

5 October 2012

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## **Agreement**

### **Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions\***

(Revision 2, including the amendments which entered into force on 16 October 1995)

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### **Addendum 95: Regulation No. 96**

#### **Revision 2**

Incorporating all valid text up to:

Erratum to Revision 1 (English and French only)

02 series of amendments to the Regulation - Date of entry into force 3: February 2008

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**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**



**UNITED NATIONS**

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\* Former title of the Agreement: Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, done at Geneva on 20 March 1958.



## Regulation No. 96

### 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

#### Contents

	<i>Page</i>
1. Scope .....	5
2. Definitions and abbreviations .....	5
3. Application for approval .....	14
4. Approval .....	14
5. Specification and tests .....	15
6. Installation on the vehicle .....	21
7. Conformity of production .....	22
8. Penalties for non-conformity of production .....	23
9. Modifications and extension of approval of the approved type .....	23
10. Production definitively discontinued .....	24
11. Transitional provisions .....	24
12. Names and addresses of Technical Services responsible for conducting approval tests and of Type Approval Authorities .....	26

#### Annexes

1A Information document No ... relating to the type approval and referring to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery .....	27
Appendix 1 - Essential characteristics of the (parent) engine .....	28
Appendix 2 - Essential characteristics of the engine family .....	32
Appendix 3 - Essential characteristics of engine types within the family .....	34
1B Characteristics of the engine family and choice of the parent engine .....	38
2 Communication .....	42
Appendix 1 - Test results .....	44
3 Arrangements of approval marks .....	48
4A Method of determining emissions of gaseous and particulate pollutants .....	49
Appendix 1 - Measurement and sampling procedures (NRSC, NRTC) .....	69
Appendix 2 - Calibration procedure (NRSC, NRTC) .....	88

	Appendix 3 - Data evaluation and calculations .....	106
	Appendix 4 - Analytical and sampling system.....	126
4B	Test procedure for compression-ignition 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 .....	153
	Appendix A.1 (reserved).....	263
	Appendix A.2 - Statistics .....	264
	Appendix A.3 - 1980 international gravity formula.....	270
	Appendix A.4 - Carbon flow check .....	271
	Appendix A.5 (reserved).....	273
	Appendix A.6 (reserved).....	274
	Appendix A.7 - Molar based emission calculations.....	275
	Appendix A.7.1 - Diluted exhaust flow (CVS) calibration.....	304
	Appendix A.7.2 - Drift correction .....	314
	Appendix A.8 - Mass based emission calculations .....	316
	Appendix A.8.1 - Diluted exhaust flow (CVS) calibration.....	343
	Appendix A.8.2 - Drift correction .....	347
5	Test cycles .....	348
6	Technical characteristics of reference fuel prescribed for approval tests and to verify conformity of production .....	361
7	Installation requirements for equipment and auxiliaries .....	365
8	Durability requirements .....	368

## 1. Scope

This Regulation applies to the emission of gaseous and particulate pollutants from C.I. engines:

- 1.1. Used in category T vehicles<sup>1</sup> having an installed net power higher than 18 kW but not more than 560 kW,
- 1.2. Used in non-road mobile machinery<sup>1</sup> having an installed net power higher than 18 kW but not more than 560 kW, operated under variable speed.
- 1.3. Used in non-road mobile machinery<sup>1</sup> having an installed net power higher than 18 kW, but not more than 560 kW, operated under constant speed.

## 2. Definitions and abbreviations

- 2.1. For the purpose of this Regulation,
  - 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. "*Applicable emission limit*" means an emission limit to which an engine is subject;
  - 2.1.3. "*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;
  - 2.1.4. "*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;
  - 2.1.5. "*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;
  - 2.1.6. "*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";
  - 2.1.7. "*Calibration gas*" means a purified gas mixture used to calibrate gas analysers. Calibration gases shall meet the specifications of paragraph 9.5.1. 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;

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<sup>1</sup> As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3) (ECE/TRANS/WP.29/78/Rev.2, para. 2) - [www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html)

- 2.1.8. "*Compression ignition (C.I.) engine*" means an engine which works on the compression-ignition principle (e.g. diesel engine);
- 2.1.9. "*Constant-speed engine*" means 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;
- 2.1.10. "*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;
- 2.1.11. "*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;
- 2.1.12. "*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 ( $E_{\text{CH}_4} = 0$ ) and for the other hydrocarbons represented by ethane is 100 per cent ( $E_{\text{C}_2\text{H}_6} = 100$  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";
- 2.1.13. "*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 3.1);
- 2.1.14. "*DeNO<sub>x</sub> system*" means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO<sub>x</sub>) (e.g. passive and active lean NO<sub>x</sub> catalysts, NO<sub>x</sub> adsorbers and selective catalytic reduction (SCR) systems);
- 2.1.15. "*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;
- 2.1.16. "*Discrete-mode*" means relating to a discrete-mode type of steady-state test, as described in paragraph 7.4.1.1. and Annex 5;
- 2.1.17. "*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;
- 2.1.18. "*Electronic control unit*" means an engine's electronic device that uses data from engine sensors to control engine parameters;
- 2.1.19. "*Emission control system*" means any device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine;

- 2.1.20. "*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 non-road mobile machinery into which the engine is installed;
- 2.1.21. "*Emission durability period*" means the number of hours indicated in Annex 8 used to determine the deterioration factors;
- 2.1.22. "*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 paragraph 7. of this Regulation;
- 2.1.23. "*Engine governed speed*" means the engine operating speed when it is controlled by the installed governor;
- 2.1.24. "*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;
- 2.1.25. "*Engine type*" means a category of engines which do not differ in such essential engine characteristics as defined in paragraphs 1. to 4. of Annex 1A, Appendix 3 to this Regulation;
- 2.1.26. "*Exhaust after-treatment system*" means a catalyst, particulate filter, deNO<sub>x</sub> system, combined deNO<sub>x</sub> 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;
- 2.1.27. "*Exhaust-gas recirculation*" means a technology that reduces emissions by routing exhaust gases that had 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 Regulation;
- 2.1.28. "*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;
- 2.1.29. "*Gaseous pollutants*" means carbon monoxide, hydrocarbons (assuming a ratio of C<sub>1</sub>H<sub>1.85</sub>) and oxides of nitrogen, the last named being expressed in nitrogen dioxide (NO<sub>2</sub>) equivalent;
- 2.1.30. "*Good engineering judgment*" means judgments made consistent with generally accepted scientific and engineering principles and available relevant information;
- 2.1.31. "*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;
- 2.1.32. "*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;
- 2.1.33. "*High speed (n<sub>hi</sub>)*" means the highest engine speed where 70 per cent of the maximum power occurs;

- 2.1.34. "*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;
- 2.1.35. "*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.
- 2.1.36. "*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;
- 2.1.37. "*Low speed ( $n_{10}$ )*" means the lowest engine speed where 50 per cent of the maximum power occurs;
- 2.1.38. "*Maximum power ( $P_{max}$ )*" means the maximum power in kW as designed by the manufacturer;
- 2.1.39. "*Maximum torque speed*" means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer;
- 2.1.40. "*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;
- 2.1.41. "*Net power*" means the power in "ECE kW" obtained on the test bench at the end of the crankshaft, or its equivalent, measured in accordance with the method described in Regulation No. 120 on the measurement of the net power, net torque and specific fuel consumption of internal combustion engines for agricultural and forestry tractors and non-road mobile machinery.
- 2.1.42. "*Non-methane hydrocarbons (NMHC)*" means the sum of all hydrocarbon species except methane;
- 2.1.43. "*Open crankcase emissions*" means any flow from an engine's crankcase that is emitted directly into the environment;
- 2.1.44. "*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 setpoint or signal;

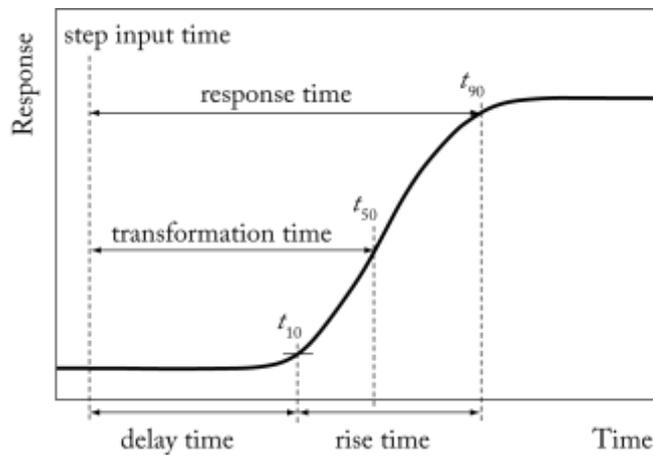
- 2.1.45. "*Oxides of nitrogen*" means compounds containing only nitrogen and oxygen as measured by the procedures specified in this Regulation. Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO<sub>2</sub>, such that an effective molar mass is used for all oxides of nitrogen equivalent to that of NO<sub>2</sub>;
- 2.1.46. "*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 of this Regulation;
- 2.1.47. "*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*;
- 2.1.48. "*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;
- 2.1.49. "*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;
- 2.1.50. "*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);
- 2.1.51. "*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<sub>CH<sub>4</sub></sub>, of 1.000 (that is, a methane conversion efficiency E<sub>CH<sub>4</sub></sub> of 0), and the penetration fraction for all other hydrocarbons would be 0.000, as represented by PF<sub>C<sub>2</sub>H<sub>6</sub></sub> (that is, an ethane conversion efficiency E<sub>C<sub>2</sub>H<sub>6</sub></sub> of 1). The relationship is:  
$$PF_{CH_4} = 1 - E_{CH_4} \text{ and } PF_{C_2H_6} = 1 - E_{C_2H_6};$$
- 2.1.52. "*Per cent load*" means the fraction of the maximum available torque at an engine speed;
- 2.1.53. "*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 standards may be exceeded;
- 2.1.54. "*Placing on the market*" means the action of making available a product covered by this Regulation on the market of a country applying this Regulation, for payment or free of charge, with a view to distribution and/or use in the country;
- 2.1.55. "*Probe*" means the first section of the transfer line which transfers the sample to next component in the sampling system;
- 2.1.56. "*PTFE*" means polytetrafluoroethylene, commonly known as Teflon™;
- 2.1.57. "*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;

- 2.1.58. "*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;
- 2.1.59. "*Reagent*" means any consumable or non-recoverable medium required and used for the effective operation of the exhaust after-treatment system;
- 2.1.60. "*Regeneration*" means an event during which emissions levels change while the aftertreatment performance is being restored by design. Two types of regeneration can occur: continuous regeneration (see paragraph 6.6.1.) and infrequent (periodic) regeneration (see paragraph 6.6.2.);
- 2.1.61. "*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;
- 2.1.62. "*Rise time*" means the difference in time between the 10 per cent and 90 per cent response of the final reading ( $t_{90} - t_{10}$ );
- 2.1.63. "*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;
- 2.1.64. "*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;
- 2.1.65. "*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;
- 2.1.66. "*Span gas*" means a purified gas mixture used to span gas analysers. Span gases shall meet the specifications of paragraph 9.5.1. 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;
- 2.1.67. "*Specific emissions*" means the mass emissions expressed in g/kWh;
- 2.1.68. "*Standalone*" means something that has no dependencies; it can "stand alone";
- 2.1.69. "*Steady-state*" means relating to emission tests in which engine speed and load are held at a finite set of nominally constant values. Steady-state tests are either discrete-mode tests or ramped-modal tests;
- 2.1.70. "*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;
- 2.1.71. "*Storage medium*" means a particulate filter, sample bag, or any other storage device used for batch sampling;
- 2.1.72. "*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;

- 2.1.73. "*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 Regulation may specify additional calculations that weigh and combine results to arrive at composite values for comparison against the applicable emission limits;
- 2.1.74. "*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;
- 2.1.75. "*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;
- 2.1.76. "*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 3.1;
- 2.1.77. "*Transient test cycle*" means a test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time (NRTC);
- 2.1.78. "*Type approval*" means the approval of an engine type with regard to its emissions measured in accordance with the procedures specified in this Regulation;
- 2.1.79. "*Updating-recording*" means the frequency at which the analyser provides new, current, values;
- 2.1.80. "*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;
- 2.1.81. "*Variable-speed engine*" means an engine that is not a constant-speed engine;
- 2.1.82. "*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";
- 2.1.83. "*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;
- 2.1.84. "*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 (paragraph 2.1.13.), response time (paragraph 2.1.59.), rise time (paragraph 2.1.60.) and transformation time (paragraph 2.1.74.)**



2.2. Symbols and abbreviations

2.2.1. Symbols

The symbols are explained in Annex 4A, paragraph 1.4. and Annex 4B, paragraph 3.2. respectively.

2.2.2. Symbols and abbreviations for the chemical components

Ar	Argon
C <sub>1</sub>	Carbon 1 equivalent hydrocarbon
CH <sub>4</sub>	Methane
C <sub>2</sub> H <sub>6</sub>	Ethane
C <sub>3</sub> H <sub>8</sub>	Propane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
DOP	Di-octylphthalate
H	Atomic hydrogen
H <sub>2</sub>	Molecular hydrogen
HC	Hydrocarbon
H <sub>2</sub> O	Water
He	Helium
N <sub>2</sub>	Molecular nitrogen
NMHC	Non-methane hydrocarbon
NO <sub>x</sub>	Oxides of nitrogen
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide

	O <sub>2</sub>	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 <sub>x</sub>	NO <sub>x</sub> 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 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 triplicate and the following particulars:

A description of the engine type comprising the particulars referred to in Annex 1A of this Regulation and if applicable the particulars of the engine family as referred to in Annex 1B of this Regulation.
  - 3.1.3. An engine conforming to the engine type characteristics described in Annex 1A shall be submitted to the technical service responsible for conducting the approval tests defined in paragraph 5. If the technical service determines that the submitted engine does not fully represent the engine family described in Annex 1A, Appendix 2, an alternative and, if necessary, an additional engine shall be submitted for test according to paragraph 5.

