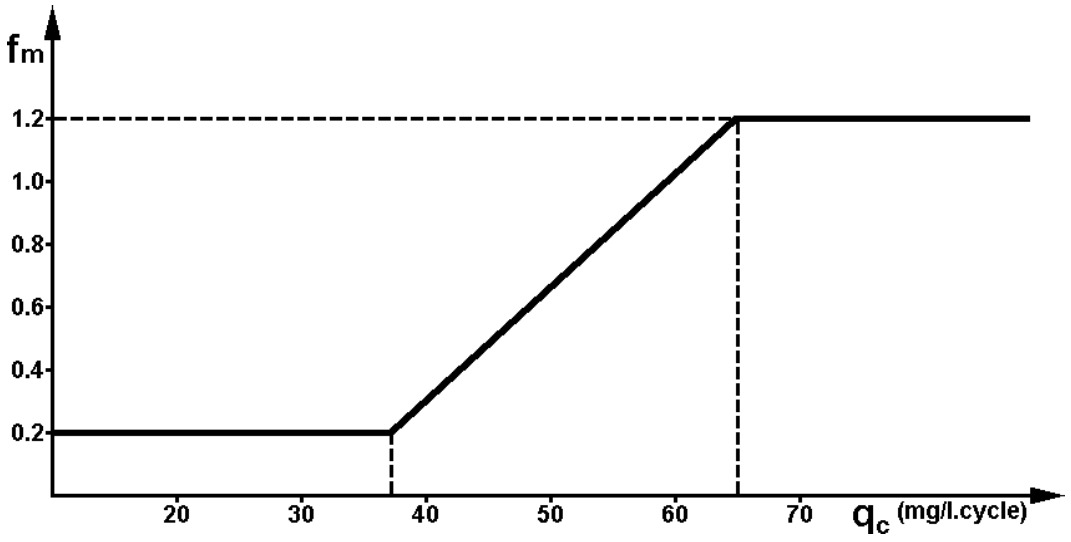
q is the fuel flow in milligram per cycle per litre of total swept volume (mg/(l.cycle))

r is the pressure ratio of compressor outlet and compressor inlet in case of multiple turbochargers r represents the total compression ratio (r = 1 for naturally aspirated engines)

This formula is valid for a value interval of q_c included between 37.2 mg/(l.cycle) and 65 mg/(l.cycle).

For q_c values lower than 37.2 mg/(l.cycle), a constant value of f_m equal to 0.2 ($f_m = 0.2$) will be taken.

For q_c values higher than 65 mg/(l.cycle), a constant value of f_m equal to 1.2 ($f_m = 1.2$) will be taken (see figure):



5.4.2.3. Conditions to be complied with in the laboratory

For a test to be valid, the correction factors α_a must be such that

$$0.93 < \alpha_a < 1.07$$

If these limits are exceeded, the corrected value obtained shall be given and the test conditions (temperature and pressure) precisely stated in the test report.

ANNEX 12 - APPENDIX 2

RESULTS OF TESTS FOR MEASURING GROSS ENGINE POWER

This form shall be completed by the laboratory performing the test.

1. Test conditions

1.1. Location of exhaust back-pressure measuring point

1.2. Location of inlet depression measuring point

1.3. Characteristics of the dynamometer

1.3.1. Make: ..... Model: .....

1.3.2 Type: .....

2. Fuel

2.1. For positive-ignition engines operating on liquid fuel

2.1.1. Make: .....

2.1.2. Specification: .....

2.1.3. Anti-knock additive (lead, etc): .....

2.1.3.1. Type: .....

2.1.3.2. Content: ..... mg/l

2.1.4. Octane number RON: .....(ASTM D 26 99-70)

2.1.4.1. Specify density: .....g/cm^3 at 288 K

2.1.4.2. Lower calorific value: ..... kJ/kg

2.2. For positive-ignition engines operating on gaseous fuel

2.2.1. Make: .....

2.2.2. Specification: .....

2.2.3. Storage pressure: .....bar

2.2.4. Utilization pressure: .....bar

2.2.5. Lower calorific value: ..... kJ/kg

2.3. For compression-ignition engines operating on gaseous fuels

2.3.1. Feed system: gas

2.3.2. Specification of gas used: .....

2.3.3. Fuel oil/gas proportion: .....

2.3.4. Lower calorific value: .....

2.4. For compression-ignition engines operating on liquid fuel

2.4.1. Make: .....

2.4.2. Specification of fuel used: .....

2.4.3. Cetane number (ASTM D 976-71): .....

2.4.4. Specify density: .....g/cm^3 at 288 K
2.4.5. Lower calorific value: .....kJ/kg
3. Lubricant
3.1. Make: .....
3.2. Specification: .....
3.3. SAE viscosity: .....
4. Detailed results of measurements*

Engine speed, min^{-1}			
Measured torque, Nm			
Measured power, kW			
Measured fuel flow, g/h			
Barometric pressure, kPa			
Water vapour pressure, kPa			
Inlet air temperature, K			
Power to be added for equipment and auxiliaries in excess of Table 1, kW Total, kW	No. 1 No. 2 No. 3		
Power correction factor			
Corrected power, kW			
Corrected torque, Nm			
Corrected specific fuel consumption g/(kWh)[2]			
Cooling liquid temperature at outlet, K			
Lubricating oil temperature at measuring point, K			
Air temperature after pressure-charger, K [1]			
Fuel temperature at injection pump inlet, K			
Air temperature after charge air cooler, K [1]			
Pressure after pressure-charger, kPa			
Pressure after charge air cooler, kPa			
Inlet depression, Pa			
Exhaust back-pressure, Pa			
Fuel delivery, mm^3/stroke or cycle [1]			

* The characteristic curves of the gross power and the gross torque shall be drawn as a function of the engine speed.

[1] Strike out what does not apply.

[2] Calculated with the gross power for compression-ignition and positive-ignition engines, in the latter case multiplied by the power correction factor.

ANNEX 12- APPENDIX 3

ESSENTIAL CHARACTERISTICS OF THE ENGINE FAMILY

1. GENERAL

An engine family is characterized by design parameters. These shall be common to all engines within the family. The engine manufacturer may decide which engines belong to an engine family, as long as the membership criteria listed in clause 3 below are respected. The engine family shall be approved by the Test Agency.

2. SPECIAL CASES

2.1. Interactions between parameters

In some cases there may be interaction between parameters, which may cause emissions to change. This shall be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.2. Devices or features having a strong influence on emissions

In case of devices or features, which are not listed in clause 3 below and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer using good engineering judgment, and shall be notified to the Test Agency. It shall then be taken into account as a criterion for creating a new engine family.

2.3. Additional criteria

In addition to the parameters listed in clause 3 below, the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

3. PARAMETERS DEFINING THE ENGINE FAMILY

3.1. Combustion cycle:

(a) 2-stroke cycle;

(b) 4-stroke cycle;

(c) Rotary engine;

(d) Others.

3.2. Fuel type:

(a) Diesel;

(b) Petrol;

(c) Gaseous (NG or LPG).

3.3. Configuration of the cylinders

3.3.1. Position of the cylinders in the block:

(a) V;

(b) In-line;

(c) Radial;

(d) Others (F, W, etc.).

3.3.2. Relative position of the cylinders

Engines with the same block may belong to the same family as long as their bore centre-to-centre dimensions are the same.

3.4. Main cooling medium:

(a) Air;

(b) Water;

(c) Oil.

3.5. Individual cylinder displacement

Within 85 per cent and 100 per cent for engines with a unit cylinder displacement ≥ 0.75 dm^3 of the largest displacement within the engine family.

Within 70 per cent and 100 per cent for engines with a unit cylinder displacement < 0.75 dm^3 of the largest displacement within the engine family.

3.6. Method of air aspiration:

(a) Naturally aspirated;

(b) Pressure charged;

(c) Pressure charged with charge cooler.

3.7. Combustion chamber type/design:

(a) Open chamber;

(b) Divided chamber;

(c) Other types.

3.8. Valves and porting:

(a) Configuration;

(b) Number of valves per cylinder;

(c) Cylinder wall;

(d) Crankcase.

3.9. Fuel supply type

3.9.1. For compression ignition engines:

(a) Pump, (high pressure) line and injector;

(b) In-line pump or distributor pump;

(c) Unit injector;

(d) Common rail.

3.9.2. For positive ignition engines:

(a) Carburettor;

(b) Port fuel injection;

(c) Direct injection.

3.10. Miscellaneous devices:

(a) Exhaust gas recirculation (EGR);

(b) Water injection;

(c) Air injection;

(d) Others.

3.11. Electronic control strategy

The presence or absence of an Electronic Control Unit (ECU) on the engine is regarded as a basic parameter of the family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engines can be expected to satisfy the same emission requirements.

The electronic governing of speed does not need to be in a different family from those with mechanical governing. The need to separate electronic engines from mechanical engines should only apply to the fuel injection characteristics, such as timing, pressure, rate shape, etc.

3.12. Exhaust after-treatment systems

The function and combination of the following devices are regarded as membership criteria for an engine family:

(a) Oxidation catalyst;

(b) $DeNO_x$ system with selective reduction of NO_x (addition of reducing agent);

(c) Other $DeNO_x$ systems;

(d) Particulate trap with passive regeneration;

(e) Particulate trap with active regeneration;

(f) Other particulate traps;

(g) Other devices.

When an engine has been certified without an after-treatment system, whether as a parent engine or as a member of the family, then this engine, when equipped with an oxidation catalyst (not with particulate trap), may be included in the same engine family, if it does not require different fuel characteristics.

If it requires specific fuel characteristics (e.g. particulate traps requiring special fuel additives to ensure the regeneration process), the decision to include it in the same family shall be based on technical elements provided by the manufacturer. These elements shall indicate that the expected emission level of the equipped engine complies with the same limit value as the non-equipped engine.

When an engine has been certified with an after-treatment system, whether as a parent engine or as a member of a family, where the parent engine is equipped with the same after-treatment system, then this engine, when equipped without an after-treatment system, shall not be added to the same engine family.