### **4. Approval**

- 4.1. If the engine submitted for approval pursuant to paragraph 3.1. of this Regulation meets the requirements of paragraph 5.2. below, approval of that type of engine or family of engines shall be granted.
- 4.2. An approval number shall be assigned to each type or family approved. Its first two digits shall indicate the series of amendments (at present 01) incorporating the most recent major technical amendments made to the Regulation at the time of issue of the approval. The same Contracting Party shall not assign the same number to another engine type or family.
- 4.3. Notice of approval or of extension or refusal of approval of an engine type or family pursuant to this Regulation shall be communicated to the Parties to the 1958 Agreement which apply this Regulation, by means of a form conforming to the model in Annex 2, as applicable, to this Regulation. Values measured during the type test shall also be shown.
- 4.4. There shall be affixed, conspicuously and in a readily accessible place to every engine conforming to an engine type or family approved under this Regulation, an international approval mark consisting of:

- 4.4.1. A circle surrounding the letter "E" followed by the distinguishing number of the country which has granted approval<sup>2</sup>;
- 4.4.2. The number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle prescribed in paragraph 4.4.1.
- 4.4.3. An additional symbol consisting of a letter from D to R indicating the emission level (paragraph 5.2.1.) according to which the engine or the engine family has been approved.
- 4.5. If the engine conforms to an approved type or family under one or more Regulations Annexed to the Agreement, in the country which has granted approval under this Regulation, the symbol prescribed need not be repeated; in such a case, the regulation and approval numbers and the additional symbols of all the Regulations under which approval has been granted under this Regulation shall be placed in vertical columns to the right of the symbol prescribed in paragraph 4.4.2.
- 4.6. The approval mark shall be placed close to or on the data plate affixed by the manufacturer to the approved type.
- 4.7. Annex 3 to this Regulation gives examples of arrangements of approval marks.
- 4.8. The engine approved as a technical unit shall bear, in addition to the approval mark:
  - 4.8.1. The trademark or trade name of the manufacturer of the engine;
  - 4.8.2. The manufacturer's engine code;
- 4.9. These marks shall be clearly legible and indelible.

## **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 Regulation.

- 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 Regulation, 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 paragraphs 5.2.1. and 7.2.2.1. are respectively complied with, and
  - (b) If, in addition, for engines of power bands L and upwards, the provisions of paragraph 5.3. are complied with.

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<sup>2</sup> The distinguish numbers of the Contracting Parties to the 1958 Agreement are reproduced in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev.2/Amend.1 - [www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html)

- 5.1.2. For engines of power bands H and upwards, the manufacturer shall prove the durability of the engine and after-treatment device, if applicable, 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 customer's manual and be approved before an approval is granted. For engines of power bands L and upwards, further information shall be included according to the requirements of paragraph 5.3.3.
- 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 Regulation.
- 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 described in Annex 4A for the power bands up to P, and in Annex 4B for power bands Q and R. At the request of the manufacturer and with the agreement of the Type Approval Authority the methods described in Annex 4B may be used for power bands up to P.
- 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:

<i>Power band</i>	<i>Net power (P) (kW)</i>	<i>Carbon monoxide (CO) (g/kWh)</i>	<i>Hydrocarbons (HC) (g/kWh)</i>	<i>Oxides of nitrogen (NOx) (g/kWh)</i>	<i>Particulate Matter (PM) (g/kWh)</i>
E	130 ≤ P ≤ 560	3.5	1.0	6.0	0.2
F	75 ≤ P < 130	5.0	1.0	6.0	0.3
G	37 ≤ P < 75	5.0	1.3	7.0	0.4
D	18 ≤ P < 37	5.5	1.5	8.0	0.8
	<i>Net power (P) (kW)</i>	<i>Carbon monoxide (CO) (g/kWh)</i>	<i>Sum of hydro-carbons and oxides of nitrogen (HC + NOx) (g/kWh)</i>		<i>Particulate Matter (PM) (g/kWh)</i>
H	130 ≤ P ≤ 560	3.5	4.0		0.2
I	75 ≤ P < 130	5.0	4.0		0.3
J	37 ≤ P < 75	5.0	4.7		0.4
K	19 ≤ P < 37	5.5	7.5		0.6
	<i>Net power (P) (kW)</i>	<i>Carbon monoxide (CO) (g/kWh)</i>	<i>Hydrocarbons (HC) (g/kWh)</i>	<i>Oxides of nitrogen (NOx) (g/kWh)</i>	<i>Particulate Matter (PM) (g/kWh)</i>
L	130 ≤ P ≤ 560	3.5	0.19	2.0	0.025
M	75 ≤ P < 130	5.0	0.19	3.3	0.025
N	56 ≤ P < 75	5.0	0.19	3.3	0.025
			<i>Sum of hydro-carbons and oxides of nitrogen (HC + NOx) (g/kWh)</i>		
P	37 ≤ P < 56	5.0		4.7	0.025
	<i>Net power (P) (kW)</i>	<i>Carbon monoxide (CO) (g/kWh)</i>	<i>Hydrocarbons (HC) (g/kWh)</i>	<i>Oxides of nitrogen (NOx) (g/kWh)</i>	<i>Particulate Matter (PM) (g/kWh)</i>
Q	130 ≤ P ≤ 560	3.5	0.19	0.4	0.025
R	56 ≤ P < 130	5.0	0.19	0.4	0.025

- The limit values for power bands H to R shall include deterioration factors calculated in accordance with Annex 8.
- 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.
- 5.3. Type approval requirements for power bands L to R
- 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 paragraph 5.2.1. of this Regulation.
- 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 Regulation.
- 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 non-road mobile machine, 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, paragraphs 5.3.2.2.2. and 5.3.2.2.3. 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 paragraph 5.3.2.2.3.
- 5.3.2.2.2. The control conditions applicable to this paragraph are all of the following:
- (a) An altitude not exceeding 1,000 metres (or equivalent atmospheric pressure of 90 kPa);
- (b) An ambient temperature within the range 275 K to 303 K (2 °C to 30 °C);
- (c) 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 sub-paragraphs (a), (b) and (c), the strategy shall only be activated exceptionally.

- 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 non-road mobile machine into which the engine is installed from damage;
  - (b) For operational safety and strategies;
  - (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 technical service at the time of the type approval test that the operation of any auxiliary emission strategy complies with the provisions of paragraph 5.3.2.2. The demonstration shall consist of an evaluation of the documentation referred to in paragraph 5.3.2.3.
- 5.3.2.2.5. Any operation of an auxiliary emission control strategy not compliant with paragraph 5.3.2.2. 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 technical service, 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 technical service 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<sub>x</sub> control system;
    - (iv) The tolerance used to satisfy the requirements in paragraph 5.3.3.7.2., regardless of the used means.
- 5.3.2.3.2. The additional material referred to in sub-paragraph (b) of paragraph 5.3.2.3.1. shall be treated as strictly confidential. It shall be made available to the Type Approval Authority on request. The Type Approval Authority shall treat this material as confidential.
- 5.3.3. Requirements to ensure correct operation of NO<sub>x</sub> control measures
- 5.3.3.1. The manufacturer shall provide information that fully describes the functional operational characteristics of the NO<sub>x</sub> control measures using the documents set out in paragraph 2. of Appendix 1 and paragraph 2. of Appendix 3 to Annex 1A.
- 5.3.3.2. 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 paragraph 2.2.1.13. of Appendix 1 and in paragraph 3.2.1.13. of Appendix 3 to Annex 1A.
- 5.3.3.3. The engine emission control strategy shall be operational under all environmental conditions regularly pertaining in the territory of the Community, especially at low ambient temperatures.
- 5.3.3.4. 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 25 ppm.
- 5.3.3.5. If separate reagent containers are installed on or connected to a non-road mobile machine, 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 specialized tool or device.
- 5.3.3.6. Use and maintenance requirements
- 5.3.3.6.1. The type approval shall be made conditional, in accordance with paragraph 5.1.3., upon providing to each operator of non-road mobile machinery written instructions comprising the following:
  - (a) Detailed warnings, explaining possible malfunctions generated by incorrect operation, use or maintenance of the installed engine, accompanied by respective rectification measures;
  - (b) Detailed warnings on the incorrect use of the machine resulting in possible malfunctions of the engine, accompanied by respective rectification measures;
  - (c) Information on the correct use of the reagent, accompanied by an instruction on refilling the reagent between normal maintenance intervals;
  - (d) A clear warning, that the type approval certificate, issued for the type of engine concerned, is valid only when all of the following conditions are met:

- (i) The engine is operated, used and maintained in accordance with the instructions provided;
- (ii) Prompt action has been taken for rectifying incorrect operation, use or maintenance in accordance with the rectification measures indicated by the warnings referred to in sub-paragraphs (a) and (b);
- (iii) No deliberate misuse of the engine has taken place, in particular de-activating or not maintaining an EGR or reagent dosing system.

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 non-road mobile machinery or engine.

5.3.3.7. Reagent control (where applicable)

5.3.3.7.1. The type approval shall be made conditional, in accordance with the provisions of paragraph 6.1., upon providing indicators or other appropriate means, according to the configuration of the non-road mobile machinery, informing the operator on:

- (a) The amount of reagent remaining in the reagent storage container and by an additional specific signal, when the remaining reagent is less than 10 per cent of the full container's capacity;
- (b) When the reagent container becomes empty, or almost empty;
- (c) When the reagent in the storage tank does not comply with the characteristics declared and recorded in paragraph 2.2.1.13. of Appendix 1 and paragraph 2.2.1.13. of Appendix 3 to Annex 1A, according to the installed means of assessment;
- (d) When the dosing activity of the reagent is interrupted, in cases other than those executed by the engine ECU or the dosing controller, reacting to engine operating conditions where the dosing is not required, provided that these operating conditions are made available to the Type Approval Authority.

5.3.3.7.2. By the choice of the manufacturer the requirements of reagent compliance with the declared characteristics and the associated NO<sub>x</sub> emission tolerance shall be satisfied by one of the following means:

- (a) Direct means, such as the use of a reagent quality sensor.
- (b) Indirect means, such as the use of a NO<sub>x</sub> sensor in the exhaust to evaluate reagent effectiveness.
- (c) Any other means provided that its efficacy is at least equal to the one resulting by the use of the means of sub-paragraphs (a) or (b) and the main requirements of this paragraph are maintained.

## 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.
- 6.1.2. Exhaust back pressure shall not exceed that specified for the approved engine in Annex 1A, Appendix 1.
- 6.1.3. The operator shall be informed on the reagent control as defined in paragraph 5.3.3.7.1., if applicable.

## 7. Conformity of production

- 7.1. The conformity of production procedures shall comply with those set out in the Agreement, Appendix 2 (E/ECE/324-E/ECE/TRANS/505/Rev.2) with the following requirements:
- 7.2. The Type Approval Authority which has granted approval may at any time verify the conformity control methods applicable to each production unit.
  - 7.2.1. In every inspection, the test books and production survey record shall be presented to the visiting inspector.
  - 7.2.2. When the quality level appears unsatisfactory or when it seems necessary to verify the validity of the data presented in application of paragraph 5.2., the following procedure is adopted:
    - 7.2.2.1. An engine is taken from the series and subjected to the test described in Annex 4A or Annex 4B according to paragraph 5.2. 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 paragraph 5.2.1., subject to the requirements of paragraph 5.2.2.
    - 7.2.2.2. If the engine taken from the series does not satisfy the requirements of paragraph 7.2.2.1. 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 technical service. Engines other than the engine originally taken shall be subjected to a test. The arithmetical mean ( $\bar{x}$ ) 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 paragraph 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

$$\text{if } n \geq 20, \quad k = \frac{0.860}{\sqrt{n}}$$

- 7.2.3. The Technical Service responsible for verifying the conformity of production shall carry out tests on engines which have been run-in partially or completely, according to the manufacturer's specifications.
- 7.2.4. The normal frequency of inspections authorized by the Type Approval Authority shall be one per year. If the requirements of paragraph 7.2.2.1. are not met, the Type Approval Authority shall ensure that all necessary steps are taken to re-establish the conformity of production as rapidly as possible.

## 8. Penalties for non-conformity of production

- 8.1. The approval granted in respect of an engine type or family pursuant to this Regulation may be withdrawn if the requirements laid down in paragraph 7.2. are not complied with or if the engine or engines taken fail to pass the tests prescribed in paragraph 7.2.2.1.
- 8.2. If a Contracting Party to the Agreement applying this Regulation withdraws an approval it has previously granted, it shall forthwith so notify the other Contracting Parties applying this Regulation by means of a communication form conforming to the model in Annex 2 to this Regulation.

## 9. Modifications and extension of approval of the approved type

- 9.1. Every modification of the approved type or family shall be notified to the Type Approval Authority which approved the type. The Type Approval Authority may then either:
- 9.1.1. Consider that the modifications made are unlikely to have an appreciable adverse effect and that in any case the modified type still complies with the requirement; or
- 9.1.2. Require a further test report from the Technical Service conducting the tests.
- 9.2. Confirmation or refusal of approval, specifying the alterations, shall be communicated by the procedure specified to the Parties to the Agreement applying this Regulation.

- 9.3. The Type Approval Authority issuing the extension of approval shall assign a series number for such an extension and inform thereof the other Contracting Parties to the 1958 Agreement applying this Regulation by means of a communication form conforming to the model in Annex 2 to this Regulation.

## **10. Production definitively discontinued**

If the holder of the approval completely ceases to manufacture the type or family approved in accordance with this Regulation he shall so inform the authority which granted the approval. Upon receiving the relevant communication that authority shall inform thereof the other Parties to the Agreement which apply this Regulation by means of a communication form conforming to the model in Annex 2 to this Regulation.

## **11. Transitional provisions**

- 11.1. As from the official date of entry into force of the 02 series of amendments, no Contracting Party applying this Regulation shall refuse to grant approval under this Regulation as amended by the 02 series of amendments.
- 11.2. As from the date of entry into force of the 02 series of amendments, Contracting Parties applying this Regulation may refuse to grant approvals to variable speed engines, or engine families, of the power bands H, I, J and K which do not meet the requirements of this Regulation as amended by the 02 series of amendments.
- 11.3. As from the date of entry into force of the 02 series of amendments, Contracting Parties applying this Regulation may refuse the placing on the market of variable speed engines, or engine families, included in the power bands H, I, J and K not approved under this Regulation as amended by the series 02 of amendments.
- 11.4. As from 1 January 2010, Contracting Parties applying this Regulation may refuse to grant approvals to constant speed engines, or engine families, of the power bands H, I and K which do not meet the requirements of this Regulation as amended by the 02 series of amendments.
- 11.5. As from 1 January 2011, Contracting Parties applying this Regulation may refuse to grant approvals to constant speed engines, or engine families, of the power band J which do not meet the requirements of this Regulation as amended by the 02 series of amendments.
- 11.6. As from 1 January 2011, Contracting Parties applying this Regulation may refuse the placing on the market of constant speed engines, or engine families, included in the power bands H, I and K not approved under this Regulation as amended by the series 02 of amendments.
- 11.7. As from 1 January 2012, Contracting Parties applying this Regulation may refuse the placing on the market of constant speed engines, or engine families, included in the power band J not approved under this Regulation as amended by the series 02 of amendments.
- 11.8. By derogation to the provisions stipulated on paragraphs 11.3., 11.6. and 11.7., Contracting Parties applying this Regulation may postpone each date mentioned in the above paragraphs for two years in respect of engines with a production date prior to the said dates.

- 11.9. By derogation to the provisions stipulated in paragraphs 11.3., 11.6. and 11.7., Contracting Parties applying this Regulation may continue to permit the placing on the market of engines approved on the basis of a previous technical standard, provided that the engines are intended as replacement for fitting in vehicles in use, and that it is not technically feasible for the engines in question to satisfy the new requirements of the 02 series of amendments.
- 11.10. As from the official date of entry into force of the 03 series of amendments, no Contracting Party applying this Regulation shall refuse to grant approval under this Regulation as amended by the 03 series of amendments.
- 11.11. As from the date of entry into force of the 03 series of amendments, Contracting Parties applying this Regulation may refuse to grant approvals to variable speed engines, or engine families, of the power bands L, M, N and P which do not meet the requirements of this Regulation as amended by the 03 series of amendments.
- 11.12. As from 1 January 2013, Contracting Parties applying this Regulation may refuse to grant approvals to variable speed engines, or engine families, of the power band Q which do not meet the requirements of this Regulation as amended by the 03 series of amendments.
- 11.13. As from 1 October 2013, Contracting Parties applying this Regulation may refuse to grant approvals to variable speed engines, or engine families, of the power band R which do not meet the requirements of this Regulation as amended by the 03 series of amendments.
- 11.14. As from the date of entry into force of the 03 series of amendments, Contracting Parties applying this Regulation may refuse the placing on the market of variable speed engines, or engine families, included in the power bands L, M, N and P not approved under this Regulation as amended by the series 03 of amendments.
- 11.15. As from 1 January 2014, Contracting Parties applying this Regulation may refuse the placing on the market of variable speed engines, or engine families, included in the power band Q not approved under this Regulation as amended by the series 03 of amendments.
- 11.16. As from 1 October 2014, Contracting Parties applying this Regulation may refuse the placing on the market of variable speed engines, or engine families, included in the power band R not approved under this Regulation as amended by the series 03 of amendments.
- 11.17. By derogation to the provisions stipulated in paragraphs 11.14. to 11.16. Contracting Parties applying this Regulation shall postpone each date mentioned in the above paragraphs for two years in respect of engines with a production date prior to the said dates.
- 11.18. By derogation to the provisions stipulated in paragraphs 11.14., 11.15. and 11.16., Contracting Parties applying this Regulation may continue to permit the placing on the market of engines approved on the basis of a previous technical standard, provided that the engines are intended as replacement for fitting in vehicles in use, and that it is not technically feasible for the engines in question to satisfy the new requirements of the 03 series of amendments.

## **12. Names and addresses of Technical Services responsible for conducting approval tests and of Type Approval Authorities**

The Contracting Parties to the 1958 Agreement applying this Regulation shall communicate to the United Nations Secretariat the names and addresses of the Technical Services responsible for conducting approval tests and the Type Approval Authorities which grant approval and to which forms certifying approval or extension or refusal or withdrawal of approval, issued in other countries are to be sent.

## Annex 1A

### **Information document No ... relating to the type approval and referring to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery**

Parent engine/engine type<sup>1</sup>:.....

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 machinery to be propelled by the engine<sup>2</sup>:.....
- 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 of the mobile machinery (if applicable)
3. Photographs of the parent engine
4. List further attachments if any

Date, file

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<sup>1</sup> Strike out what does not apply.

<sup>2</sup> Specify the tolerance.

## Annex 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<sup>1</sup>
  - 1.4. Bore:.....mm
  - 1.5. Stroke: .....mm
  - 1.6. Number and layout of cylinders: .....
  - 1.7. Engine capacity: .....cm<sup>3</sup>
  - 1.8. Rated speed:.....
  - 1.9. Maximum torque speed:.....
  - 1.10. Volumetric compression ratio<sup>2</sup>:.....
  - 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<sup>1</sup>
      - 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<sup>1</sup>
      - 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

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<sup>1</sup> Strike out what does not apply.

<sup>2</sup> Specify the tolerance.

- 1.15.3. Maximum charge air outlet temperature of the inlet intercooler (if applicable):K
- 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<sup>1</sup>
- 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<sup>1</sup>
- 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<sup>1</sup>
- 2.2. Additional anti-pollution devices (if any, and if not covered by another heading)
- 2.2.1. Catalytic converter: yes/no<sup>1</sup>
- 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: .....

- 2.2.1.13.3. International standard (where appropriate): .....
- 2.2.1.14. NO<sub>x</sub> sensor: yes/no<sup>1</sup>
- 2.2.2. Oxygen sensor: yes/no<sup>1</sup>
- 2.2.2.1. Make(s): .....
- 2.2.2.2. Type: .....
- 2.2.2.3. Location: .....
- 2.2.3. Air injection: yes/no<sup>1</sup>
- 2.2.3.1. Type (pulse air, air pump, etc.): .....
- 2.2.4. EGR: yes/no<sup>1</sup>
- 2.2.4.1. Characteristics (cooled/uncooled, high pressure/low pressure, etc.): .....
- 2.2.5. Particulate trap: yes/no<sup>1</sup>
- 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<sup>1</sup>
- 2.2.6.1. Description and operation: .....
- 3. Fuel feed
- 3.1. Feed pump
  - Pressure<sup>2</sup> 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<sup>3</sup> per stroke<sup>2</sup> or cycle at pump speed of: ..... min<sup>-1</sup>  
at full injection, or characteristic diagram.  
Mention the method used: On engine/on pump bench<sup>1</sup>
    - 3.2.1.4. Injection advance
      - 3.2.1.4.1. Injection advance curve<sup>2</sup>: .....
      - 3.2.1.4.2. Timing<sup>2</sup>: .....
  - 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<sup>2</sup> 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<sup>2</sup>: .....min<sup>-1</sup>
  - 3.2.4.4. Maximum no-load speed<sup>2</sup>: .....min<sup>-1</sup>
  - 3.2.4.5. Idling speed<sup>2</sup>: .....min<sup>-1</sup>
- 3.3. Cold Start System
  - 3.3.1. Make(s): .....
  - 3.3.2. Type(s): .....
  - 3.3.3. Description: .....
- 4. Valve timing
  - 4.1. Maximum lift and angles of opening and closing in relation to dead centres or equivalent data: .....
  - 4.2. Reference and/or setting ranges<sup>1</sup>

## Annex 1A - Appendix 2

### Essential characteristics of the engine family

1. Common parameters<sup>1</sup>
  - 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<sup>2</sup>: .....
  - 1.7.3. Water injection/emulsion<sup>2</sup>: .....
  - 1.7.4. Air injection<sup>2</sup>: .....
  - 1.8. Exhaust after-treatment system<sup>2</sup>: .....
  - 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: .....

---

<sup>1</sup> Strike out what does not apply.

<sup>2</sup> Specify the tolerance.

2.2. Specification of engines within this family:

<i>Engine type</i>	<i>No. of cylinders</i>	<i>Rated speed</i>	<i>Rated net power (kW)</i>	<i>Maximum torque speed</i>	<i>Maximum torque</i>	<i>Low idle speed</i>
<i>Parent engine (for full details see Annex 1A)</i>						

2.3. In addition, for each engine type within the family, the information required in Annex 1B – Appendix 3 shall be submitted to the Type Approval Authority.

## 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<sup>1</sup>
  - 1.4. Bore:.....mm
  - 1.5. Stroke: .....mm
  - 1.6. Number and layout of cylinders: .....
  - 1.7. Engine capacity: .....cm<sup>3</sup>
  - 1.8. Rated speed:.....
  - 1.9. Maximum torque speed:.....
  - 1.10. Volumetric compression ratio<sup>2</sup>:.....
  - 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<sup>1</sup>
      - 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<sup>1</sup>
      - 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

---

<sup>1</sup> Strike out what does not apply.

<sup>2</sup> Specify the tolerance.

- 1.15.3. Maximum charge air outlet temperature of the inlet intercooler (if applicable):K
- 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<sup>1</sup>
- 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<sup>1</sup>
- 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<sup>1</sup>
- 2.2. Additional anti-pollution devices (if any, and if not covered by another heading)
- 2.2.1. Catalytic converter: yes/no<sup>1</sup>
- 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: .....

- 2.2.1.13.3. International standard (where appropriate): .....
- 2.2.1.14. NO<sub>x</sub> sensor: yes/no<sup>1</sup>
- 2.2.2. Oxygen sensor: yes/no<sup>1</sup>
- 2.2.2.1. Make(s): .....
- 2.2.2.2. Type: .....
- 2.2.2.3. Location: .....
- 2.2.3. Air injection: yes/no<sup>1</sup>
- 2.2.3.1. Type (pulse air, air pump, etc.): .....
- 2.2.4. EGR: yes/no<sup>1</sup>
- 2.2.4.1. Characteristics (cooled/uncooled, high pressure/low pressure, etc.): .....
- 2.2.5. Particulate trap: yes/no<sup>1</sup>
- 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<sup>1</sup>
- 2.2.6.1. Description and operation: .....
- 3. Fuel feed
- 3.1. Feed pump
- Pressure<sup>2</sup> 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<sup>3</sup> per stroke<sup>2</sup> or cycle at pump speed of ..... min<sup>-1</sup>  
at full injection, or characteristic diagram.  
Mention the method used: On engine/on pump bench<sup>1</sup>
- 3.2.1.4. Injection advance
- 3.2.1.4.1. Injection advance curve<sup>2</sup>: .....
- 3.2.1.4.2. Timing<sup>2</sup>: .....
- 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<sup>2</sup> 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<sup>2</sup>: .....min<sup>-1</sup>
  - 3.2.4.4. Maximum no-load speed<sup>2</sup>:.....min<sup>-1</sup>
  - 3.2.4.5. Idling speed<sup>2</sup>: .....min<sup>-1</sup>
- 3.3. Cold Start System
  - 3.3.1. Make(s): .....
  - 3.3.2. Type(s):.....
  - 3.3.3. Description:.....
- 4. Valve timing
  - 4.1. Maximum lift and angles of opening and closing in relation to dead centres or equivalent data:.....
  - 4.2. Reference and/or setting ranges<sup>1</sup>

## 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 paragraph 1.3. are respected. The engine family shall be approved by the Type Approval Authority. The manufacturer shall provide to the Type Approval Authority 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 Type Approval Authority. 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 paragraph 1.3. 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 Type Approval Authority. 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 paragraph 1.3., 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  $\geq 0.75 \text{ dm}^3$  of the largest displacement within the engine family.
- Within 70 per cent and 100 per cent for engines with a unit cylinder displacement  $< 0.75 \text{ dm}^3$  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<sub>x</sub> system with selective reduction of NO<sub>x</sub> (addition of reducing agent);
  - (c) Other DeNO<sub>x</sub> 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 approval authority may

conclude that the worst case emission rate of the family can best be characterized by testing a second engine. Thus, the approval authority 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

### Communication

(Maximum format: A4 (210 x 297 mm))

issued by :

Name of administration:

.....  
 .....  
 .....



- concerning<sup>2</sup>:
- Approval granted
  - Approval extended
  - Approval refused
  - Approval withdrawn
  - Production definitively discontinued

of a compression ignition engine type or family of engine types as separate technical units with regard to the emission of pollutants pursuant to Regulation No. 96

Approval No.: ..... Extension No.: .....

1. Trade name or mark of the engine: .....
2. Engine type(s): .....
- 2.1. Engine family: .....
- 2.2. Types included in the engine family: .....
- 2.3. Tested type of engine or the representative of the engine family:.....
3. Manufacturer's name and address: .....
4. If applicable, name and address of manufacturer's representative: .....
5. Maximum allowable intake depression: ..... kPa
6. Maximum allowable back pressure: ..... kPa
7. Restriction of use (if any): .....

---

<sup>1</sup> Distinguishing number of the country which has granted/extended/refused/withdrawn an approval (see approval provisions in the Regulation).

<sup>2</sup> Strike out what does not apply.

8. Emission levels - final test results with DF:

	<i>NRSC</i>	<i>NRTC</i>
CO (g/kWh)		
HC (g/kWh)		
NO <sub>x</sub> (g/kWh)		
PM (g/kWh)		

9. Engine submitted for test on:.....
10. Technical Service responsible for conducting the approval test: .....
11. Date of test report issued by that service: .....
12. Number of test report issued by that service:.....
13. Site of approval mark on the engine: .....
14. Place:.....
15. Date:.....
16. Signature: .....
17. The following documents, bearing the approval number shown above, are annexed to this communication:

One copy of Annex 1A or Annex 1B to this Regulation completed and with drawings and diagrams referred to attached.

## Annex 2 - Appendix 1

### Test results

1. Information concerning the conduct of the test<sup>1</sup>:
  - 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: .....
    - 1.3.2. Power absorbed at indicated engine speeds (as specified by the manufacturer):

	<i>Power P<sub>AE</sub> (kW) absorbed at various engine speeds<sup>a</sup>, taking into account Annex 7</i>	
<i>Equipment</i>	<i>Intermediate (if applicable)</i>	<i>Rated</i>
Total:		

<sup>a</sup> Shall not be greater than 10 per cent of the power measured during the test.

- 1.4. Engine performance
  - 1.4.1. Engine speeds:
    - Idle: .....min<sup>-1</sup>
    - Intermediate: .....min<sup>-1</sup>
    - Rated: .....min<sup>-1</sup>

<sup>1</sup> For the case of several parent engines, the following are to be indicated for each of them.

1.4.2. Engine power<sup>2</sup>

	<i>Power setting (kW) at various engine speeds</i>	
<i>Condition</i>	<i>Intermediate (if applicable)</i>	<i>Rated</i>
Maximum power measured on test (P <sub>M</sub> ) (kW) (a)		
Total power absorbed by engine driven equipment as per paragraph 1.3.2. of this appendix or Annex 7 (kW) (b)		
Net engine power as specified in paragraph 2.1.41. (kW) (c)		
c = a + b		

2. Information concerning the conduct of the NRSC test:

2.1. Dynamometer setting (kW)

	<i>Dynamometer setting (kW) at various engine speeds</i>	
<i>Per cent Load</i>	<i>Intermediate (if applicable)</i>	<i>Rated</i>
10 (if applicable)		
25 (if applicable)		
50		
75		
100		

<sup>2</sup> Uncorrected power measured in accordance with paragraph 2.1.41.