ANNEX 12 - APPENDIX 4
CHECKS ON CONFORMITY OF PRODUCTION

1. GENERAL

These requirements are consistent with tests to be held to check conformity of production (COP), according to clause 6.2. of this Part.

2. TEST PROCEDURES

The methods of testing and measuring instruments shall be those described in Apeendix 1 to this annex.

3. COLLECTION OF SAMPLES AS PER AIS-137 (Part 6)

3.1. Case of an engine type

One engine has to be chosen. If after the test of clause 5.1. below, the engine is not considered as conforming to the requirements of this Part, two more engines have to be tested.

3.2. Case of a family of engines

In case of an approval granted to a family of engines the COP shall be run on one member of the family, which is not the parent engine. In case of failure of the COP test, the two more engines shall be of the same member type.

4. MEASUREMENT CRITERIA

4.1. Gross power of internal combustion engine

Measurements shall be taken at a sufficient number of engine speeds to define correctly the power and torque curves between the lowest and the highest engine speeds recommended by the manufacturer as defined in clauses 2.9. and 2.11. of this Part.

Engine type	Rated gross power (torque) [%]	Other measurement points on the curve [%]	Tolerance for engine speed [%]
General	± 5	± 10	± 5
Petrol fuelled spark ignited engines with governor	± 8	± 12	± 8
Petrol fuelled spark ignited engines without governor	± 8	± 20	± 8

5. EVALUATION OF RESULTS

If the gross power and fuel consumption figures of the second and/or third engine of clause 3. do not fulfil the requirements of clause 4. above, the production shall be considered not to conform to the requirements of this Part and the provision of clause 7. of this Part shall be put into effect.

ANNEX 12 - APPENDIX 5
TECHNICAL DATA OF REFERENCE FUELS

Test fuel shall be as per Gazette Notification:

ANNEX 13

IN-SERVICE MONITORING PROCEDURE

0. INTRODUCTION

Agricultural tractors, construction equipment vehicles and combine harvesters specified under this Part and manufactured after the 1st April 2026 shall be monitored for gaseous pollutant emission from in-service internal combustion engines as per procedure laid down in this Annex, as amended from time to time.

0.1 Scope

This Annex applies to monitoring of the gaseous pollutant emissions from the following categories of in- service engines of emission Bharat Stage (CEV/TREM)-V installed in agricultural tractors, construction equipment vehicles and combine harvesters:

(a) NRE-v-5;

(b) NRE-v-6. .

1. **GENERAL REQUIREMENTS FOR IN-SERVICE MONITORING**

1.1. For the purposes of this Annex 'category of agricultural tractor, construction equipment vehicle and combine harvester ' means a grouping of agricultural tractors, construction equipment vehicles and combine harvesters that fulfil the same generic function(s),

1.2. The manufacturer shall obtain access to engines installed in agricultural tractors, construction equipment vehicles and combine harvesters in order to conduct in-service monitoring tests.

When conducting the in-service monitoring test the manufacturer shall perform the emissions data sampling, measurement of exhaust parameters and data logging of an in-service engine installed in a agricultural tractor, construction equipment vehicle and combine harvester operated over its normal operating duty cycles until reaching the minimum test duration as set out in clause 2 of Appendix 2.

1.3. Engines subject to in-service monitoring test shall:

(a) be installed in one of the most representative categories of agricultural tractor, construction equipment vehicle and combine harvester for the selected engine type or, where applicable, engine family;

(b) be placed on the Indian market after 1st Aperil 2026;

(c) have a maintenance record to show that the engine has been properly maintained and serviced in accordance with the manufacturer's recommendations;

(d) exhibit no indications of misuse (e.g. overloading or misfuelling), or other factors (such as tampering) that could affect the gaseous pollutant emissions performance;

(e) be in conformity with the ~~EU~~ type-approval documents with regard to the components of the emission control system(s) installed in the engine and in the agricultural tractor, construction equipment vehicle and combine harvester.

1.4. The following engines shall be considered as non-eligible for in-service monitoring test, and an alternative engine shall be selected:

(a) engines without a communication interface which permits the collection of the necessary Electronic Control Unit (ECU) data as specified in Appendix 7;

(b) engines with an ECU with missing data or a data protocol that does not enable clear identification and validation of the necessary signals.

1.5. Engines where the collection of ECU data influences the agricultural tractor, construction equipment vehicle and combine harvester gaseous pollutant emissions or performance shall be considered as non-eligible for in-service monitoring test. An alternative engine shall only be selected if the manufacturer can substantially prove to the Test Agency the absence of any defeat strategy.

2. PLAN FOR MONITORING IN-SERVICE ENGINES

2.1. The manufacturer shall submit to the Test Agency that has granted approval of an engine type or, where applicable, engine family, within 1 month of the start of production of the approved engine type or engine family, the initial plan for monitoring in-service engines.

2.2. The initial plan shall include the criteria used for and the justification of the selection of:

(a) the engine families or engine types and category(ies) of agricultural tractors, construction equipment vehicles and combine harvesters included in the plan;

(b) the list of particular engine(s) and agricultural tractor, construction equipment vehicle and combine harvester selected for in-service monitoring test, if already identified;

(c) the chosen testing scheme.

2.3. Manufacturers shall submit to the Test Agency an updated plan for monitoring in-service engines whenever the list of particular engine(s) and non-road mobile machinery selected is completed or revised. The updated plan shall be include a justification of the criteria used for the selection and the reasons for revising the previous list, if applicable.

2.4. The Test Agency shall approve the initial and subsequently updated plan(s) or request the appropriate amendments within 2 months of their submission, and shall ensure that the final plan includes the widest variety of engine types and categories of agricultural tractors, construction equipment vehicles and combine harvesters.

2.5. Each initial or subsequently updated monitoring plan shall be approved by the Test Agency before the testing of engines and agricultural tractor, construction equipment vehicle and combine harvester identified therein is started.

2.6. Testing scheme

The manufacturer shall choose one of the following testing schemes for in-service monitoring:

2.6.1. Testing scheme based on the Emission Durability Period (EDP)

2.6.1.1. Testing 9 engines with an accumulated service of less than 30 % of the EDP. Test results shall be submitted to the Test Agency by 31 March 2028.

2.6.1.2. Testing 9 engines with an accumulated service higher than 70 % of the EDP. Test reports shall be submitted to the Test Agency by 31 March 2030.

2.6.1.3. When the manufacturer cannot fulfil the requirement under clause 2.6.1 due to an unavailability of engines with the required service accumulation, the Test Agency shall not reject a change to the testing scheme based on a 4 years' period set out in clause 2.6.2. Engines already tested in accordance with clause 2.6.1 shall remain valid under clause 2.6.2.

2.6.2. Testing scheme based on a 4 years' period:

Testing nine engines per year during 4 consecutive years. Test reports shall be submitted to the Test Agency every year.

2.6.2.1. The test results of the first nine engines shall be submitted 12 months after the first engine was installed in a agricultural tractor, construction equipment vehicle and combine harvester and not later than 18 months after starting the production of the approved engine type or engine family.

2.6.2.2. When the manufacturer demonstrates to the Test Agency that no engine has been installed in a agricultural tractor, construction equipment vehicle and combine harvester 18 months after starting the production, the test results shall be submitted after the installation of the first engine, on a date agreed with the Test Agency.

2.6.2.3. Small volume manufacturers

The number of engines tested shall be adapted in case of small volume manufacturers:

(a) manufacturers producing only two engine families shall submit six engines' test results per year;

(b) manufacturers producing more than 250 engines per year of one single engine family shall submit three engine's test results per year;

(c) manufactures producing between 125 and 250 engines per year of one single engine family shall submit two engine's test results per year;

(d) manufactures producing less than 125 engines per year of one single engine family shall submit one engine's test results per year.

The Test Agency shall verify the declared production quantities.

2.6.3. The manufacturer may conduct more tests than those established by the testing schemes set out in clause 2.6.1 and 2.6.2.

2.6.4. Multiple testing of the same engine to provide data for the consecutive service accumulation stages in accordance with clause 2.6.1 and 2.6.2 is allowed but not mandatory

3. **TEST CONDITIONS**

The in-service monitoring test shall reflect the engine's performance when installed in a non-road mobile machinery, in actual operation and operated by its usual professional operator.

3.1. Operator

3.1.1. The agricultural tractor's, construction equipment vehicle's and combine harvester's operator performing the in-service monitoring test may be other than the usual professional one if the operator demonstrates enough skills and training to the Test Agency.

3.1.2. The manufacturer shall provide detailed explanations to the Test Agency on the usual operator's skills and training, and demonstrate that the selected operator is adequate for the in-service monitoring test.

3.2. Agricultural tractor's, construction equipment vehicle's and combine harvester's operation

3.2.1. The test shall be performed during the complete (or partial) agricultural tractor's, construction equipment vehicle's and combine harvester's actual operation.

3.2.2. When the manufacturer demonstrates to the Test Agency that it is not possible to comply with clause 3.2.1, the test duty cycle shall represent, as far as possible, the agricultural tractor's, construction equipment vehicle's and combine harvester's actual operation.

3.2.2.1. The representative test duty cycle shall be determined by the manufacturer in agreement with the Test Agency.

3.2.3. Regardless of whether the test is conducted during the actual operation of the non-road mobile machinery or under a representative test duty cycle, it shall:

(a) assess the actual operation of the majority of in-service population of the selected category(ies) of non- road mobile machinery;

(b) not include a disproportionate amount of activity at idle speed;

(c) comprise of sufficient load activity to achieve the minimum test duration set out in clause 2 of Appendix 2.

3.3. Ambient conditions

The test shall be conducted under ambient conditions meeting the following requirements:

3.3.1. Atmospheric pressure shall be equal or greater than 82.5 kPa;

3.3.2. Temperature shall be equal or greater than 273 K (0°C) and equal or less than 315 k (42°C).

3.4. Lubricating oil, fuel and reagent

The lubricating oil, fuel and reagent (for exhaust after-treatment systems that use a reagent to reduce gaseous pollutant emissions) shall comply with the specifications issued by the manufacturer.