- 2.2. Emission results of the engine/parent engine<sup>3</sup>  
 Deterioration Factor (DF): calculated/fixed<sup>3</sup>  
 Specify the DF values and the emission results in the following table<sup>3</sup>:

<i>NRSC Test</i>				
DF mult/add <sup>3</sup>	CO	HC	NO <sub>x</sub>	PM
	Emissions	CO (g/kWh)	HC (g/kWh)	NO <sub>x</sub> (g/kWh)
Test result				
Final test result with DF				

- 2.3. Sampling system used for the NRSC test:  
 2.3.1. Gaseous emissions<sup>4</sup>: .....  
 2.3.2. PM<sup>4</sup>: .....  
 2.3.2.1. Method<sup>3</sup>: single/multiple filter  
 3. Information concerning the conduct of the NRTC test<sup>5</sup>:  
 3.1. Emission results of the engine/parent engine<sup>3</sup>  
 Deterioration Factor (DF): calculated/fixed<sup>3</sup>  
 Specify the DF values and the emission results in the following table<sup>3</sup>:

<sup>3</sup> Delete as appropriate.

<sup>4</sup> Indicate figure numbers of system used as defined in Annex 4A, Appendix 4.

<sup>5</sup> In the case of several parent engines, each of them shall be indicated.

<i>NRTC Test</i>				
	CO	HC	NO <sub>x</sub>	PM
DF mult/add <sup>3</sup>				
Emissions	CO (g/kWh)	HC (g/kWh)	NO <sub>x</sub> (g/kWh)	PM (g/kWh)
Cold start				
Emissions	CO (g/kWh)	HC (g/kWh)	NO <sub>x</sub> (g/kWh)	PM (g/kWh)
Hot start w/o regeneration				
Hot start with regeneration <sup>3</sup>				
k <sub>r,u</sub> (mult/add) <sup>3</sup> k <sub>r,d</sub> (mult/add) <sup>3</sup>				
Weighted test result				
Final test result with DF				

3.2. Sampling system used for the NRTC test:

Gaseous emissions<sup>4</sup>: .....

Particulates<sup>4</sup>: .....

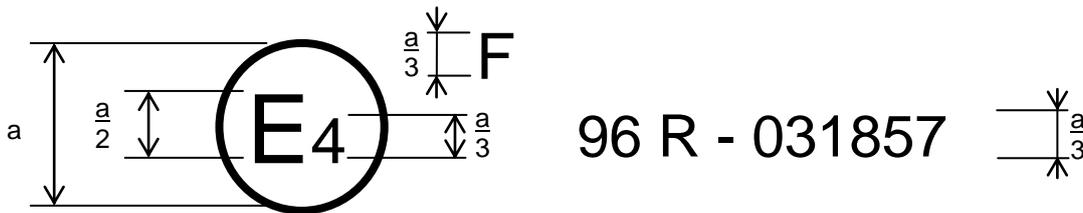
Method<sup>3</sup>: single/multiple filter

## Annex 3

### Arrangements of approval marks

#### Model A

(See paragraph 4.4. of this Regulation)

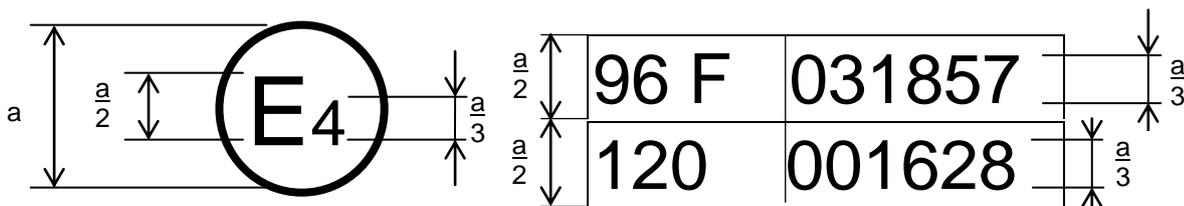


$a = 8 \text{ mm min}$

The above approval mark affixed to an engine shows that the engine type concerned has been approved in the Netherlands (E4) pursuant to Regulation No. 96 (according to the level corresponding to power band F) and under approval number 011857. The first two digits of the approval number indicate that Regulation No. 96 was in its amended form (03 series of amendments) when the approval was granted.

#### Model B

(See paragraph 4.5. of this Regulation)



$a = 8 \text{ mm min}$

The above approval mark affixed to an engine shows that the engine type concerned has been approved in the Netherlands (E4) pursuant to Regulations Nos. 96 (according to the level corresponding to power band F) and 120. The first two digits of the approval number indicate that, at the dates when the respective approvals were granted, Regulation No. 96 was in its amended form (03 series of amendments) and 120 in its original version.

## Annex 4A

### Method of determining emissions of gaseous and particulate pollutants

#### 1. Introduction

- 1.1. This Annex describes the method of determining emissions of gaseous and particulate pollutants from the engine to be tested.

The following test cycles shall apply:

The NRSC (non-road steady cycle) appropriate for the equipment specification which shall be used for the measurement of the emissions of carbon monoxide, hydrocarbons, oxides of nitrogen and particulates for all power bands of engines described in paragraphs 1.1., 1.2. and 1.3. of this Regulation, and the NRTC (non-road transient cycle) which shall be used for the measurement of the emissions of carbon monoxide, hydrocarbons, oxides of nitrogen and particulates for power bands L and upwards of engines described in paragraphs 1.1. and 1.2. of this Regulation.

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

Other systems or analysers may be accepted if they yield equivalent results to the following reference systems:

- (a) For gaseous emissions measured in the raw exhaust, the system shown in Figure 2 of Annex 4A, Appendix 4;
- (b) For gaseous emissions measured in the dilute exhaust of a full flow dilution system, the system shown in Figure 3 of Appendix 4 of Annex 4A;
- (c) For particulate emissions, the full flow dilution system, operating with a separate filter for each mode, shown in Figure 13 of Appendix 4 of Annex 4A.

The determination of system equivalency shall be based upon a seven test cycle (or larger) correlation study between the system under consideration and one or more of the above reference systems.

The equivalency criterion is defined as a  $\pm 5$  per cent agreement of the averages of the weighted cycle emissions values. The cycle to be used shall be that given in Annex 4A, paragraph 3.6.1.

For introduction of a new system into the Regulation the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725.

- 1.2. The test shall be carried out with the engine mounted on a test bench and connected to a dynamometer.

1.3. Measurement principle:

The engine exhaust emissions to be measured include the gaseous components (carbon monoxide, total hydrocarbons and oxides of nitrogen), and the particulates. Additionally, carbon dioxide is often used as a tracer gas for determining the dilution ratio of partial and full flow dilution systems. Good engineering practice recommends the general measurement of carbon dioxide as an excellent tool for the detection of measurement problems during the test run.

1.3.1. NRSC test:

During a prescribed sequence of operating conditions, with the engines warmed up, the amounts of the above exhaust emissions shall be examined continuously by taking a sample from the raw exhaust gas. The test cycle consists of a number of speed and torque (load) modes, which cover the typical operating range of diesel engines. During each mode, the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted (either by weighing factors or by sampling time). The particulate sample shall be diluted with conditioned ambient air. One sample over the complete test procedure shall be taken and collected on suitable filters.

Alternatively, for discrete mode cycles, a sample may be taken on separate filters, one for each mode, and cycle-weighted results computed.

The grams of each pollutant emitted per kilowatt-hour shall be calculated as described in Appendix 3 to this Annex.

1.3.2. NRTC test:

The prescribed transient test cycle, based closely on the operating conditions of diesel engines installed in non-road machinery, is run twice:

- (a) The first time (cold start) after the engine has soaked to room temperature and the engine coolant and oil temperatures, after treatment systems and all auxiliary engine control devices are stabilized between 20 and 30 °C.
- (b) The second time (hot start) after a twenty-minute hot soak that commences immediately after the completion of the cold start cycle.

During this test sequence the above pollutants shall be examined. The test sequence consists of a cold start cycle following natural or forced cool-down of the engine, a hot soak period and a hot start cycle, resulting in a composite emissions calculation. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to the time of the cycle, resulting in the work produced by the engine over the cycle. The concentrations of the gaseous components shall be determined over the cycle, either in the raw exhaust gas by integration of the analyser signal in accordance with Appendix 3 to this Annex, or in the diluted exhaust gas of a CVS full-flow dilution system by integration or by bag sampling in accordance with Appendix 3 to this Annex. For particulates, a proportional sample shall be collected from the diluted exhaust gas on a specified filter by either partial flow dilution or full-flow dilution. Depending on the method used, the diluted or undiluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work to give the grams of each pollutant emitted per kilowatt-hour.

Emissions (g/kWh) shall be measured during both the cold and hot start cycles. Composite weighted emissions shall be computed by weighing the cold start results 10 per cent and the hot start results 90 per cent. Weighted composite results shall meet the limits.

1.4.

Symbols for test parameters

Symbol	Unit	Term
$A_p$	$m^2$	Cross-sectional area of the isokinetic sampling probe.
$A_T$	$m^2$	Cross-sectional area of the exhaust pipe.
aver		Weighted average values for:
	$m^3/h$	volume flow;
	kg/h	mass flow;
	g/kWh	specific emission.
$\alpha$	-	Hydrogen-to-carbon ratio of the fuel.
$CI$	-	Carbon 1 equivalent hydrocarbon.
$conc$	ppm	Concentration (with suffix of
	Vol %	the component nominating).
$conc_c$	ppm	Background corrected
	Vol %	concentration.
$conc_d$	ppm	Concentration of dilution
	Vol %	air.
$DF$	-	Dilution factor.
$f_a$	-	Laboratory atmospheric factor.
$F_{FH}$	-	Fuel specific factor used for the calculations of wet concentrations from dry concentrations hydrogen to carbon ratio.
$G_{AIRW}$	kg/h	Intake air mass flow rate on wet basis.
$G_{AIRD}$	kg/h	Intake air mass flow rate on dry basis.
$G_{DILW}$	kg/h	Dilution air mass flow rate on wet basis.
$G_{EDFW}$	kg/h	Equivalent diluted exhaust gas mass flow rate on wet basis.
$G_{EXHW}$	kg/h	Exhaust gas mass flow rate on wet basis.
$G_{FUEL}$	kg/h	Fuel mass flow rate.
$G_{TOTW}$	kg/h	Diluted exhaust gas mass flow rate on wet basis.
$H_{REF}$	g/kg	Reference value of absolute humidity 10.71 g/kg for calculation of $NO_x$ and particulate humidity correction factors.
$H_a$	g/kg	Absolute humidity of the intake air.
$H_d$	g/kg	Absolute humidity of the dilution air.

$i$	-	Subscript denoting an individual mode.
$K_H$	-	Humidity correction factor for NO <sub>x</sub> .
$K_p$	-	Humidity correction factor for particulate.
$K_{W,a}$	-	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.
$L$	%	Per cent torque related to the maximum torque for the test speed.
$mass$	g/h	Subscript denoting emissions mass flow rate.
$M_{DIL}$	kg	Mass of the dilution air sample passed through the particulate sampling filters.
$M_{SAM}$	kg	Mass of the diluted exhaust sample passed through the particulate sampling filters.
$M_d$	mg	Particulate sample mass of the dilution air collected.
$M_f$	mg	Particulate sample mass collected.
$p_a$	kPa	Saturation vapour pressure of the engine intake air (ISO 3046 $p_{sy} = PSY$ test ambient).
$p_B$	kPa	Total barometric pressure (ISO 3046: $P_x = PX$ Site ambient total pressure; $P_y = PY$ Test ambient total pressure).
$p_d$	kPa	Saturation vapour pressure of the dilution air.
$p_s$	kPa	Dry atmospheric pressure.
$P$	kW	Power, brake uncorrected.
$P_{AE}$	kW	Declared total power absorbed by auxiliaries fitted for the test which are not required by paragraph 2.1.41. of this Regulation.
$P_M$	kW	Maximum measured power at the test speed under test conditions (see Annex 1A).
$P_m$	kW	Power measured at the different test modes.
$q$	-	Dilution ratio.
$r$	-	Ratio of cross sectional areas of isokinetic probe and exhaust pipe.
$R_a$	%	Relative humidity of the intake air.
$R_d$	%	Relative humidity of the dilution air.
$R_f$	-	FID response factor.
$S$	kW	Dynamometer setting.

$T_a$	K	Absolute temperature of the intake air.
$T_{Dd}$	K	Absolute dewpoint temperature.
$T_{SC}$	K	Temperature of the intercooled air.
$T_{ref}$	K	Reference temperature (of combustion air 298K (25 °C)).
$T_{SCRef}$	K	Intercooled air reference temperature.
$V_{AIRD}$	m <sup>3</sup> /h	Intake air volume flow rate on dry basis.
$V_{AIRW}$	m <sup>3</sup> /h	Intake air volume flow rate on wet basis.
$V_{DIL}$	m <sup>3</sup>	Volume of the dilution air sample passed through the particulate sample filters.
$V_{DILW}$	m <sup>3</sup> /h	Dilution air volume flow rate on wet basis.
$V_{EDFW}$	m <sup>3</sup> /h	Equivalent diluted exhaust gas volume flow rate on wet basis.
$V_{EXHD}$	m <sup>3</sup> /h	Exhaust gas volume flow rate on dry basis.
$V_{EXHW}$	m <sup>3</sup> /h	Exhaust gas volume flow rate on wet basis.
$V_{SAM}$	m <sup>3</sup>	Volume of sample through particulate sampling filters.
$V_{TOTW}$	m <sup>3</sup> /h	Diluted exhaust gas volume flow rate on wet basis.
$WF$	-	Weighing factor.
$WF_E$	-	Effective weighing factor.

2. Test conditions

2.1. General requirements

All volumes and volumetric flow rates shall be related to 273 K (0 °C) and 101.3 kPa.