3.4.1. The fuel shall be market fuel or reference fuel as specified in the Gazette Notification, as amdemeded time to time.

3.4.2. To demonstrate compliance with clause 3.4, the manufacturer shall take samples and retain them for a period of 12 months, or less if agreed by the Test Agency.

3.4.3. Reagent samples shall not be frozen.

3.5. Operating sequence

Operating sequence is the elapsed time of uninterrupted agricultural tractor, construction equipment vehicle and combine harvester operation and continuous data sampling during an in-service monitoring test.

The in-service monitoring test shall be conducted in one single operating sequence, except under the combined data sampling method set out in clause 4.2, where several operating sequences are combined in a single in-service monitoring test.

4. **DATA SAMPLING METHODS**

4.1. Continuous data sampling

Continuous data sampling shall be used when one single operating sequence is equal or more than the minimum test duration set out in clause 2 of Appendix 2.

4.1.1. A maximum of 3 minutes of data may be excluded due to one or several episodes of temporary signal loss.

4.2. Combined data sampling

As alternative to clause 4.1, the data sampling may be obtained from combining the results of several operating sequences.

4.2.1. Combined data sampling shall be used only when the test conditions do not enable reaching the minimum test duration set out in clause 2 of Appendix 2 with one single operating sequence despite attempting to achieve this, or when the category(ies) of agricultural tractors, construction equipment vehicles and combine harvesters selected for testing is employed in multiple working activities with different relevant duty cycle(s).

4.2.2. The following additional requirements shall be fulfilled when applying combined data sampling:

(a) the different operating sequences shall be obtained using the same agricultural tractor, construction equipment vehicle and combine harvester and engine;

(b) the combined data sampling shall contain a maximum of three operating sequences;

(c) each operating sequence in the combined data sampling shall contain a minimum of one Non-Road Transient Cycle (NRTC) work;

(d) the operating sequences in the combined data sampling shall be obtained and put together in a chronological order;

(e) the data analysis shall be applied to the complete combined data sampling;

(f) the maximum period elapsed between the first and last operating sequence shall be 72 hours;

(g) combined data sampling shall not be used if an engine malfunction occurs, as set out in clause 8 of Appendix 2.

5. ECU DATA STREAM

5.1. The ECU shall provide data stream information to the measurement instruments or data logger of the PEMS in accordance with the requirements set out in Appendix 7.

5.2. Conformity of information

5.2.1. The conformity of all the signals provided by the ECU in accordance with Table 1 of Appendix 7 shall be verified by the Test Agency and shall meet the requirements set out in Appendix 6 of this Annex.

5.2.2 Manufacturers shall check in accordance with the method set out in Appendix 6 the conformity of the ECU torque signal during the in-service monitoring of engines installed on agricultural tractors, construction equipment vehicles and combine harvesters using a PEMS.

6. **TEST PROCEDURES AND DATA PRE-PROCESSING AND VALIDATION**

6.1. In-service monitoring tests shall be conducted using Portable Emissions Measurement System (PEMS) in accordance with Appendix 1.

6.2. Manufacturers shall comply with the test procedure set out in Appendix 2 with regard to the in-service monitoring of engines installed on agricultural tractors, construction equipment vehicles and combine harvesters using a PEMS.

6.3. Manufacturers shall follow the procedures set out in Appendix 3 for the pre-processing of the data resulting of the in-service monitoring of engines installed on on-non-road mobile machinery using a PEMS.

6.4. Manufacturers shall follow the procedures set out in Appendix 4 for the determination of valid events during an in-service monitoring test of engines installed on on-non-road mobile machinery using a PEMS.

7. TEST DATA AVAILABILITY

No data shall be modified or removed from a test. The entire data sampling shall be retained at least for 10 years by the manufacturer and made available upon request to the Test Agency.

8. CALCULATIONS

Manufacturers shall follow the procedures set out in Appendix 5 for the gaseous pollutant emissions calculations for the in-service monitoring of engines installed on agricultural tractors, construction equipment vehicles and combine harvesters using a PEMS.

9. CONFIRMATORY TEST

9.1. Approval authorities may conduct a confirmatory in-service monitoring test in order to have an independent in-service monitoring measurement.

9.2. The confirmatory test shall be performed on the engine family/type and category(ies) of agricultural tractors, construction equipment vehicles and combine harvesters specified in clause 2; a particular engine fitted in a relevant agricultural tractor, construction equipment vehicle and combine harvester shall be tested according to the requirements set out in this Annex.

10. REPORTING PROCEDURES

10.1. Test Agency shall draft a test report of the in-service monitoring of engines installed on agricultural tractors, construction equipment vehicles and combine harvesters using a PEMS for each engine tested. The test report shall show the

activities and results of the in-service monitoring and include at least the information required by data entries 1 to 11 of Appendix 8.

10.2. Instantaneous measured data and instantaneous calculated data

10.2.1. Instantaneous measured data and instantaneous calculated data shall not be included in the test report but shall be kept by the manufacturer and made available upon request to the Test Agency for the period set out in clause 7.

10.2.2. Instantaneous measured data and instantaneous calculated data shall include at least the information required by data entries I-1 to I-2.20 of Appendix 8.

10.3. Publicly available information

To provide public aces to certain data and information relating to the results of type approvals and moitoring results of in-service engines, the manufacturer shall provide a separate report containing the information required by the following data entries of Appendix 8: 1.1, 2.2, 2.4, 3.2, 6.3, 6.4.1, 6.10, clause 9 and clause 10.

Information for data entry 6.3 shall be provided at regional level, providing approximate geographic location only.

ANNEX 13 - APPENDIX 1

PORTABLE EMISSIONS MEASUREMENT SYSTEM

1. The PEMS shall include the following measurement instruments:

(a) gas analysers to measure the concentrations of the gaseous pollutant emissions set out in the first paragraph of clause 1 of Appendix 2;

(b) an Exhaust Flow Meter (EFM) based on the averaging Pitot or equivalent principle;

(c) sensors to measure the ambient temperature and pressure;

(d) other measurement instruments required for the in-service monitoring test;

PEMS shall also include:

(a) a transfer line to transport the extracted samples from the sampling probe to the gas analysers, including a sampling probe;

(b) a data logger to store the data collected from the ECU;

(c) PEMS may include a Global Positioning System (GPS).

2. **MEASUREMENT INSTRUMENTS REQUIREMENTS**

2.1. Measurement Instruments shall meet the requirements on calibration and performance checks set out in clause 8.1 of Annex 4 of this Part. Special attention shall be given to perform the following actions:

(a) the vacuum-side leak verification of the PEMS as set out in clause 8.1.8.7 of Annex 4 of this Part;

(b) the response and updating-recording verification of the gas analyser as set out in clause 8.1.6 of Annex 4 of this Part.

2.1.2. Measurement instruments shall meet the specifications set out in clause 9.4 of Annex 4 of this Part.

2.1.3. The analytical gases used for calibrating the measurement instruments shall meet the requirements set out in clause 9.5.1 of Annex 4 of this Part.

2.2. Transfer line and sampling probe requirements

2.2.1. The transfer line shall meet the requirements set out in clause 9.3.1.2 of Annex 4 of this Part .

2.2.2. The sampling probe shall meet the requirements set out in clause 9.3.1.1 of Annex 4 of this Part.

ANNEX 13 - APPENDIX 2

TEST PROCEDURE FOR IN-SERVICE MONITORING WITH A PEMS

1. **TEST PARAMETERS**

The gaseous pollutant emissions to be measured and recorded during the in-service monitoring test are: carbon monoxide (CO), total hydrocarbons (HC) and nitrogen oxides (NOx). Additionally, carbon dioxide (CO_2) shall be measured to enable the calculation procedures described in Appendix 5. The parameters set out in the Table shall be measured and recorded during the in-service monitoring test:

Table

Test Parameters

Parameter	Unit	Source
HC concentration (1)	ppm	Gas analyser
CO concentration (1)	ppm	Gas analyser
NO_x concentration (1)	ppm	Gas analyser
CO_2 concentration (1)	ppm	Gas analyser
Exhaust mass flow (2)	kg/h	EFM
Exhaust temperature	°K	EFM or ECU or Sensor
Ambient temperature (3)	°K	Sensor
Ambient pressure	kPa	Sensor
Relative humidity	%	Sensor
Engine torque (4)	Nm	ECU or Sensor
Engine speed	rpm	ECU or Sensor
Engine fuel flow	g/s	ECU or Sensor
Engine coolant temperature	°K	ECU or Sensor
Engine intake air temperature (3)	°K	ECU or Sensor
Agricultural tractor, construction equipment vehicle and combine harvester latitude	degree	GPS (optional)
Agricultural tractors, construction equipment vehicles and combine harvesters longitude	degree	GPS (optional)

(1) Measured or corrected to a wet basis.

(2) Direct measurement of exhaust mass flow shall be used unless one of the following is applicable:

(a) the exhaust system installed in the agricultural tractor, construction equipment vehicle and combine harvester results in dilution of the exhaust by air upstream of the location where an EFM could be installed. In this case the exhaust sample shall be taken upstream of the point of dilution; or,

(b) the exhaust system installed in the agricultural tractor, construction equipment vehicle and combine harvester diverts a portion of the exhaust to another part of the

agricultural tractor, construction equipment vehicle and combine harvester (e.g. for heating) upstream of the location where an EFM could be installed.

In these cases, where the manufacturer is able to provide robust evidence to the Test Agency of the correlation between the fuel mass flow estimated by the ECU and the fuel mass flow measured on the engine dynamometer test bench, the EFM may be omitted and indirect exhaust flow measurements (from fuel and intake air flows or fuel flow and carbon balance) may be applied.

([3]) Use the ambient temperature sensor or an intake air temperature sensor. Use of an intake air temperature sensor shall comply with the requirements set out in the second paragraph of clause 5.1.

([4]) The recorded value shall be either (a) the gross torque; or (b) the gross torque calculated from the actual engine percent torque, the friction torque and the reference torque, according to standards set out in clause 2.1.1 of Appendix 7. The basis for the net torque shall be uncorrected net torque delivered by the engine inclusive of the equipment and auxiliaries to be included for an emissions test in accordance with Appendix A.2 of Annex 4 of this Part.

2. MINIMUM TEST DURATION

The test duration, comprising all operating sequences and only including valid data, shall be long enough to complete between five and seven times the work performed during the NRTC or to produce between five and seven times the CO_2 reference mass in kg/cycle from the NRTC.

3. Preparation of the agricultural tractor, construction equipment vehicle and combine harvester

The preparation of the agricultural tractor, construction equipment vehicle and combine harvester shall comprise at least the following:

(a) the check of the engine: any identified problems, once solved, shall be recorded and presented to the Test Agency;

(b) the replacement of the oil, fuel and reagent, if any;

(c) demonstration of the availability of the ECU data stream information, according to the requirements set out in clause 2 of Appendix 7.

4. **INSTALLATION OF THE PEMS**

4.1. The installation of the PEMS shall not influence the agricultural tractor, construction equipment vehicle and combine harvester gaseous pollutant emissions or performance. In any case, the installation shall comply with the locally applicable safety regulations and insurance requirements and shall follow the instructions issued by the PEMS, measurement instruments, transfer line and sampling probe manufacturer.

4.2. Electrical power supply

The electrical power supply of the PEMS shall, be provided by an external power supply unit.

4.2.1. When the manufacturer demonstrates to the Test Agency that it is not possible to comply with clause 4.2, a source drawing its energy (directly or indirectly) from the engine during the test may be used.

4.2.2. In this case, the peak power consumption of the PEMS shall not exceed 1 % of the

engine maximum power, and additional measures shall be taken to prevent the excessive discharge of the battery when the engine is not running or idling.

4.3. Measurement instruments other than the EFM

As far as possible, the measurement instruments other than the EFM shall be installed in a location subject to minimal:

(a) ambient temperature changes;

(b) ambient pressure changes;
(c) electromagnetic radiation;

(d) mechanical shock and vibration;

(e) ambient hydrocarbons — if using a FID analyser that uses ambient air as FID burner air.

4.4. EFM

The installation of the EFM shall not increase the backpressure beyond the value recommended by the manufacturer.

4.4.1. The EFM shall be attached to the agricultural tractor's, construction equipment vehicle's and combine harvester's tailpipe. The EFM's sensors should be placed between two pieces of straight tube whose length should be at least 2 times the EFM diameter (upstream and downstream).

4.4.2. The EFM shall be placed after the agricultural tractor, construction equipment vehicle and combine harvester silencer, to limit the effect of exhaust gas pulsations upon the measurement signals.

4.5. Transfer line and sampling probe

The transfer line shall be properly insulated at the connection clauses (sampling probe and back of the measurement instruments).

4.5.1. If the length of the transfer line is changed, the transport times shall be verified and if necessary corrected.

4.5.2. The transfer line and the sampling probe shall be installed in accordance with the requirements set out in clause 9.3 of of Annex 4 of this Part.

4.6. Data logger

The data logger shall be connected with the engine ECU to record the engine parameters listed in Table 1 of Appendix 7, and, where applicable, the engine parameters listed in Table 2 of Appendix 7.

4.7. GPS (where applicable) The antenna should be mounted at the highest possible location, without risking interference with any obstructions encountered during in-use operation.

5. PRE-IN-SERVICE MONITORING TEST PROCEDURES

5.1. Ambient temperature measurement

The ambient temperature shall be measured at the beginning of the test and also at the end of the test within a reasonable distance from the agricultural tractor, construction equipment vehicle and combine harvester. It is allowed to use the CAN signal for intake air temperature (temperature experienced by the engine).

If an intake air temperature sensor is used to estimate the ambient temperature the recorded ambient temperature shall be the intake air temperature adjusted by the applicable nominal offset between ambient and intake air temperature as specified by the manufacturer.

5.2. Starting and stabilising the measurement instruments

The measurement instruments shall be warmed up and stabilised until pressures, temperatures and flows have reached their operating set points, according to the instructions issued by the measurement instrument/PEMS manufacturer.

5.3. Cleaning and heating the transfer line

To prevent system contamination, the transfer line shall be purged until sampling begins, according to the instructions issued by the transfer line/PEMS manufacturer.

The transfer line shall be heated to 190 °C (+/– 10 °C) before starting the test to avoid the presence of cold spots that could lead to a contamination of the sample by condensed hydrocarbons.

5.4. Checking and calibrating the gas analysers

The zero and span calibration and the linearity checks of the gas analysers shall be performed using the analytical gases set out in clause 2.1.3 of Appendix 1.

5.5. Cleaning the EFM

The EFM shall be purged at the pressure transducer connections in accordance with the instructions issued by the PEMS or EFM manufacturer. This procedure shall remove condensation and diesel particulate matter from the pressure lines and the associated flow tube pressure measurement ports.

6. IN-SERVICE MONITORING TEST DATA LOGGING

6.1. Before the in-service monitoring test

Gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall start prior to starting the engine.

6.2. During the in-service monitoring test

Gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall continue throughout the normal in-use operation of the engine.

The engine may be stopped and started, but the gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall continue throughout the entire in-service monitoring test.

6.3. After the in-service monitoring test

At the end of the in-service monitoring test, sufficient time shall be given to the measurement instruments and data logger to allow their response times to elapse. The engine may be shut down before or after data logging is stopped.

6.4. Valid measured data for gaseous pollutant emissions calculation

The valid measured data for the gaseous pollutant emissions calculations shall be determined in accordance with Appendix 4. clause 6.4.2 shall apply to those calculations.

6.4.1. In order to determine the duration of the take-off phase after a long non-working event, as set out in clause 2.2.2 of Appendix 4, the exhaust gas temperature shall be measured during the operating sequence within 30 cm of the outlet of the after-treatment device used for NOx reduction.

6.4.2. Cold start data

Cold start gaseous pollutant emissions measured data shall be removed for the gaseous pollutant emissions calculations.

Valid measured data for gaseous pollutant emissions calculations shall start after the engine coolant temperature has reached 343 K (70 °C) for the first time or after the engine coolant temperature is stabilised within +/– 2 K over a period of 5 minutes, whichever comes first; in any case it shall start no later than 20 minutes after starting the engine.

7. CHECKING OF GAS ANALYSERS

7.1. Zero periodic verification during the operating sequence

Zero verification of the gas analysers shall be conducted at least every 2 hours during an in-service monitoring test.

7.2. Zero periodic correction during the in-service monitoring test

The results obtained with the checks performed in accordance with clause 7.1 may be used to perform a zero drift correction.

7.3. Drift verification after performing the test

The drift verification shall be performed only if no zero drift correction was made during the in-service monitoring test in accordance with clause 7.2.

7.3.1. No later than 30 minutes after the in-service monitoring test is completed, the gas analysers shall be zeroed and spanned in order to verify their drift compared to the pre-test results.

7.3.2. The zero, span and linearity checks of the gas analysers shall be performed as set out in clause 5.4.

8. ENGINE MALFUNCTION

8.1. In the case that a malfunction occurs during an operating sequence and the agricultural tractor, construction equipment vehicle and combine harvester operator is clearly notified by the on-board diagnostics system via a malfunction visual warning, text message or other indicator, the in-service monitoring test shall be considered void.

8.2. Any malfunction shall be corrected before any further in-service monitoring test is carried out on the engine.

ANNEX 13 - APPENDIX 3

DATA PRE-PROCESSING FOR GASEOUS POLLUTANT EMISSIONS CALCULATIONS

1. DEFINITIONS

1.2. For the purposes of this Appendix the following definitions shall apply:

1.2.1. 'zero response' means the mean response, including noise, to a zero gas during a time interval of at least 30 seconds;

1.2.2. 'span response' means the mean response, including noise, to a span gas during a time interval of at least 30 seconds.

2. DRIFT CORRECTION

2.1. Maximum drift allowed Drifts of the zero response and the span response shall be less than two per cent of full scale on the lowest range used:

(a) if the difference between the pre-test and post-test results is less than two per cent, the measured concentrations may be used uncorrected or may be corrected for drift according to clause 2.2;

(b) if the difference between the pre-test and post-test results is equal to or greater than two per cent, the measured concentrations shall be drift corrected according to clause 2.2. If no correction is made, the test shall be considered void.

2.2. Drift correction The drift corrected concentration value shall be calculated in accordance with the requirements set out in clause A.1.1 of Appendix A.1 of Annex 5 or clause A.2.5. of Appendix A.2 of Annex 5.

The difference between the uncorrected and the corrected brake-specific gaseous pollutant emission values shall be within ± six per cent of the uncorrected brake-specific gaseous pollutant emission values. If the drift is greater than six per cent, the test shall be considered void.

If drift correction is applied, only the drift-corrected gaseous pollutant emission results shall be used when reporting gaseous pollutant emissions.

3. TIME ALIGNMENT

To minimise the biasing effect of the time lag between the different signals on the calculations of the mass of the gaseous pollutant emissions, the data relevant for gaseous pollutant emissions calculations shall be time aligned, in accordance with the requirements set out in clause 3.1 to 3.4.

3.1. Gas analysers data The data from the gas analysers shall be properly aligned in accordance with the requirements set out in clause 8.1.5.3 of Annex 4 of this Part.

3.2. Gas analysers and EFM data The data from the gas analysers shall be properly aligned with the data of the EFM using the procedure set out in clause 3.4.

3.3. PEMS and engine data The data from the PEMS (gas analysers and EFM) shall be properly aligned with the data from the engine ECU using the procedure in clause 3.4.