2.2. Engine test conditions

2.2.1. The absolute temperature  $T_a$  of the engine intake air 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:

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left( \frac{99}{p_s} \right) \cdot \left( \frac{T}{298} \right)^{0.7}$$

Turbocharged engine with or without cooling of the intake air:

$$f_a = \left( \frac{99}{p_s} \right)^{0.7} \cdot \left( \frac{T}{298} \right)^{1.5}$$

2.2.2. Test validity

For a test to be recognized as valid, the parameter  $f_a$  shall be such that:

$$0.96 \leq f_a \leq 1.06$$

- 2.2.3. Engines with charge air cooling
- The charge air temperature shall be recorded and, at the declared rated speed and full load, shall be within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer. The temperature of the cooling medium shall be at least 293 K (20 °C).
- If a test shop system or external blower is used, the charge air temperature shall be set to within  $\pm 5$  K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle. The charge air cooler volume shall be based upon good engineering practice and typical vehicle/machinery applications.
- Optionally, the setting of the charge air cooler may be done in accordance with SAE J 1937 as published in January 1995.
- 2.3. Engine air inlet system
- The test engine shall be equipped with an air inlet system presenting an air inlet restriction within  $\pm 300$  Pa of the value specified by the manufacturer for a clean air cleaner at the engine operating conditions as specified by the manufacturer, which result in maximum air flow. The restrictions are to be set at rated speed and full load. A test shop system may be used, provided it duplicates actual engine operating conditions.
- 2.4. Engine exhaust system
- The test engine shall be equipped with an exhaust system with exhaust back pressure within  $\pm 650$  Pa of the value specified by the manufacturer at the engine operating conditions resulting in maximum declared power.
- If the engine is equipped with an exhaust after-treatment device, the exhaust pipe shall have the same diameter as found in-use for at least four pipe diameters upstream to the inlet of the beginning of the expansion section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment device shall be the same as in the machine 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.
- 2.5. Cooling system
- An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures shall be prescribed by the manufacturer.
- 2.6. Lubricating oil
- Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.
- 2.7. Test fuel
- The fuel shall be the reference fuel specified in Annex 6 for the respective power band:
- Annex 6,, Table 1 for power bands D to G

Annex 6, Table 2 for power bands H to K

Annex 6, Table 3 for power bands L to P

Optionally, the reference fuel specified in Annex 6 Table 1 may be used for power bands H to K.

The cetane number and the sulphur content of the reference fuel used for test shall be recorded at paragraph 1.1. of Appendix 1 of Annex 2.

The fuel temperature at the injection pump inlet shall be 306-316 K (33-43 °C).

3. Test run (NRSC test)

3.1. Determination of dynamometer settings

The basis of specific emissions measurement is uncorrected brake power according to Regulation No. 120.

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

Where auxiliaries have not been removed, the power absorbed by them at the test speeds shall be determined in order to calculate the dynamometer settings, except for engines where such auxiliaries form an integral part of the engine (e.g. cooling fans for air cool engines).

The settings of inlet restriction and exhaust pipe backpressure shall be adjusted to the manufacturer's upper limits, in accordance with paragraphs 2.3. and 2.4.

The maximum torque values at the specified test speeds shall be determined by experimentation in order to calculate the torque values for the specified test modes. For engines which are not designed to operate over a range on a full load torque curve, the maximum torque at the test speeds shall be declared by the manufacturer.

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

$$S = \left( (P_M + P_{AE}) \cdot \frac{L}{100} \right) - P_{AE}$$

If the ratio,

$$\frac{P_{AE}}{P_M} \geq 0.03$$

the value of  $P_{AE}$  may be verified by the Type Approval Authority granting type approval.

3.2. Preparation of the sampling filters

At least one hour before the test, each filter (pair) shall be placed in a closed, but unsealed, petri dish and placed in a weighing chamber for stabilization. At the end of the stabilization period, each filter (pair) shall be weighed and the tare weight shall be recorded. The filter (pair) shall then be stored in a closed petri dish or filter holder until needed for testing. If the filter (pair) is not used within eight hours of its removal from the weighing chamber, it shall be reweighed before use.

- 3.3. Installation of the measuring equipment
- The instrumentation and sample probes shall be installed as required. When using a full flow dilution system for exhaust gas dilution, the tailpipe shall be connected to the system.
- 3.4. Starting the dilution system and engine
- The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilized at full load and rated speed (paragraph 3.6.2.).
- 3.5. Adjustment of the dilution ratio
- The particulate sampling system shall be started and running on bypass for the single filter method (optional for the multiple filter method). The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done at any time prior to, during, or after the test. If the dilution air is not filtered, the measurement shall be done on one sample taken for the duration of the test.
- The dilution air shall be set to obtain a filter face temperature between 315 K (42 °C) and 325 K (52 °C) at each mode. The total dilution ratio shall not be less than four.
- Note:* For power bands up to and including K using discrete mode cycles the filter temperature may be kept at or below the maximum temperature of 325 K (52 °C) instead of respecting the temperature range of 42 °C to 52 °C.
- For the single and multiple filter methods, the sample mass flow rate through the filter shall be maintained at a constant proportion of the dilute exhaust mass flow rate for full flow systems for all modes. This mass ratio shall be within  $\pm 5$  per cent with respect to the averaged value of the mode, except for the first 10 s of each mode for systems without bypass capability. For partial flow dilution systems with single filter method, the mass flow rate through the filter shall be constant within  $\pm 5$  per cent with respect to the averaged value of the mode, except for the first 10 s of each mode for systems without bypass capability.
- For CO<sub>2</sub> or NO<sub>x</sub> concentration controlled systems, the CO<sub>2</sub> or NO<sub>x</sub> content of the dilution air shall be measured at the beginning and at the end of each test. The pre and post test background CO<sub>2</sub> or NO<sub>x</sub> concentration measurements of the dilution air shall be within 100 ppm or 5 ppm of each other, respectively.
- When using a dilute exhaust gas analysis system, the relevant background concentrations shall be determined by sampling dilution air into a sampling bag over the complete test sequence.
- Continuous (non-bag) background concentration may be taken at the minimum of three points, at the beginning, at the end, and a point near the middle of the cycle and averaged. At the manufacturer's request background measurements may be omitted.
- 3.6. Checking the analysers
- The emission analysers shall be set at zero and spanned.

- 3.7. Test cycle
- 3.7.1. Machinery specification according to paragraphs 1.1. to 1.3.:
- 3.7.1.1. Specification A
- For engines covered by paragraphs 1.1. and 1.2. of this Regulation, the discrete 8-mode cycle<sup>1</sup> of Annex 5, sub-paragraph (a) of paragraph 1.1. shall be followed in dynamometer operation on the test engine.
- As an option, the corresponding ramped modal 9-mode cycle of Annex 5, sub-paragraph (a) of paragraph 1.2. may be used. In this case, the cycle shall be run in accordance with Annex 4B, paragraph 7.8.2. instead of following the procedures in paragraphs 3.7.2. to 3.7.6.
- 3.7.1.2. Specification B
- For engines covered by paragraph 1.3. of this Regulation, the discrete 5-mode cycle<sup>2</sup> of Annex 5, sub-paragraph (b) of paragraph 1.1. shall be followed in dynamometer operation on the test engine.
- As an option, the ramped modal 5-mode cycle of Annex 5, sub-paragraph (b) of paragraph 1.2. may be used. In this case, the cycle shall be run in accordance with Annex 4B, paragraph 7.8.2. instead of following the procedures in paragraphs 3.7.2. to 3.7.6.
- The load figures are percentage values of the torque corresponding to the prime power 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.
- 3.7.2. Conditioning of the engine
- Warming up of the engine and the system shall be at maximum speed and torque in order to stabilize the engine parameters according to the recommendations of the manufacturer.
- Note:* The conditioning period should also prevent the influence of deposits from a former test in the exhaust system. There is also a required period of stabilization between test points which has been included to minimize point to point influences.
- 3.7.3. Test sequence
- The test sequence shall be started. The test shall be performed in the order of the mode numbers as set out above for the test cycles.
- During each mode of the given test cycle after the initial transition period, the specified speed shall be held to within  $\pm 1$  per cent of rated speed or  $\pm 3 \text{ min}^{-1}$ , whichever is greater, except for low idle which shall be within the tolerances declared by the manufacturer. The specified torque shall be held so that the average over the period during which the measurements are being taken is within  $\pm 2$  per cent of the maximum torque at the test speed.

<sup>1</sup> Identical with C1 cycle as described in paragraph 8.3.1.1. of ISO 8178-4:2008.

<sup>2</sup> Identical with D2 cycle as described in paragraph 8.4.1. of ISO 8178-4: 2008.

For each measuring point a minimum time of ten minutes is necessary. If for the testing of an engine, longer sampling times are required for reasons of obtaining sufficient particulate mass on the measuring filter the test mode period can be extended as necessary.

The mode length shall be recorded and reported.

The gaseous exhaust emission concentration values shall be measured and recorded during the last three minutes of the mode.

The particulate sampling and the gaseous emission measurement should not commence before engine stabilization, as defined by the manufacturer, has been achieved and their completion shall be coincident.

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.

3.7.4. Analyser response

The output of the analysers shall be recorded on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analysers at least during the last three minutes of each mode. If bag sampling is applied for the diluted CO and CO<sub>2</sub> measurement (see Annex 4A, Appendix 1, paragraph 1.4.4.), a sample shall be bagged during the last three minutes of each mode, and the bag sample analysed and recorded.

3.7.5. Particulate sampling

The particulate sampling can be done either with the single filter method or with the multiple filter method (Annex 4A, Appendix 1, paragraph 1.5.). 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 shall be taken into account during sampling by adjusting sample flow rate and/or sampling time, accordingly.

Sampling shall be conducted as late as possible within each mode. 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.

3.7.6. Engine conditions

The engine speed and load, intake air temperature, fuel flow and air or exhaust gas flow shall be measured for each mode once the engine has been stabilized.

If the measurement of the exhaust gas flow or the measurement of combustion air and fuel consumption is not possible, it can be calculated using the carbon and oxygen balance method (see Annex 4A, Appendix 1, paragraph 1.2.3.).

Any additional data required for calculation shall be recorded (see Annex 4A, Appendix 3, paragraphs 1.1. and 1.2.).

3.8. Re-checking the analysers

After the emission test a zero gas and the same span gas will be used for re-checking. The test will be considered acceptable if the difference between the two measuring results is less than 2 per cent.

4. Test run (NRTC test)

4.1. Introduction

The non-road transient cycle (NRTC) is listed in Annex 5 as a second-by-second sequence of normalized speed and torque values applicable to all diesel engines covered by this Regulation. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test, based on the engine mapping curve. This conversion is referred to as denormalization, and the test cycle developed is referred to as the reference cycle of the engine to be tested. With these reference speed and torque values, the cycle shall be run on the test cell, and the feedback speed and torque values recorded. In order to validate the test run, a regression analysis between reference and feedback speed and torque values shall be conducted upon completion of the test.

4.1.1. The use of defeat devices or irrational control or irrational emission control strategies shall be prohibited

4.2. Engine mapping procedure

When generating the NRTC on the test cell, the engine shall be mapped before running the test cycle to determine the speed vs. torque curve.

4.2.1. Determination of the mapping speed range

The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed	=	idle speed
Maximum mapping speed	=	$n_{hi} \times 1.02$ or speed where full load torque drops off to zero, whichever is lower (where $n_{hi}$ is the high speed, defined as the highest engine speed where 70 per cent of the rated power is delivered).

4.2.2. Engine mapping curve

The engine shall be warmed up at maximum power in order to stabilize the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilized, the engine mapping shall be performed according to the following procedures.

4.2.2.1. Transient map

- (a) The engine shall be unloaded and operated at idle speed.
- (b) The engine shall be operated at full load setting of the injection pump at minimum mapping speed.
- (c) The engine speed shall be increased at an average rate of  $8 \pm 1 \text{ min}^{-1}/\text{s}$  from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

4.2.2.2. Step map

- (a) The engine shall be unloaded and operated at idle speed.
- (b) The engine shall be operated at full load setting of the injection pump at minimum mapping speed.
- (c) While maintaining full load, the minimum mapping speed shall be maintained for at least 15 s, and the average torque during the last 5 s shall be recorded. The maximum torque curve from minimum to maximum mapping speed shall be determined in no greater than  $100 \pm 20 \text{ min}^{-1}$  speed increments. Each test point shall be held for at least 15 s, and the average torque during the last 5 s shall be recorded.

4.2.3. Mapping curve generation

All data points recorded under paragraph 4.2.2. shall be connected using linear interpolation between points. The resulting torque curve is the mapping curve and shall be used to convert the normalized torque values of the engine dynamometer schedule of Annex 5 into actual torque values for the test cycle, as described in paragraph 4.3.3.

4.2.4. Alternate mapping

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 paragraph for reasons of safety or representativeness shall be approved by the parties involved along with the justification for their use. In no case, however, shall the torque curve be run by descending engine speeds for governed or turbocharged engines.

4.2.5. Replicate tests

An engine need not be mapped before each and every test cycle. An engine shall be remapped prior to a test cycle if:

- (a) An unreasonable amount of time has transpired since the last map, as determined by engineering judgement, or,
- (b) Physical changes or recalibrations have been made to the engine, which may potentially affect engine performance.

4.3. Generation of the reference test cycle

4.3.1. Reference speed

The reference speed ( $n_{\text{ref}}$ ) corresponds to the 100 per cent normalized speed values specified in the engine dynamometer schedule of Annex 5. The actual engine cycle resulting from denormalization to the reference speed depends largely on selection of the proper reference speed. The reference speed shall be determined by the following formula:

$$n_{\text{ref}} = \text{low speed} + 0.95 (\text{high speed} - \text{low speed})$$

(The high speed is the highest engine speed where 70 per cent of the rated power is delivered, while the low speed is the lowest engine speed where 50 per cent of the rated power is delivered).

If the measured reference speed is within  $\pm 3$  per cent of the reference speed as declared by the manufacturer, the declared reference speed may be used for the emissions test. If the tolerance is exceeded, the measured reference speed shall be used for the emissions test. (This is consistent with the ISO 8178-11:2006 standard.)

4.3.2. Denormalization of engine speed

The speed shall be denormalized using the following equation:

$$ActualSpeed = \frac{\%speed}{100} \cdot (referencespeed - idlespeed) + idlespeed$$

4.3.3. Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex 5 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 paragraph 4.2.2., as follows:

$$Actualtorque = \frac{\%torque}{100} \cdot max.torque$$

for the respective actual speed as determined in paragraph 4.3.2.