3.4. Procedure for improved time alignment of the PEMS data

The test parameters listed in the Table of Appendix 2 are split into three different categories:

Category 1: Gas analysers (HC, CO, CO2, NOx concentrations);

Category 2: EFM (Exhaust mass flow and exhaust temperature);

Category 3: Engine (Torque, speed, temperatures, fuel rate from ECU).

The time alignment of each category with the other two categories shall be verified by finding the highest correlation coefficient between two series of test parameters. All the test parameters in a category shall be shifted to maximise the correlation factor. The following test parameters shall be used to calculate the correlation coefficients:

(a) Categories 1 and 2 (Gas analysers and EFM data) with Category 3 (Engine data): from the ECU;

(b) Category 1 with Category 2: the CO2 concentration and the exhaust mass flow;

(c) Category 2 with Category 3: the CO2 concentration and the engine fuel flow.

4. **DATA CONSISTENCY CHECK**

4.1. Gas analysers and EFM data

The consistency of the data (exhaust mass flow measured by the EFM and gas concentrations) shall be verified using a correlation between the measured engine fuel flow from the ECU and the engine fuel flow calculated in accordance with the procedure set out in clause A.1.1.6.4 of Appendix A.1 of Anex 5 of this Part.

A linear regression shall be performed for the measured and calculated fuel rate values. The method of least squares shall be used, with the best fit equation having the form:

$y = mx + b$

Where:

— y is the calculated fuel flow [g/s],

— m is the slope of the regression line,

— x is the measured fuel flow [g/s],

— b is the y intercept of the regression line.

The slope (m) and the coefficient of determination (r^2) shall be calculated for each regression line. It is recommended to perform this analysis in the range from 15 per cent of the maximum value to the maximum value and at a frequency greater or equal to 1 Hz. For a test to be considered valid, the following two criteria shall be evaluated:

Table
Tolerances

Slope of the regression line, m	0,9 to 1,1 — Recommended
Coefficient of determination r2	min. 0,90 — Recommended

4.2. ECU torque data

The consistency of the ECU torque data shall be verified by comparing the maximum ECU torque values at different (if appropriate) engine speeds with the corresponding values on the official engine full load torque curve and in accordance with Appendix 6.

4.3. Brake-Specific Fuel Consumption (BSFC)

The BSFC shall be checked using:

(a) the fuel consumption calculated from the gaseous pollutant emissions data (gas analysers concentrations and exhaust mass flow data), in accordance with the procedure set out in clause A.1.1.6.4 of Appendix A.1 of Anex 5 of this Part.

(b) the work calculated using the data from the ECU (Engine torque and engine speed).

4.4. Ambient pressure

The ambient pressure value shall be checked against the altitude indicated by the GPS data, if available.

4.5. The Test Agency may consider the test void if it is not satisfied with the results of the data consistency check.

5. DRY-WET CORRECTION

If the concentration is measured on a dry basis, it shall be converted to a wet basis in accordance with the procedure set out in Appendix A.1 or Appendix A.2 of Annex 5 of this Part.

6. NOX CORRECTION FOR HUMIDITY AND TEMPERATURE

The NOx concentrations measured by the gas analysers shall not be corrected for ambient air temperature and humidity.

ANNEX 13 - APPENDIX 4

ALGORITHM FOR THE DETERMINATION OF VALID EVENTS DURING IN-SERVICE MONITORING

1. GENERAL PROVISIONS

1.1. For the purposes of this Appendix 'event' means the data measured in an in-service monitoring test for the gaseous pollutant emissions calculations obtained in a time increment Δt equal to the data sampling period,

1.2. The methodology set out in this Appendix is based on the concept of working and non-working events.

1.3. Any event considered as a non-working event in accordance with this Appendix shall not be considered as valid for the calculations of the work or CO_2 mass and the gaseous pollutant emissions and conformity factors of the averaging windows set out in clause 2 of Appendix 5. Only working events shall be used for the purpose of calculations.

1.4. Non-working events shall be categorised as short non-working events (≤ D2) and long non-working events (> D2) (see the Table for the value of D2).

2. PROCEDURE TO DETERMINE NON-WORKING EVENTS

2.1. The following events shall be considered as non-working events:

2.1.1. Events where the engine power is below 10 % of the engine maximum net power.

2.1.2. Events corresponding to engine system cold conditions (cold start) set out in clause 6.4.2 of Appendix 2.

2.1.3. Events logged under ambient conditions not fulfilling the requirements set out in clause 3.3 of this Appendix.

2.1.4. Events logged during the periodic checks of the measurement instruments.

2.2. The following additional steps shall be conducted:

2.2.1. Non-working events shorter than D0 shall be considered as working events and merged with the surrounding working events (see the Table for the values of D0).

2.2.2. The take-off phase following long non-working events (> D2) shall also be considered as a non-working event until the exhaust gas temperature reaches 523 K. If the exhaust gas temperature does not reach 523 K within D3 minutes, all events after D3 shall be considered as working events (see the Table for the values of D3).

2.2.3. For all non-working events, the first D1 minutes of the event shall be considered as working event (see the Table for the values of D1).

3. 'MACHINE WORK' MARKING ALGORITHM

3.1. Step 1

Detect and split into working events and non-working events.

3.1.1. Define the working events and non-working events in accordance with clause 2.

3.1.2. Calculate the duration of non-working events.

3.1.3. Mark the non-working events shorter than D0 as working events (see the Table for the values of D0).

3.1.4. Calculate the duration of the remaining non-working events.

3.2. Step 2

Merge short working events (≤ D0) into non-working events.

3.2.1. Merge working events shorter than D0 with the surrounding non-working events of duration longer than D1.

3.3. Step 3 Exclude working events after long non-working events (take off phase).

3.3.1. Consider as non-working events those events after long (> D2) non-working events until the exhaust gas temperature reaches 523 K or until D3 minutes have elapsed (see the Table for the values of D3), whatever happens first.

3.4. Step 4

Include non-working events after working events.

3.4.1. Include D1 minutes of non-working event at the end of any working event (see the Table for the values of D1).

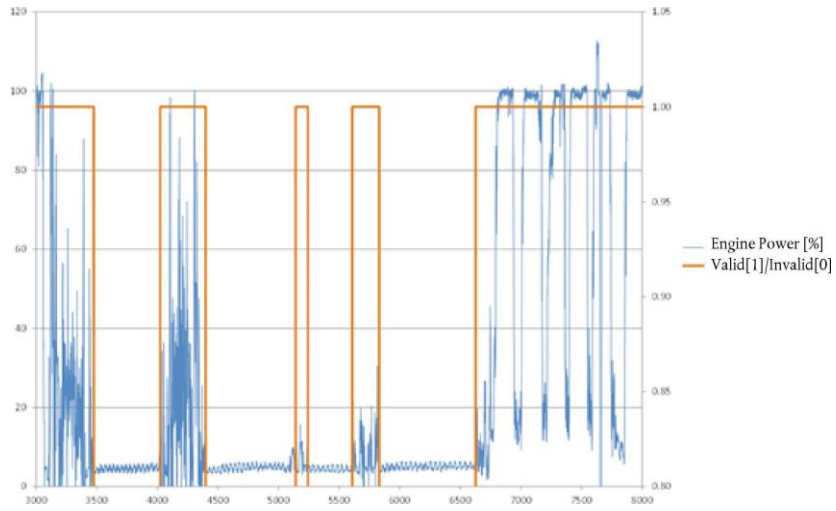
Table

Values for the parameters D0, D1, D2 and D3

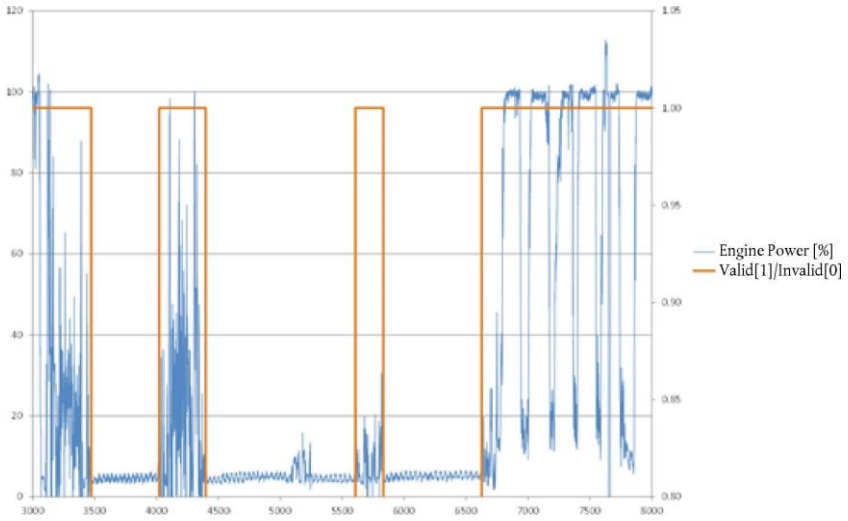
Parameters	Value
D0	2 minutes
D1	2 minutes
D2	10 minutes
D3	4 minutes

4. **Examples**

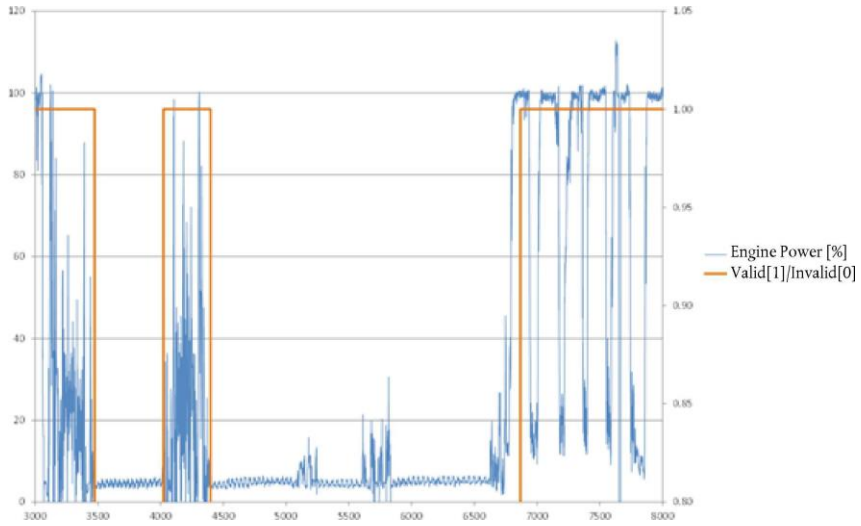
4.1. Exclusions of non-working data at the end of Step 1