4.3.4. Example of denormalization procedure

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

$$\% speed = 43 \text{ per cent}$$

$$\% torque = 82 \text{ per cent}$$

Given the following values:

$$referencespeed = 2,200 \text{ min}^{-1}$$

$$idlespeed = 600 \text{ min}^{-1}$$

results in

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

With the maximum torque of 700 Nm observed from the mapping curve at 1,288  $\text{min}^{-1}$

$$Actualtorque = \frac{82}{100} \cdot 700 = 574 \text{ Nm}$$

4.4. Dynamometer

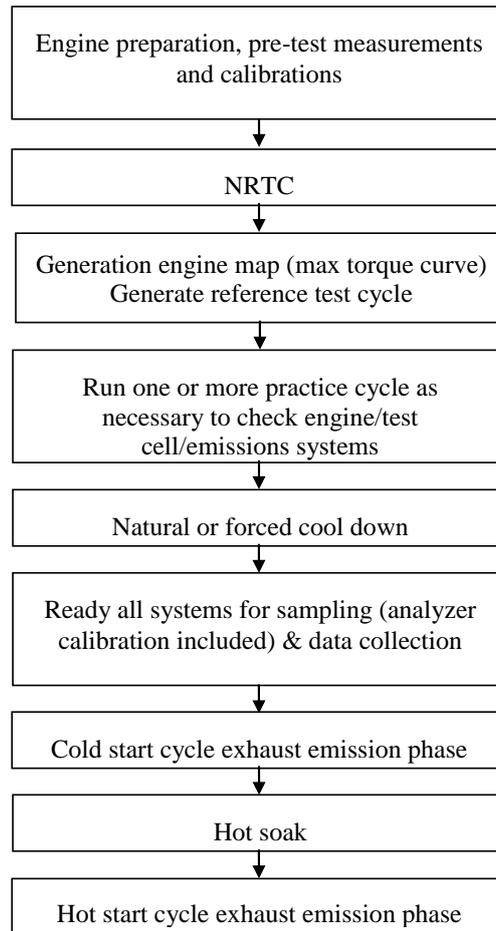
4.4.1. When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dyno shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform this calculation in real time.

4.4.2. If the engine is tested with an eddy-current dynamometer, it is recommended that the number of points, where the difference  $T_{sp} - 2 \cdot \pi \cdot \dot{n}_{sp} \cdot \Theta_D$  is smaller than  $-5$  per cent of the peak torque, does not exceed 30 (where  $T_{sp}$  is

the demanded torque,  $\dot{n}$  is the derivative of the engine speed,  $\Theta_D$  is the rotational inertia of the eddy-current dynamometer).

4.5. Emissions test run

The following flow chart outlines the test sequence:



One or more practice cycles may be run as necessary to check engine, test cell and emissions systems before the measurement cycle.

4.5.1. Preparation of the sampling filters

At least one hour before the test, each filter shall be placed in a petri dish, which is protected against dust contamination and allows air exchange, and placed in a weighing chamber for stabilization. At the end of the stabilization period, each filter shall be weighed and the weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber. The tare weight shall be recorded.

- 4.5.2. Installation of the measuring equipment
- The instrumentation and sample probes shall be installed as required. The tailpipe shall be connected to the full-flow dilution system, if used.
- 4.5.3. Starting the dilution system
- The dilution system shall be started. The total diluted exhaust gas flow of a full-flow dilution system or the diluted exhaust gas flow through a partial flow dilution system shall be set to eliminate water condensation in the system, and to obtain a filter face temperature between 315 K (42 °C) and 325 K (52 °C).
- 4.5.4. Starting the particulate sampling system
- The particulate sampling system shall be started and run on by-pass. The particulate background level of the dilution air may be determined by sampling the dilution air prior to entrance of the exhaust into the dilution tunnel. It is preferred that background particulate sample be collected during the transient cycle if another PM sampling system is available. Otherwise, the PM sampling system used to collect transient cycle PM can be used. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements should be carried out prior to the beginning and after the end of the cycle and the values averaged.
- 4.5.5. Checking the analysers
- The emission analysers shall be set at zero and spanned. If sample bags are used, they shall be evacuated.
- 4.5.6. Cool-down requirements
- 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.
- The cold start cycle exhaust emission test may begin after a cool-down only when the engine oil, coolant and after-treatment temperatures are stabilized between 20 °C and 30 °C for a minimum of fifteen minutes.
- 4.5.7. Cycle run
- 4.5.7.1. Cold start cycle
- The test sequence shall commence with the cold start cycle at the completion of the cool-down when all the requirements specified in paragraph 4.5.6. are met.
- The engine shall be started according to the starting procedure recommended by the manufacturer in the owner's manual, using either a production starter motor or the dynamometer.

As soon as it is determined that the engine is started, start a "free idle" timer. Allow the engine to idle freely with no-load for  $23 \pm 1$  s. Begin the transient engine cycle such that the first non-idle record of the cycle occurs at  $23 \pm 1$  s. The free idle time is included in the  $23 \pm 1$  s.

The test shall be performed according to the reference cycle as set out in Annex 5. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. The set points shall be calculated by linear interpolation between the 1 Hz set points of the reference cycle. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

#### 4.5.7.2. Analyser response

At the start of the engine the measuring equipment shall be started, simultaneously:

- (a) Start collecting or analysing dilution air, if a full flow dilution system is used;
- (b) Start collecting or analysing raw or diluted exhaust gas, depending on the method used;
- (c) Start measuring the amount of diluted exhaust gas and the required temperatures and pressures;
- (d) Start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;
- (e) Start recording the feedback data of speed and torque of the dynamometer.

If raw exhaust measurement is used, the emission concentrations (HC, CO and NO<sub>x</sub>) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analysers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

If a full flow dilution system is used, HC and NO<sub>x</sub> shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyser signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO and CO<sub>2</sub> shall be determined by integration or by analysing the concentrations in the sample bag collected over the cycle. The concentrations of the gaseous pollutants in the dilution air shall be determined by integration or by collection in the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

#### 4.5.7.3. Particulate sampling

At the start of the engine the particulate sampling system shall be switched from by-pass to collecting particulates.

If a partial flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate.

If a full flow dilution system is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within  $\pm 5$  per cent of the set flow rate. If flow compensation (i.e. proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than  $\pm 5$  per cent of its set value (except for the first 10 s of sampling).

*Note:* For double dilution operation, sample flow is the net difference between the flow rate through the sample filters and the secondary dilution airflow rate.

The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within  $\pm 5$  per cent) because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower flow rate and/or a larger diameter filter.

4.5.7.4. Engine stalling during the cold start test cycle

If the engine stalls anywhere during the cold start test cycle, the engine shall be preconditioned, then the cool-down procedure repeated; finally the engine shall be restarted, and the test repeated. If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided.

4.5.7.5. Operations after cold start cycle

At the completion of the cold start cycle of the test, the measurement of the exhaust gas mass flow rate, the diluted exhaust gas volume, the gas flow into the collecting bags and the particulate sample pump shall be stopped. For an integrating analyser system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analysed as soon as possible and in any case not later than 20 minutes after the end of the test cycle.

After the emission test, a zero gas and the same span gas shall be used for rechecking the analysers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 per cent of the span gas value.

The particulate filters shall be returned to the weighing chamber no later than one hour after completion of the test. They shall be conditioned in a petri dish, which is protected against dust contamination and allows air exchange, for at least one hour, and then weighed. The gross weight of the filters shall be recorded.

4.5.7.6. Hot soak

Immediately after the engine is turned off, the engine cooling fan(s) shall be turned off if used, as well as the CVS blower (or disconnect the exhaust system from the CVS), if used.

Allow the engine to soak for  $20 \pm 1$  minutes. Prepare the engine and dynamometer for the hot start test. Connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems. Start the CVS (if used or not already on) or connect the exhaust system to the CVS (if disconnected). Start the sample pumps (except the particulate sample pump(s), the engine cooling fan(s) and the data collection system.

The heat exchanger of the constant volume sampler (if used) and the heated components of any continuous sampling system(s) (if applicable) shall be preheated to their designated operating temperatures before the test begins.

Adjust the sample flow rates to the desired flow rate and set the CVS gas flow measuring devices to zero. Carefully install a clean particulate filter in each of the filter holders and install assembled filter holders in the sample flow line.

4.5.7.7. Hot start cycle

As soon as it is determined that the engine is started, start a "free idle" timer. Allow the engine to idle freely with no-load for  $23 \pm 1$  s. Begin the transient engine cycle such that the first non-idle record of the cycle occurs at  $23 \pm 1$  s. The free idle time is included in the  $23 \pm 1$  s.

The test shall be performed according to the reference cycle as set out in Annex 5. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. The set points shall be calculated by linear interpolation between the 1 Hz set points of the reference cycle. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

The procedure described in previous paragraphs 4.5.7.2. and 4.5.7.3. shall then be repeated.

4.5.7.8. Engine stalling during the hot start cycle

If the engine stalls anywhere during the hot start cycle, the engine may be shut off and re-soaked for 20 minutes. The hot start cycle may then be rerun. Only one hot re-soak and hot start cycle restart is permitted.

4.5.7.9. Operations after hot start cycle

At the completion of the hot start cycle, the measurement of the exhaust gas mass flow rate, the diluted exhaust gas volume, the gas flow into the collecting bags and the particulate sample pump shall be stopped. For an integrating analyser system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analysed as soon as possible and in any case not later than 20 minutes after the end of the test cycle.

After the emission test, a zero gas and the same span gas shall be used for re-checking the analysers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 per cent of the span gas value.

The particulate filters shall be returned to the weighing chamber no later than one hour after completion of the test. They shall be conditioned in a petri dish, which is protected against dust contamination and allows air exchange, for at least one hour, and then weighed. The gross weight of the filters shall be recorded.

4.6. Verification of the test run

4.6.1. Data shift

To minimize the biasing effect of the time lag between the feedback and reference 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.

4.6.2. Calculation of the cycle work

The actual cycle work  $W_{act}$  (kWh) shall be calculated using each pair of engine feedback speed and torque values recorded. The actual cycle work  $W_{act}$  is used for comparison to the reference cycle work  $W_{ref}$  and for calculating the brake specific emissions. The same methodology shall be used for integrating both reference and actual engine power. If values are to be determined between adjacent references or adjacent measured values, linear interpolation shall be used.

In integrating the reference and actual cycle work, all negative torque values shall be set equal to zero and included. If integration is performed at a frequency of less than 5 Hz, and if, during a given time segment, the torque value changes from positive to negative or negative to positive, the negative portion shall be computed and set equal to zero. The positive portion shall be included in the integrated value.

$W_{act}$  shall be between -15 per cent and +5 per cent of  $W_{ref}$ .

4.6.3. Validation statistics of the test cycle

Linear regressions of the feedback values on the reference values shall be performed for speed, torque and power. This shall be done after any feedback data shift has occurred, if this option is selected. The method of least squares shall be used, with the best fit equation having the form:

$$y = mx + b$$

where:

$y$  = feedback (actual) value of speed ( $\text{min}^{-1}$ ), torque (N·m), or power (kW)

$m$  = slope of the regression line

$x$  = reference value of speed ( $\text{min}^{-1}$ ), torque (N·m), or power (kW)

$b$  = y intercept of the regression line

The standard error of estimate (SE) of  $y$  on  $x$  and the coefficient of determination ( $r^2$ ) shall be calculated for each regression line.

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

Table 1  
**Regression line tolerances**

	<i>Speed</i>	<i>Torque</i>	<i>Power</i>
Standard error of estimate (SEE) of $y$ on $x$	max 100 $\text{min}^{-1}$	max 13 % of power map maximum engine torque	max 8 % of power map maximum engine power
Slope of the regression line, $m$	0.95 to 1.03	0.83 – 1.03	0.89 – 1.03
Coefficient of determination, $r^2$	min 0.9700	min 0.8800	min 0.9100
y intercept of the regression line, $b$	$\pm 50 \text{ min}^{-1}$	$\pm 20 \text{ Nm}$ or $\pm 2 \%$ of max torque, whichever is greater	$\pm 4 \text{ kW}$ or $\pm 2 \%$ of max power, whichever is greater

For regression purposes only, point deletions are permitted where noted in Table 2 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 normalized 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.

Table 2

**Permitted point deletions from regression analysis (points to which the point deletion is applied have to be specified)**

<i>Condition</i>	<i>Speed and/or torque and/or power points which may be deleted with reference to the conditions listed in the left column</i>
First 24 ( $\pm 1$ ) s and last 25 s	Speed, torque and power
Wide open throttle, and torque feedback < 95 % torque reference	Torque and/or power
Wide open throttle, and speed feedback < 95 % speed reference	Speed and/or power
Closed throttle, speed feedback > idle speed + 50 min <sup>-1</sup> , and torque feedback > 105 % torque reference	Torque and/or power
Closed throttle, speed feedback $\leq$ idle speed + 50 min <sup>-1</sup> , and torque feedback = Manufacturer defined/measured idle torque $\pm 2$ % of max torque	Speed and/or power
Closed throttle and speed feedback > 105 % speed reference	Speed and/or power

## Annex 4A - Appendix 1

### Measurement and sampling procedures (NRSC, NRTC)

1. Measurement and sampling procedures (NRSC test)

Gaseous and particulate components emitted by the engine submitted for testing shall be measured by the methods described in Annex 4A, Appendix 4. The methods of Annex 4A, Appendix 4 describe the recommended analytical systems for the gaseous emissions (paragraph 1.1.) and the recommended particulate dilution and sampling systems (paragraph 1.2.).

At the request of the manufacturer and with the agreement of the approval authority the methods described in Annex 4B, paragraph 9. may be used as an alternative to those in paragraph 1. of this appendix.
- 1.1. Dynamometer specification

An engine dynamometer with adequate characteristics to perform the test cycle described in Annex 4A, paragraph 3.7.1. shall be used. The instrumentation for torque and speed measurement shall allow the measurement of the power within the given limits. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the maximum tolerances of the figures given in paragraph 1.3. are not exceeded.
- 1.2. Exhaust gas flow

The exhaust gas flow shall be determined by one of the methods mentioned in paragraphs 1.2.1. to 1.2.4.

  - 1.2.1. Direct measurement method

Direct measurement of the exhaust flow by flow nozzle or equivalent metering system (for detail see ISO 5167:2000).

*Note:* Direct gaseous flow measurement is a difficult task. Precautions shall be taken to avoid measurement errors that will impact emission value errors.
  - 1.2.2. Air and fuel measurement method

Measurement of the airflow and the fuel flow.

Air flow-meters and fuel flow-meters with the accuracy defined in paragraph 1.3. shall be used.

The calculation of the exhaust gas flow is as follows:

$$G_{\text{EXHW}} = G_{\text{AIRW}} + G_{\text{FUEL}} \text{ (for wet exhaust mass)}$$
  - 1.2.3. Carbon balance method

Exhaust mass calculation from fuel consumption and exhaust gas concentrations using the carbon balance method (Annex 4A, Appendix 3).
  - 1.2.4. Tracer measurement method

This method involves measurement of the concentration of a tracer gas in the exhaust. A known amount of an inert gas (e.g. pure helium) shall be injected

into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe, whichever is larger, downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the tracer gas concentration at engine idle speed after mixing becomes lower than the full scale of the trace gas analyser.