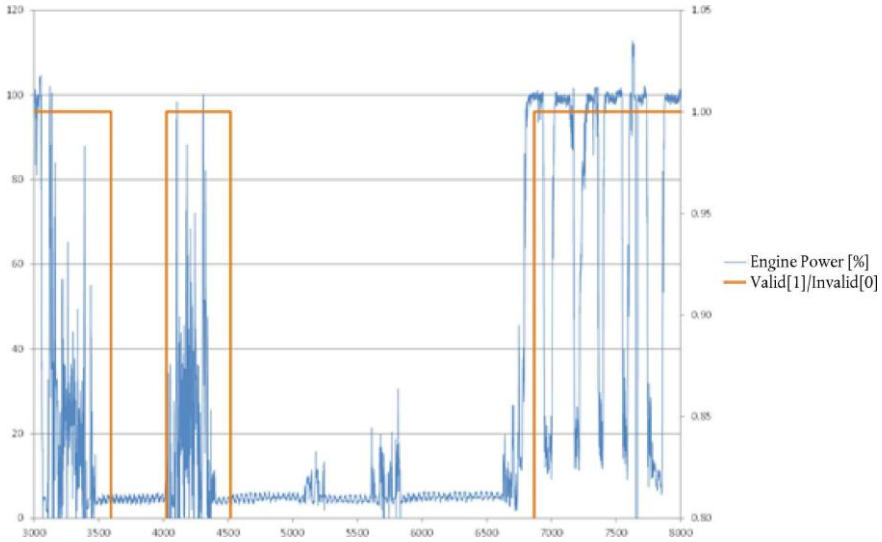
4.2 Exclusions of non-working data at the end of Step 2



4.3 Exclusions of non-working data at the end of Step 3



4.4 End of Step 4 -Final



ANNEX 13 - APPENDIX 5

GASEOUS POLLUTANT EMISSIONS CALCULATIONS

1. CALCULATION OF THE INSTANTANEOUS GASEOUS POLLUTANT EMISSIONS

The instantaneous mass of the gaseous pollutant emissions shall be calculated on the basis of the instantaneous concentration of the gaseous pollutant emissions measured during the in-service monitoring test and in accordance with the procedure set out in Appendix A.1 or Appendix A.2 of Annex 5 of this Part.

2. DETERMINATION OF AVERAGING WINDOWS' GASEOUS POLLUTANT EMISSIONS AND CONFORMITY FACTORS

2.1. Averaging window method

Averaging window is the sub-set of the complete calculated data set during the in-service monitoring test whose CO2 mass or work is equal to the engine CO2 mass or work measured over the reference laboratory NRTC.

The mass of the gaseous pollutant emissions and the conformity factors shall be calculated using the moving averaging window method, based on the reference work (procedure set out clause 2.2) and the reference CO2 mass (procedure set out in clause 2.3) measured over the reference laboratory NRTC.

The calculations shall be conducted in accordance with the following general requirements:

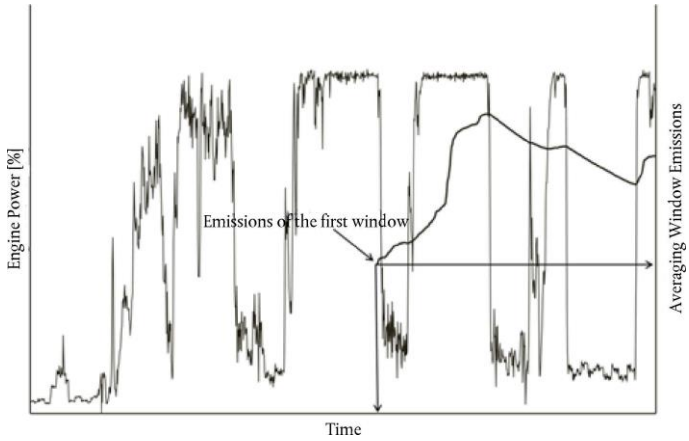
2.1.1. Any data excluded, under the terms of Appendix 4, shall not be considered for the calculations of the work or CO2 mass and the gaseous pollutant emissions and conformity factors of the averaging windows.

2.1.2. The moving averaging window calculations shall be conducted with a time increment Δt equal to the data sampling period.

2.1.3. The mass of the gaseous pollutant emissions for each averaging window (mg/averaging window) shall be obtained by integrating the mass of the instantaneous gaseous pollutant emissions in the averaging window.

2.1.4. The calculations shall be conducted and presented for both procedures: the reference CO2 mass and the reference work.

Figure 1
Engine power versus time and averaging window gaseous pollutant emissions, starting from the first averaging window,versus time



2.2 Work based method

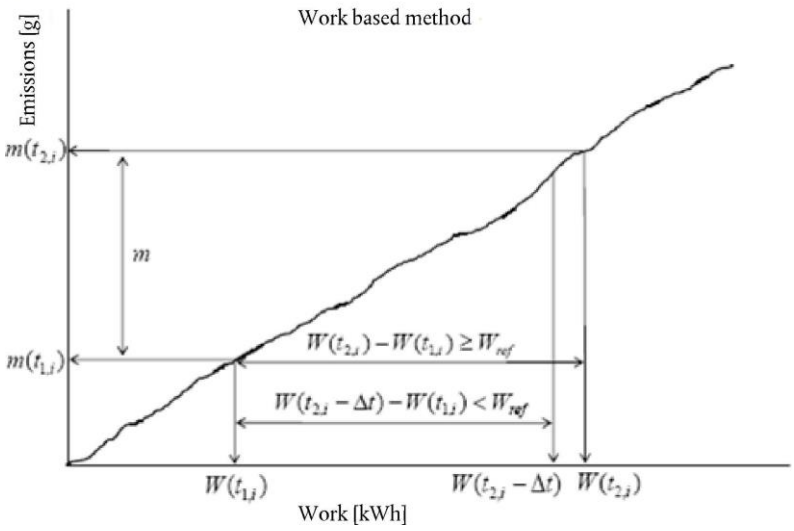


Figure 2

Work based Method

The duration ($t_{2,i} - t_{1,i}$) of the i[th] averaging window is determined by:

$$W(t_2,i) - W(t_1,i) \geq W_{ref}$$

Where:

— $W(t_{j,i})$ is the engine work measured between the start and time $t_{j,i}$, kWh,

— W_{ref} is the engine work for the NRTC, kWh,

— t_2,i shall be selected such that:

$$W(t_2,i - \Delta t) - W(t_1,i) < Wref \leq W(t_2,i) - W(t_{1,i})$$

Where Δt is the data sampling period, equal to 1 second or less.

2.2.1. Calculations of the brake specific gaseous pollutant emissions The brake specific gaseous pollutant emissions *egas* (g/kWh) shall be calculated for each averaging window and each gaseous pollutant in the following way:

$$e_{gas} = \frac{m}{W(t_2,i) - W(t_1,i)}$$

Where:

— *m* is the mass emission of the gaseous pollutant, mg/averaging window,

— $W(t_2,i) - W(t_1,i)$ is the engine work during the ith averaging window, kWh

2.2.2. Selection of valid averaging windows

The valid averaging windows are the averaging windows whose average power exceeds the power threshold of 20 % of the maximum engine power. The percentage of valid averaging windows shall be equal or greater than 50 %.

2.2.2.1. The test shall be considered void if the percentage of valid averaging windows is less than 50 %.

2.2.3. Calculations of the conformity factors

The conformity factors shall be calculated for each individual valid averaging window and each individual gaseous pollutant in the following way:

$$CF = \frac{e}{L}$$

Where:

— *e* is the brake-specific emission of the gaseous pollutant, g/kWh,

— *L* is the applicable limit, g/kWh. 2.3. CO2 mass based method

2.3 CO_2 mass based method

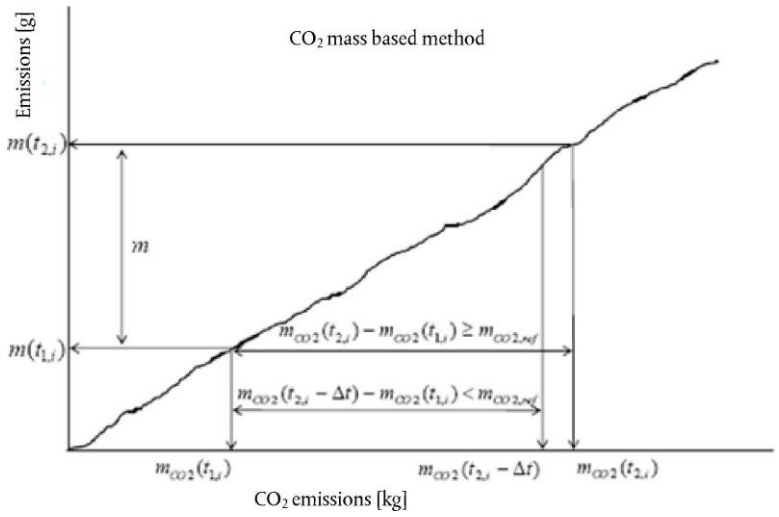


Figure 3

CO_2 mass based method

The duration (t_2,i – t_1,i) of the i[th] averaging window is determined by:

$$m_{CO2}(\ t_2,i) - m_{CO2}(t_1,i) \geq m_{CO2,ref}$$

Where:

— $m_{CO2}\ (t_{j,i})$ is the CO_2 mass measured between the test start and time t_j,i, kg,

— $m_{CO2,ref}$ is the CO_2 mass determined for the NRTC, kg,

— t_2,i shall be selected such as:

$$m_{CO2}(\ t_{2,i}\ - \Delta t) - m_{CO2}\ (t_1,i) < m_{CO2,ref} \leq m_{CO2}\ (t_2,i)\ - m_{CO2}\ (t_1,i)$$

Where Δt is the data sampling period, equal to 1 second or less.