The calculation of the exhaust gas flow is as follows:

$$G_{\text{EXHW}} = \frac{G_{\text{T}} \cdot \rho_{\text{EXH}}}{60 \cdot (\text{conc}_{\text{mix}} - \text{conc}_{\text{a}})}$$

where:

- $G_{\text{EXHW}}$  = instantaneous exhaust mass flow (kg/s)
- $G_{\text{T}}$  = tracer gas flow (cm<sup>3</sup>/min)
- $\text{conc}_{\text{mix}}$  = instantaneous concentration of the tracer gas after mixing, (ppm)
- $\rho_{\text{EXH}}$  = density of the exhaust gas (kg/m<sup>3</sup>)
- $\text{conc}_{\text{a}}$  = background concentration of the tracer gas in the intake air (ppm)

The background concentration of the tracer gas ( $\text{conc}_{\text{a}}$ ) may be determined by averaging the background concentration measured immediately before and after the test run.

When the background concentration is less than 1 per cent of the concentration of the tracer gas after mixing ( $\text{conc}_{\text{mix}}$ ) at maximum exhaust flow, the background concentration may be neglected.

The total system shall meet the accuracy specifications for the exhaust gas flow and shall be calibrated according to Appendix 2, paragraph 1.11.2.

#### 1.2.5. Air flow and air to fuel ratio measurement method

This method involves exhaust mass calculation from the air flow and the air to fuel ratio. The calculation of the instantaneous exhaust gas mass flow is as follows:

$$G_{\text{EXHW}} = G_{\text{AIRW}} \cdot \left(1 + \frac{1}{A / F_{\text{st}} \cdot \lambda}\right)$$

with  $A / F_{\text{st}} = 14.5$

$$\lambda = \frac{\left(100 - \frac{conc_{CO} \cdot 10^{-4}}{2} - conc_{HC} \cdot 10^{-4}\right) + \left(0.45 \cdot \frac{1 - \frac{2 \cdot conc_{CO} \cdot 10^{-4}}{3.5 \cdot conc_{CO_2}}}{1 + \frac{conc_{CO} \cdot 10^{-4}}{3.5 \cdot conc_{CO_2}}}\right) \cdot (conc_{CO_2} + conc_{CO} \cdot 10^{-4})}{6.9078 \cdot (conc_{CO_2} + conc_{CO} \cdot 10^{-4} + conc_{HC} \cdot 10^{-4})}$$

where:

- $A/F_{st}$  = stoichiometric air/fuel ratio (kg/kg)  
 $\lambda$  = relative air/fuel ratio  
 $conc_{CO_2}$  = dry CO<sub>2</sub> concentration (%)  
 $conc_{CO}$  = dry CO concentration (ppm)  
 $conc_{HC}$  = HC concentration (ppm)

*Note:* The calculation refers to a diesel fuel with a H/C ratio equal to paragraph 1.8.

The air flow-meter shall meet the accuracy specifications in Table 3, the CO<sub>2</sub> analyser used shall meet the specifications of paragraph 1.4.1., and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air to fuel ratio measurement equipment, such as a zirconia type sensor, may be used for the measurement of the relative air to fuel ratio in accordance with the specifications of paragraph 1.4.4.

#### 1.2.6. Total dilute exhaust gas flow

When using a full flow dilution system, the total flow of the dilute exhaust ( $G_{TOTW}$ ) shall be measured with a PDP or CFV or SSV (Annex 4A, Appendix 4, paragraph 1.2.1.2.). The accuracy shall conform to the provisions of Annex 4A, Appendix 2, paragraph 2.2.

#### 1.3. Accuracy

The calibration of all measurement instruments shall be traceable to national or international standards and comply with the requirements listed in Table 3.

Table 3  
**Accuracy of measuring instruments**

No.	Measuring instrument	Accuracy
1	Engine speed	±2 % of reading or ±1 % of engine's max. value whichever is larger
2	Torque	±2 % of reading or ±1 % of engine's max. value whichever is larger
3	Fuel consumption	±2 % of engine's max. value
4	Air consumption	±2 % of reading or ±1 % of engine's max. value whichever is larger
5	Exhaust gas flow	±2.5 % of reading or ±1.5 % of engine's max. value whichever is larger

No.	Measuring instrument	Accuracy
6	Temperatures $\leq$ 600 K	$\pm 2$ K absolute
7	Temperatures $>$ 600 K	$\pm 1$ % of reading
8	Exhaust gas pressure	$\pm 0.2$ kPa absolute
9	Intake air depression	$\pm 0.05$ kPa absolute
10	Atmospheric pressure	$\pm 0.1$ kPa absolute
11	Other pressures	$\pm 0.1$ kPa absolute
12	Absolute humidity	$\pm 5$ % of reading
13	Dilution air flow	$\pm 2$ % of reading
14	Diluted exhaust gas flow	$\pm 2$ % of reading

#### 1.4. Determination of the gaseous components

##### 1.4.1. General analyser specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (paragraph 1.4.1.1.). It is recommended that the analysers be operated in such a way that the measured concentration falls between 15 per cent and 100 per cent of full scale.

If the full scale value is 155 ppm (or ppm C) or less or if read-out systems (computers, data loggers) that provide sufficient accuracy and resolution below 15 per cent of full scale are used, concentrations below 15 per cent of full scale are also acceptable. In this case, additional calibrations are to be made to ensure the accuracy of the calibration curves – Annex 4A, Appendix 2, paragraph 1.5.5.2.

The electromagnetic compatibility (EMC) of the equipment shall be on a level as to minimize additional errors.

##### 1.4.1.1. Measurement error

The analyser shall not deviate from the nominal calibration point by more than  $\pm 2$  per cent of the reading or  $\pm 0.3$  per cent of full scale, whichever is larger.

*Note:* For the purpose of this standard, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas ( $\equiv$  true value)

##### 1.4.1.2. Repeatability

The repeatability, defined as 2.5 times the standard deviation of ten repetitive responses to a given calibration or span gas, shall be no greater than  $\pm 1$  per cent of full scale concentration for each range used above 155 ppm (or ppm C) or  $\pm 2$  per cent of each range used below 155 ppm (or ppm C).

- 1.4.1.3. Noise  
The analyser peak-to-peak response to zero and calibration or span gases over any ten second period shall not exceed 2 per cent of full scale on all ranges used.
- 1.4.1.4. Zero drift  
The zero drift during a one-hour period shall be less than 2 per cent of full scale on the lowest range used. The zero response is defined as the mean response, including noise, to a zero gas during a 30 s time interval.
- 1.4.1.5. Span drift  
The span drift during a one-hour period shall be less than 2 per cent of full scale on the lowest range used. Span is defined as the difference between the span response and the zero response. The span response is defined as the mean response, including noise, to a span gas during a 30 s time interval.
- 1.4.2. Gas drying  
The optional gas drying device shall have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.
- 1.4.3. Analysers  
Paragraphs 1.4.3.1. to 1.4.3.5. of this appendix describe the measurement principles to be used. A detailed description of the measurement systems is given in Annex 4A, Appendix 4.  
The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.
- 1.4.3.1. Carbon monoxide (CO) analysis  
The carbon monoxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.
- 1.4.3.2. Carbon dioxide (CO<sub>2</sub>) analysis  
The carbon dioxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.
- 1.4.3.3. Hydrocarbon (HC) analysis  
The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework, etc, heated so as to maintain a gas temperature of 463 K (190 °C) ± 10 K.
- 1.4.3.4. Oxides of nitrogen (NO<sub>x</sub>) analysis  
The oxides of nitrogen analyser shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO<sub>2</sub>/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (Annex 4A, Appendix 2, paragraph 1.9.2.2.) is satisfied.  
For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55 to 200 °C) up to the converter for dry measurement, and up to the analyser for wet measurement.

1.4.4. Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in paragraph 1.2.5. shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type.

The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be within:

$\pm 3$  per cent of reading  $\lambda < 2$

$\pm 5$  per cent of reading  $2 \leq \lambda < 5$

$\pm 10$  per cent of reading  $5 \leq \lambda$

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

1.4.5. Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0.5 m or three times the diameter of the exhaust pipe (whichever is the larger) upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a 'V'-engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emissions calculation the total exhaust mass flow of the engine shall be used.

When a full flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe in the dilution tunnel (Annex 4A, Appendix 4, paragraph 1.2.1.2., DT and paragraph 1.2.2., PSP). CO and CO<sub>2</sub> may optionally be determined by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

1.5. Determination of the particulates

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system or a full flow dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42 °C) and 325 K (52 °C) immediately upstream of the filter holders. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. Dilution air pre-heating above the temperature limit of 303 K (30 °C) is recommended, if the ambient temperature is below 293 K (20 °C). However, the diluted air temperature shall not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel.

*Note:* For power bands up to and including K using discrete mode cycles, the filter temperature may be kept at or below the maximum temperature of 325 K (52 °C) instead of respecting the temperature range of 42 to 52 °C.

For a partial flow dilution system, the particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in paragraph 4.4. and in accordance with Annex 4A, Appendix 4, paragraph 1.2.1.1., Figure 4-12 EP and SP.

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. From that it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (Annex 4A, Appendix 4, paragraph 1.2.1.1.).

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance and a temperature and humidity controlled weighing chamber are required.

For particulate sampling, two methods may be applied:

- (a) The single filter method uses one pair of filters (paragraph 1.5.1.3. of this appendix) for all modes of the test cycle. Considerable attention shall be paid to sampling times and flows during the sampling phase of the test. However, only one pair of filters will be required for the test cycle,
- (b) The multiple filter method dictates that one pair of filters (paragraph 1.5.1.3. of this appendix) is used for each of the individual modes of the test cycle. This method allows more lenient sample procedures but uses more filters.

1.5.1. Particulate sampling filters

1.5.1.1. Filter specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required for certification tests. For special applications different filter materials may be used. All filter types shall have a 0.3 µm DOP (dioctylphthalate) collection efficiency of at least 99 per cent at a gas face velocity between 35 and 100 cm/s. When performing correlation tests between laboratories or between a manufacturer and an approval authority, filters of identical quality shall be used.

1.5.1.2. Filter size

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (paragraph 1.5.1.5.).

1.5.1.3. Primary and back-up filters

The diluted exhaust shall be sampled by a pair of filters placed in series (one primary and one back-up filter) during the test sequence. The back-up filter shall be located no more than 100 mm downstream of, and shall not be in contact with, the primary filter. The filters may be weighed separately or as a pair with the filters placed stain side to stain side.

1.5.1.4. Filter face velocity

A gas face velocity through the filter of 35 to 100 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

1.5.1.5. Filter loading

The recommended minimum filter loadings for the most common filter sizes are shown in the following table. For larger filter sizes, the minimum filter loading shall be 0.065 mg/1000 mm<sup>2</sup> filter area.

<i>Filter diameter (mm)</i>	<i>Recommended stain diameter (mm)</i>	<i>Recommended minimum loading (mg)</i>
47	37	0.11
70	60	0.25
90	80	0.41
110	100	0.62

For the multiple filter method, the recommended minimum filter loading for the sum of all filters shall be the product of the appropriate value above and the square root of the total number of modes.

1.5.2. Weighing chamber and analytical balance specifications

1.5.2.1. Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295 K (22 °C) ± 3 K during all filter conditioning and weighing. The humidity shall be maintained to a dew point of 282.5 (9.5 °C) ± 3 K and a relative humidity of 45 ± 8 per cent.

1.5.2.2. Reference filter weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilization. Disturbances to weighing room specifications as outlined in paragraph 1.5.2.1. will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personnel entrance into the weighing room. At least two unused reference filters or reference filter pairs shall be weighed within four hours of, but preferably at the same time as the sample filter (pair) weighing. They shall be the same size and material as the sample filters.

If the average weight of the reference filters (reference filter pairs) changes between sample filter weighing by more than 10 µg, then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in paragraph 1.5.2.1. is not met, but the reference filter (pair) weighing meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

- 1.5.2.3. Analytical balance
- The analytical balance used to determine the weights of all filters shall have a precision (standard deviation) of 2 µg and a resolution of 1 µg (1 digit = 1 µg) specified by the balance manufacturer.
- 1.5.2.4. Elimination of static electricity effects
- To eliminate the effects of static electricity, the filters shall be neutralized prior to weighing, for example, by a Polonium neutralizer or a device of similar effect.
- 1.5.3. Additional specifications for particulate measurement
- All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition or alteration of the particulates. 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.
2. Measurement and sampling procedures (NRTC test)
- 2.1. Introduction
- Gaseous and particulate components emitted by the engine submitted for testing shall be measured by the methods of Annex 4A, Appendix 4. The methods of Annex 4A, Appendix 4 describe the recommended analytical systems for the gaseous emissions (paragraph 1.1.) and the recommended particulate dilution and sampling systems (paragraph 1.2.).
- 2.2. Dynamometer and test cell equipment
- The following equipment shall be used for emission tests of engines on engine dynamometers:
- 2.2.1. Engine dynamometer
- An engine dynamometer shall be used with adequate characteristics to perform the test cycle described in Appendix 4 to this Annex. The instrumentation for torque and speed measurement shall allow the measurement of the power within the given limits. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the maximum tolerances of the figures given in Table 4 are not exceeded.
- 2.2.2. Other instruments
- Measuring instruments for fuel consumption, air consumption, temperature of coolant and lubricant, exhaust gas pressure and intake manifold depression, exhaust gas temperature, air intake temperature, atmospheric pressure, humidity and fuel temperature shall be used, as required. These instruments shall satisfy the requirements given in Table 4:

Table 4  
**Accuracy of measuring instruments**

<i>No.</i>	<i>Measuring instrument</i>	<i>Accuracy</i>
1	Engine speed	$\pm 2$ % of reading or $\pm 1$ % of engine's max. value, whichever is larger
2	Torque	$\pm 2$ % of reading or $\pm 1$ % of engine's max. value, whichever is larger
3	Fuel consumption	$\pm 2$ % of engine's max. value
4	Air consumption	$\pm 2$ % of reading or $\pm 1$ % of engine's max. value, whichever is larger
5	Exhaust gas flow	$\pm 2.5$ % of reading or $\pm 1.5$ % of engine's max. value, whichever is larger
6	Temperatures $\leq 600$ K	$\pm 2$ K absolute
7	Temperatures $> 600$ K	$\pm 1$ % of reading
8	Exhaust gas pressure	$\pm 0.2$ kPa absolute
9	Intake air depression	$\pm 0.05$ kPa absolute
10	Atmospheric pressure	$\pm 0.1$ kPa absolute
11	Other pressures	$\pm 0.1$ kPa absolute
12	Absolute humidity	$\pm 5$ % of reading
13	Dilution air flow	$\pm 2$ % of reading
14	Diluted exhaust gas flow	$\pm 2$ % of reading

### 2.2.3. Raw exhaust gas flow

For calculating the emissions in the raw exhaust gas and for controlling a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For determining the exhaust mass flow rate, either of the methods described below may be used.