The CO_2 masses are calculated in the averaging windows by integrating the instantaneous gaseous pollutant emissions calculated according to the requirements introduced in clause 1.

2.3.1. Selection of valid averaging windows

The valid averaging windows shall be those whose duration does not exceed the maximum duration calculated from:

$$Dmax = 3600\ x\frac{Wref}{0.2xPmax}$$

Where:

— Dmax is the maximum averaging window duration, s,

— Pmax is the maximum engine power, kW.

The percentage of valid averaging windows shall be equal or greater than 50 per cent.

2.3.2. Calculations of the conformity factors

The conformity factors shall be calculated for each individual averaging window and each individual pollutant in the following way:

$$CF = \frac{CF_I}{CF_C}$$

With $CF_I = \frac{m}{m_{CO_2}(t_{2,i}) - m_{CO_2}(t_{1,i})}$ (in service ratio) and

$CF_C = \frac{m_L}{m_{CO_{2,ref}}}$ (certification ratio)

Where:

— m is the mass emission of the gaseous pollutant, mg/averaging window,

— $m_{CO2}(t_{2,i}) - m_{CO2}(t_1,i)$ is the CO_2 mass during the ith averaging window, kg,

— $m_{CO2,ref}$ is the engine CO_2 mass determined for the NRTC, kg,

— m_L is the mass emission of gaseous pollutant corresponding to the applicable limit on the NRTC, mg.

3. ROUNDING OF GASEOUS POLLUTANT EMISSIONS CALCULATIONS

In accordance with Standard ASTM E 29-06b (Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications), the final test results shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure. No rounding of intermediate values leading to the final brake-specific gaseous pollutant emission result shall be allowed.

4. GASEOUS POLLUTANT EMISSION RESULTS

The following results shall be reported in accordance with clause 10 of this Annex:

(a) the instantaneous concentration of the gaseous pollutant emissions measured during the in-service monitoring test;

(b) the average of the concentration of the gaseous pollutant emissions for the whole in-service monitoring test;

(c) the instantaneous mass of the gaseous pollutant emissions calculated in accordance to clause 1;

(d) the integrated mass of the gaseous pollutant emissions for the whole in-service monitoring test, calculated as the addition of the mass of the instantaneous gaseous pollutant emissions calculated in accordance to clause 1;

(e) the distribution of the conformity factors for the valid windows, calculated in accordance with clause 2.2.3 and 2.3.2 (minimum, maximum and 90th cumulative percentile);

(f) the distribution of the conformity factors for all windows, calculated in accordance with clause 2.2.3 and 2.3.2 without the determination of the valid data in accordance with Appendix 4 and without the determination of the valid windows set out in clause 2.2.2 and 2.3.1 (minimum, maximum and 90^{th} cumulative percentile).

ANNEX 13 - APPENDIX 6

CONFORMITY OF THE ECU TORQUE SIGNAL

1. **MAXIMUM TORQUE METHOD**

1.1. The maximum torque method consists on confirming that a point on the reference maximum torque curve as a function of the engine speed has been reached during the in-service monitoring test.

1.2. If a point on the reference maximum torque curve as a function of the engine speed has not been reached during the in-service monitoring test, the manufacturer is entitled to modify the load activity of the agricultural tractor, construction equipment vehicle and combine harvester and/or the minimum test duration set out in clause 2 of Appendix 2 as necessary in order to perform that demonstration after the in-service monitoring test.

1.3. The requirements set out in clause 1.2 shall not be applied in the case that, in the opinion of the manufacturer and prior agreement of the Test Agency, it is not possible to reach a point on the maximum torque curve under normal operation without overloading the engine installed in the agricultural tractor, construction equipment vehicle and combine harvester, or to do so would not be safe.

1.4. In this case, the manufacturer shall propose to the Test Agency an alternative method for checking the signal. The alternative method shall be employed only if the Test Agency considers it feasible and applicable without overloading the engine or any safety risk.

1.5. The manufacturer may propose to the Test Agency, a more accurate and complete method for checking the conformity of the ECU torque signal during the in-service monitoring test than the method set out in clause 1.1 to 1.4. In that case, the method proposed by the manufacturer shall be used instead of the method set out in those points.

2. IMPOSSIBILITY TO CHECK THE CONFORMITY OF THE ECU TORQUE SIGNAL

When the manufacturer demonstrates to the Test Agency that it is not possible to check the ECU torque signal during the in-service monitoring test, the verification performed during the tests required for EU type-

ANNEX 13 - APPENDIX 7

ECU DATA STREAM INFORMATION REQUIREMENTS

1. **DATA TO BE PROVIDED**

1.1. The ECU shall provide at a minimum the measurement data listed in the Table 1.

Table 1

Measurement Data

Parameter	Unit
Engine torque (1)	Nm
Engine speed	rpm
Engine coolant temperature	K

(1) The provided value shall be either (a) the net brake engine torque; or (b) the net brake engine torque calculated from other appropriate torque values as defined in the corresponding protocol standard set out in clause 2.1.1. The basis for the net torque shall be uncorrected net torque delivered by the engine inclusive of the equipment and auxiliaries to be included for an emissions test in accordance with Appendix A.2 of Annex 4 of this Part.

1.2. Where either ambient pressure or ambient temperature are not measured by external sensors, they shall be provided by the ECU according to Table 2.

Table 2
Additional Measurement Data

Parameter	Unit
Ambient temperature (1)	K
Ambient pressure	kPa
Engine fuel flow	g/s

(1) Use of an intake air temperature sensor shall comply with the requirements set out in the second paragraph of clause 5.1 of Appendix 2

1.3. Where exhaust mass flow is not measured directly, the engine fuel flow shall be provided according to the Table of clause 1 of Appendix 2.

2. COMMUNICATION REQUIREMENTS

2.1. Access to data stream information

2.1.1. Access to data stream information shall be provided in accordance with at least one of the following series of standards:

(a) ISO 27145 with ISO 15765-4 (CAN-based);

(b) ISO 27145 with ISO 13400 (TCP/IP-based);

(c) SAE J1939-73.

2.1.2. The ECU shall support the corresponding services of at least one of the standards listed above in order to provide the data set out in Table 1.

Implementation of additional features of the standard(s) in the ECU is permitted but not mandatory.

2.1.3. Access to data stream information shall be possible by means of a wired connection (external scan-tool).

2.2. CAN-based wired communication

2.2.1. The communication speed on the wired data link shall be either 250 kbps or 500 kbps.

2.2.2. The connection interface between the engine and the measurement instruments of the PEMS shall be standardised and shall meet all requirements of ISO 15031-3 Type A (12 VDC power supply), Type B (24 VDC power supply) or SAE J1939-13 (12 or 24 VDC power supply).

2.3 Documentation requirements

The manufacturer shall indicate in the information document on administrative requirements the communication standard(s) used for providing access to data stream information in accordance with clause 2.1.1.

ANNEX 13 - APPENDIX 8

TEST REPORT FOR IN-SERVICE MONITORING

1. **Engine manufacturer information**

1.1. Make (trade name(s) of manufacturer)

1.2. Company name and address of manufacturer

1.3. Name and address of manufacturer's authorised representative (if any)

1.4. Name(s) and address(es) of assembly/manufacture plant(s)

2. Engine information

2.1. Engine type/family designation

2.2. Category and sub-category of the engine type/engine family

2.3. Type approval number

2.4. Commercial name(s) (if applicable)

2.5. Engine identification number

2.6. Engine production year and month

2.7. Engine rebuilt

2.8. Engine displacement [dm3]

2.9. Number of cylinders

2.10. Engine declared rated net power/rated speed [kW/rpm]

2.11. Engine maximum net power/power speed [kW/rpm]

2.12. Engine declared maximum torque/torque speed [kW/rpm]

2.13. Idle speed [rpm]

2.14. Manufacturer supplied full-load torque curve available (yes/no)

2.15. Manufacturer supplied full-load torque curve reference number

2.16. DeNOx system (e.g. EGR, SCR)

2.17. Type of catalytic converter

2.18. Type of particulate trap

2.19. After-treatment modified with respect to type approval (yes/no)

2.20. ECU information (Software calibration number)

3. Agricultural tractor, construction equipment vehicles and combine harvester information

3.1. Agricultural tractor, construction equipment vehicle and combine harvester owner

3.2. Category(ies) of agricultural tractors, construction equipment vehicles and combine harvesters

3.3. Agricultural tractor, construction equipment vehicle and combine harvesters manufacturer

3.4. Agricultural tractor, construction equipment vehicle and combine harvester identification number

3.5. Agricultural tractor, construction equipment vehicle and combine harvester registration number

3.6. Agricultural tractor's, construction equipment vehicle's and combine harvester's commercial name(s) (if applicable)

3.7. Agricultural tractor, construction equipment vehicle and combine harvester production year and month

4. Engine/ Agricultural tractor, construction equipment vehicle and combine harvester selection

4.1. Agricultural tractor, construction equipment vehicle and combine harvester or engine location method

4.2. Selection criteria for agricultural tractor, construction equipment vehicle and combine harvester, engines, in-service families

4.3. Location where the tested agricultural tractors, construction equipment vehicles and combine harvesters normally operates

4.4. Operating hours at test start:

4.4.1. Agricultural tractors, construction equipment vehicles or combine harvester [h]

4.4.2. Engine [h]

5. Portable emissions measurement system (PEMS)

5.1. PEMS power supply: external/sourced from agricultural tractor, construction equipment vehicle and combine harvester.

5.2. Measurement instruments (PEMS) brand and type

5.3. Measurement instruments (PEMS) calibration date

5.4. Calculation software and version used (e.g. EMROAD 4.0)

5.5. Location of ambient conditions sensors

6. **Test conditions**

6.1. Date and time of test

6.2. Test duration [s]

6.3. Test Location

6.4. General weather and ambient conditions (e.g. temperature, humidity, altitude)

6.4.1. Average ambient conditions (as calculated from the instantaneous measured data)

6.5. Hours operated per agricultural tractor, construction equipment vehicle and combine harvester /engine

6.6. Detailed information on agricultural tractor's, construction equipment vehicle's and combine harvester's actual operation

6.7. Test fuel specifications

6.8. Lubrication oil specifications

6.9. Reagent specifications (if applicable)

6.10. Brief description of the work performed

7. Average concentration of gaseous pollutant emissions

7.1. Average HC concentration [ppm] [Not mandatory]

7.2. Average CO concentration [ppm] [Not mandatory]

7.3. Average NOx concentration [ppm] [Not mandatory]

7.4. Average CO2 concentration [ppm] [Not mandatory]

7.5. Average Exhaust mass flow [kg/h] [Not mandatory]

7.6. Average Exhaust temperature [°C] [Not mandatory]

8. Integrated mass of gaseous pollutant emissions

8.1. THC emissions [g]

8.2. CO emissions [g]

8.3. NOx emissions [g]

8.4. CO2 emissions [g]

9. Averaging window (1) conformity factors (calculated in accordance with Appendices 2 to 5) (Minimum, maximum and 90th cumulative percentile)

9.1. Work averaging window THC conformity factor [-]

9.2. Work averaging window CO conformity factor [-]

9.3. Work averaging window NOx conformity factor [-]

9.4. CO2 mass averaging window THC conformity factor [-]

9.5. CO2 mass averaging window CO conformity factor [-]

9.6. CO2 mass averaging window NOx conformity factor [-]

9.7. Work averaging window: minimum and maximum averaging window power [%]

9.8. CO2 mass averaging window: minimum and maximum averaging window duration [s]

9.9. Work averaging window: percentage of valid averaging windows

9.10. CO2 mass averaging window: percentage of valid averaging windows

9.11. CO2 emissions

10. Averaging window conformity factors (calculated in accordance with Appendices 2, 3 and 5 without the determination of valid data in accordance with Appendix 4 and without the determination of valid windows as set out in clause 2.2.2 and 2.3.1 of Appendix 5) (Minimum, maximum and 90th cumulative percentile)

10.1. Work averaging window THC conformity factor [-]

10.2. Work averaging window CO conformity factor [-]

10.3. Work averaging window NOx conformity factor [-]

10.4. CO2 mass averaging window THC conformity factor [-]

10.5. CO2 mass averaging window CO conformity factor [-]

10.6. CO2 mass averaging window NOx conformity factor [-]

10.7. Work averaging window: minimum and maximum averaging window power [%]

10.8. CO2 mass averaging window: minimum and maximum averaging window duration [s]

11. **Test results verification**

11.1. THC analyser zero, span and audit results, pre and post test

11.2. CO analyser zero, span and audit results, pre and post test

11.3. NOx analyser zero-span and audit results, pre and post test

11.4. CO2 analyser zero, span and audit results, pre and post test

(1) Averaging window is the sub-set of the complete calculated data set during the in-service monitoring test whose CO2 mass or work is equal to the engine CO2 mass or work measured over the reference laboratory Non-Road Transient Cycle (NRTC).

11.5. Data consistency check results, according to Section 4 of Appendix 3

I-1. **Instantaneous measured data**

I-1.1. THC concentration [ppm]

I-1.2. CO concentration [ppm]

I-1.3. NOx concentration [ppm]

I-1.4. CO2 concentration [ppm]

I-1.5. Exhaust mass flow [kg/h]

I-1.6. Exhaust temperature [°C]

I-1.7. Ambient air temperature [°C]

I-1.8. Ambient pressure [kPa]

I-1.9. Ambient humidity [g/kg] [Not mandatory]

I-1.10. Engine torque [Nm]

I-1.11. Engine speed [rpm]

I-1.12. Engine fuel flow [g/s]

I-1.13. Engine coolant temperature [°C]

I-1.14. Agricultural tractor, construction equipment vehicle and combine harvester latitude [degree]

I-1.15. Agricultural tractor, construction equipment vehicle and combine harvester longitude [degree]

I-2. **Instantaneous calculated data**

I-2.1. THC mass [g/s]

I-2.2. CO mass [g/s]

I-2.3. NOx mass [g/s]

. NOx cumulated mass [g]

I-2.8. CO2 cumulated mass [g]

I-2.9. Calculated fuel rate[g/s]

I-2.10. Engine power [kW]

I-2.11. Engine work [kWh]

I-2.12. Work averaging window duration [s]

I-2.13. Work averaging window average engine power [%]

I-2.14. Work averaging window THC conformity factor [-]

I-2.15. Work averaging window CO conformity factor [-]

I-2.16. Work averaging window NOx conformity factor [-]

I-2.17. CO2 mass averaging window duration [s]

I-2.18. CO2 mass averaging window THC conformity factor [-]

I-2.19. CO2 mass averaging window CO conformity factor [-]

I-2.20. CO2 mass averaging window NOx conformity factor [-]

	ANNEX 14 **EMISSION OF VISIBLE POLLUTANTS AT STEADY SPEEDS OVER THE FULL-LOAD CURVE**
1.	**SCOPE** This Annex describes the method of determining emissions of visible pollutants at different steady speeds over the full load curve. The test to be carried out either on an engine or on a vehicle. This annex is applicable for emission of visible exhaust pollutants from C.I. engines which are intended for fitting to agricultural tractors, construction equipment vehicles and combine harvesters.
2.	**MEASUREMENT PRINCIPLE**
2.1	The opacity of the exhaust gases produced by the engine shall be measured with the engine running under full-load and at steady speed.
2.2	A sufficient number of measurements will be carried out ranging between the maximum rated speed and the minimum rated speed. The extreme points of measurement shall be situated at the limits of interval defined above and one point of measurement will coincide with the speed at which the engine develops its maximum power and the speed at which it develops maximum torque.
3	**TEST CONDITIONS**
3.1	Vehicle or engine:
3.1.1	The engine or the vehicle shall be submitted in good mechanical condition. The engine/vehicle shall have been run in as recommended by the manufacturer.
3.1.2	The engine shall be tested with the equipment prescribed in Table1 of Appendix 1 of Annex 12 of this Part.
3.1.3	The settings of the engine shall be those prescribed by the manufacturer and shown in Appendix 1 of Annex 12 of this Part.
3.1.4	In the case of a test on an engine the power of the engine shall be measured in accordance with Appendix 1 of Annex 12 of this Part. and it should meet the requirements of power tolerance given in clause 5.3 of Annex 12. In the case of a test on a vehicle, it should be established that the fuel flow is not less than that declared by the manufacturer.
3.1.5	The exhaust device shall not have any orifice through which the gases emitted by the engine might be diluted. In cases where an engine has several exhaust outlets, these shall be connected to a single outlet in which the opacity measurement shall be made.
3.1.6	The engine shall be in the normal working condition prescribed by the manufacturer. In particular, the cooling water and the oil shall each be at the normal temperature prescribed by the manufacturer.

Table 1

Limit Values Applicable in the Test at Steady Speeds

	Nominal Flow G (l/s)	Light Absorption Coefficient K (1/m)	Nominal Flow G (1/s)	Light Absorption Coefficient K (1/m)
	<=42	2.26	120	1.37
	45	2.19	125	1.345
	50	2.08	130	1.32
	55	1.985	135	1.30
	60	1.90	140	1.27
	65	1.84	145	1.25
	70	1.775	150	1.205
	75	1.72	160	1.19
	80	1.665	165	1.17
	85	1.62	170	1.155
	90	1.575	175	1.14
	95	1.535	180	1.125
	100	1.495	185	1.11
	105	1.465	190	1.095
	110	1.425	195	1.08
	115	1.395	>200	1.065
	The emissions of visible pollutants when tested as detailed in this Annex shall not exceed the limit values of light absorption coefficient given above for various nominal flows:			

3.2 Fuel: The fuel used shall be the reference fuel as specified in the Gazette Notification.

3.3 Test Laboratory

The absolute temperature T of the air (The test may be carried out in air condition test rooms where the atmospheric conditions may be controlled) at the inlet to the engine measured within 0.15 m upstream of the point of entry to the air cleaner, or if no air cleaner is used, within 0.15 m of the air inlet manifold expressed in degrees Kelvin, and the atmospheric pressure Ps, expressed in

Kilopascals, shall be measured, and the atmospheric factor fa shall be determined as give below :
Naturally aspirated and mechanically super charged engines:-

$fa = (99/Ps) * (T/298)^{0.7}$

Turbo super charge engines with or without cooling of inlet air

$f = (99/Ps)^{0.7} * (T/298)^{1.5}$

3.3.1 For a test to be recognised as valid, the parameter fa shall be such that $0.98 \leq fa \leq 1.02$.

3.4 Sampling and measuring apparatus:
The light-absorption coefficient of the exhaust gases shall be measured with an opacimeter satisfying the conditions of installation of opacimeter mentioned in Appendix 7 of Chapter 1 of AIS-137(Part 5).

4.0 EVALUATION OF THE ABSORPTION COEFFICIENT

4.1 For each of the engine speeds at which the absorption coefficient is measured pursuant to clause 2.2 of this Annex, the nominal gas flow shall be calculated by means of the following formulae:

for two-stroke engines $G = V * n/60$

for four-stroke engines $G = V * n/120$

Where:

G is the nominal gas flow, in liters per second, (l/s)

V is the cylinder capacity of the engine, in liters, (l)

N is the engine speed, in revolutions per minute(rpm)

ANNEX 15

(See Introduction)

COMPOSITION OF COMMITTEE FOR FORMULATION OF THIS PART 7

(To be included)