For the purpose of emissions calculation, the response time of either method described below shall be equal to or less than the requirement for the analyser response time, as defined in Appendix 2, paragraph 1.11.1.

For the purpose of controlling a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, a response time of  $\leq 0.3$  s is required. For partial flow dilution systems with look ahead control based on a pre-recorded test run, a response time of the exhaust flow measurement system of  $\leq 5$  s with a rise time of  $\leq 1$  s is required. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for exhaust gas flow and partial flow dilution system are indicated in paragraph 2.4.

#### Direct measurement method

Direct measurement of the instantaneous exhaust flow may be done by systems, such as:

- (a) Pressure differential devices, like flow nozzle, (for details see ISO 5167: 2000);
- (b) Ultrasonic flow-meter;
- (c) Vortex flow-meter.

Precautions shall be taken to avoid measurement errors, which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. Especially, engine performance and emissions shall not be affected by the installation of the device.

The flow-meters shall meet the accuracy specifications of Table 3.

#### Air and fuel measurement method

This involves measurement of the airflow and the fuel flow with suitable flow-meters. The calculation of the instantaneous exhaust gas flow is as follows:  
 $G_{\text{EXHW}} = G_{\text{AIRW}} + G_{\text{FUEL}}$  (for wet exhaust mass)

The flow-meters shall meet the accuracy specifications of Table 3, but shall also be accurate enough to also meet the accuracy specifications for the exhaust gas flow.

#### Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust.

A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe, whichever is larger, downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the tracer gas concentration at engine idle speed after mixing becomes lower than the full scale of the trace gas analyser.

The calculation of the exhaust gas flow is as follows:

$$G_{\text{EXHW}} = G_{\text{AIRW}} \cdot \left(1 + \frac{1}{A / F_{\text{st}} \cdot \lambda}\right)$$

with  $A / F_{\text{st}} = 14.5$

$$\lambda = \frac{\left(100 - \frac{conc_{CO} \cdot 10^{-4}}{2} - conc_{HC} \cdot 10^{-4}\right) + \left(0.45 \cdot \frac{1 - \frac{2 \cdot conc_{CO} \cdot 10^{-4}}{3.5 \cdot conc_{CO_2}}}{1 + \frac{conc_{CO} \cdot 10^{-4}}{3.5 \cdot conc_{CO_2}}}\right) \cdot (conc_{CO_2} + conc_{CO} \cdot 10^{-4})}{6.9078 \cdot (conc_{CO_2} + conc_{CO} \cdot 10^{-4} + conc_{HC} \cdot 10^{-4})}$$

where:

$A/F_{st}$	=	stoichiometric air/fuel ratio (kg/kg)
$\lambda$	=	relative air/fuel ratio
$conc_{CO_2}$	=	dry CO <sub>2</sub> concentration (%)
$conc_{CO}$	=	dry CO concentration (ppm)
$conc_{HC}$	=	HC concentration (ppm)

*Note:* The calculation refers to a diesel fuel with a H/C ratio equal to 1.8.

The air flow-meter shall meet the accuracy specifications in Table 3, the CO<sub>2</sub> analyser used shall meet the specifications of paragraph 2.3.1., and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air to fuel ratio measurement equipment, such as a zirconia type sensor, may be used for the measurement of the excess air ratio in accordance with the specifications of paragraph 2.3.4.

#### 2.2.4. Diluted exhaust gas flow

For calculation of the emissions in the diluted exhaust gas, it is necessary to know the diluted exhaust gas mass flow rate. The total diluted exhaust gas flow over the cycle (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device ( $V_0$  for PDP,  $K_V$  for CFV,  $C_d$  for SSV): the corresponding methods described in Appendix 3, paragraph 2.2.1. shall be used. If the total sample mass of particulates and gaseous pollutants exceeds 0.5 per cent of the total CVS flow, the CVS flow shall be corrected or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

#### 2.3. Determination of the gaseous components

##### 2.3.1. General analyser specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (paragraph 1.4.1.1.). It is recommended that the analysers be operated in such a way that the measured concentration falls between 15 and 100 per cent of full scale.

If the full scale value is 155 ppm (or ppm C) or less, or if read-out systems (computers, data loggers) that provide sufficient accuracy and resolution below 15 per cent of full scale are used, concentrations below 15 per cent of full scale are also acceptable. In this case, additional calibrations are to be made to ensure the accuracy of the calibration curves – Annex 4A, Appendix 2, paragraph 1.5.5.2.

The electromagnetic compatibility (EMC) of the equipment shall be of a level such as to minimize additional errors.

2.3.1.1. Measurement error

The analyser shall not deviate from the nominal calibration point by more than  $\pm 2$  per cent of the reading or  $\pm 0.3$  per cent of full scale, whichever is larger.

*Note:* For the purpose of this standard, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas ( $\equiv$  true value).

2.3.1.2. Repeatability

The repeatability, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than  $\pm 1$  per cent of full scale concentration for each range used above 155 ppm (or ppm C) or  $\pm 2$  per cent for each range used below 155 ppm (or ppm C).

2.3.1.3. Noise

The analyser peak-to-peak response to zero and calibration or span gases over any 10 s periods shall not exceed 2 per cent of full scale on all ranges used.

2.3.1.4. Zero drift

The zero drift during a one-hour period shall be less than 2 per cent of full scale on the lowest range used. The zero response is defined as the mean response, including noise, to a zero gas during a 30 s time interval.

2.3.1.5. Span drift

The span drift during a one-hour period shall be less than 2 per cent of full scale on the lowest range used. Span is defined as the difference between the span response and the zero response. The span response is defined as the mean response, including noise, to a span gas during a 30 s time interval.

2.3.1.6. Rise time

For raw exhaust gas analysis, the rise time of the analyser installed in the measurement system shall not exceed 2.5 s.

*Note:* Only evaluating the response time of the analyser alone will not clearly define the suitability of the total system for transient testing. Volumes, and especially dead volumes, throughout the system will not only affect the transportation time from the probe to the analyser, but also affect the rise time. Also transport times inside of an analyser would be defined as analyser response time, like the converter or water traps inside of a NO<sub>x</sub> analyser. The determination of the total system response time is described in Appendix 2, paragraph 1.11.1.

2.3.2. Gas drying

Same specifications as for NRSC test cycle apply (paragraph 1.4.2.) as described here below.

The optional gas drying device shall have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

- 2.3.3.           Analysers
- Same specifications as for NRSC test cycle apply (paragraph 1.4.3.) as described here below.
- The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.
- 2.3.3.1.       Carbon monoxide (CO) analysis
- The carbon monoxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.
- 2.3.3.2.       Carbon dioxide (CO<sub>2</sub>) analysis
- The carbon dioxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.
- 2.3.3.3.       Hydrocarbon (HC) analysis
- The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework etc., heated so as to maintain a gas temperature of 463K (190 °C) ±10 K.
- 2.3.3.4.       Oxides of nitrogen (NO<sub>x</sub>) analysis
- The oxides of nitrogen analyser shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO<sub>2</sub>/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C shall be used, provided the water quench check (Annex 4A, Appendix 2, paragraph 1.9.2.2.) is satisfied.
- For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328K to 473 K (55 to 200 °C) up to the converter for dry measurement, and up to the analyser for wet measurement.
- 2.3.4.           Air to fuel measurement
- The air to fuel measurement equipment used to determine the exhaust gas flow as specified in paragraph 2.2.3. shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type.
- The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.
- The accuracy of the sensor with incorporated electronics shall be within:
- ±3 per cent of reading  $\lambda < 2$
- ±5 per cent of reading  $2 \leq \lambda < 5$
- ±10 per cent of reading  $5 \leq \lambda$
- To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

2.3.5. Sampling of gaseous emissions

2.3.5.1. Raw exhaust gas flow

For calculation of the emissions in the raw exhaust gas the same specifications as for NRSC test cycle apply (paragraph 1.4.4.), as described here below.

The gaseous emissions sampling probes shall be fitted at least 0.5 m or three times the diameter of the exhaust pipe — whichever is the larger — upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

In the case of a multicylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multicylinder engines having distinct groups of manifolds, such as in a "V"-engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emissions calculation the total exhaust mass flow of the engine shall be used.

2.3.5.2. Diluted exhaust gas flow

If a full flow dilution system is used, the following specifications apply.

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of Annex 4A, Appendix 4.

The gaseous emissions sample probe(s) shall be installed in the dilution tunnel at a point where the dilution air and exhaust gas are well mixed, and in close proximity to the particulates sampling probe.

Sampling can generally be done in two ways:

- (a) The pollutants are sampled into a sampling bag over the cycle and measured after completion of the test.
- (b) The pollutants are sampled continuously and integrated over the cycle; this method is mandatory for HC and NO<sub>x</sub>.

The background concentrations shall be sampled upstream of the dilution tunnel into a sampling bag, and shall be subtracted from the emissions concentration according to Appendix 3, paragraph 2.2.3.

2.4. Determination of the particulates

Determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system or a full flow dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42 °C) and 325 K (52 °C) immediately upstream of the filter holders. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. Dilution air pre-heating above the temperature limit of 303 K (30 °C) is recommended if the ambient temperature is below 293 K (20 °C). However, the diluted air temperature shall not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel.

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, and the installation shall comply with the provisions of paragraph 2.3.5.

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, microgram balance, and a temperature and humidity controlled weighing chamber, are required.

#### Partial flow dilution system specifications

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. For this it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (Annex 4A, Appendix 4, paragraph 1.2.1.1.).

For the control of a partial flow dilution system, a fast system response is required. The transformation time for the system shall be determined by the procedure described in Appendix 2, paragraph 1.11.1.

If the combined transformation time of the exhaust flow measurement (see previous paragraph) and the partial flow system is less than 0.3 s, online control may 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 rise time shall be  $\leq 1$  s and the delay time of the combination  $\leq 10$  s.

The total system response shall be designed as to ensure a representative sample of the particulates,  $G_{SE}$ , proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of  $G_{SE}$  versus  $G_{EXHW}$  shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

- (a) The correlation coefficient  $r$  of the linear regression between  $G_{SE}$  and  $G_{EXHW}$  shall be not less than 0.95;
- (b) The standard error of estimate of  $G_{SE}$  on  $G_{EXHW}$  shall not exceed 5 per cent of  $G_{SE}$  maximum;
- (c)  $G_{SE}$  intercept of the regression line shall not exceed  $\pm 2$  per cent of  $G_{SE}$  maximum.

Optionally, a pre-test may be run, and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system (look-ahead control). Such a procedure is required if the transformation time of the particulate system,  $t_{50,P}$  or/and the transformation time of the exhaust mass flow signal,  $t_{50,F}$  are  $> 0.3$  s. A correct control of the partial dilution system is obtained, if the time trace of  $G_{EXHW,pre}$  of the pre-test, which controls  $G_{SE}$ , is shifted by a 'look-ahead' time of  $t_{50,P} + t_{50,F}$ .

For establishing the correlation between  $G_{SE}$  and  $G_{EXHW}$  the data taken during the actual test shall be used, with  $G_{EXHW}$  time aligned by  $t_{50,F}$  relative to  $G_{SE}$  (no contribution from  $t_{50,P}$  to the time alignment). That is, the time shift between  $G_{EXHW}$  and  $G_{SE}$  is the difference in their transformation times that were determined in Appendix 2, paragraph 2.6.

For partial flow dilution systems, the accuracy of the sample flow  $G_{SE}$  is of special concern, if not measured directly, but determined by differential flow measurement:

$$G_{SE} = G_{TOTW} - G_{DILW}$$

In this case an accuracy of  $\pm 2$  per cent for  $G_{TOTW}$  and  $G_{DILW}$  is not sufficient to guarantee acceptable accuracies of  $G_{SE}$ . If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of  $G_{SE}$  is within  $\pm 5$  per cent when the dilution ratio is less than 15. It can be calculated by taking the root-mean-square of the errors of each instrument.

Acceptable accuracies of  $G_{SE}$  can be obtained by either of the following methods:

- (a) The absolute accuracies of  $G_{TOTW}$  and  $G_{DILW}$  are  $\pm 0.2$  per cent which guarantees an accuracy of  $G_{SE}$  of  $\leq 5$  per cent at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.
- (b) Calibration of  $G_{DILW}$  relative to  $G_{TOTW}$  is carried out such that the same accuracies for  $G_{SE}$  as in (a) are obtained. For the details of such a calibration see Appendix 2, paragraph 2.6.
- (c) The accuracy of  $G_{SE}$  is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g.  $CO_2$ . Again, accuracies equivalent to method (a) for  $G_{SE}$  are required.
- (d) The absolute accuracy of  $G_{TOTW}$  and  $G_{DILW}$  is within  $\pm 2$  per cent of full scale, the maximum error of the difference between  $G_{TOTW}$  and  $G_{DILW}$  is within 0.2 per cent, and the linearity error is within  $\pm 0.2$  per cent of the highest  $G_{TOTW}$  observed during the test.

#### 2.4.1. Particulate sampling filters

##### 2.4.1.1. Filter specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required for certification tests. For special applications different filter materials may be used. All filter types shall have a  $0.3 \mu m$  DOP (dioctylphthalate) collection efficiency of at least 99 per cent at a gas face velocity between 35 and 100 cm/s. When performing correlation tests between laboratories or between a manufacturer and an approval authority, filters of identical quality shall be used.

##### 2.4.1.2. Filter size

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (paragraph 2.4.1.5).

##### 2.4.1.3. Primary and back-up filters

The diluted exhaust shall be sampled by a pair of filters placed in series (one primary and one back-up filter) during the test sequence. The back-up filter shall be located no more than 100 mm downstream of, and shall not be in contact with, the primary filter. The filters may be weighed separately or as a pair with the filters placed stain side to stain side.

2.4.1.4. Filter face velocity

A gas face velocity through the filter of 35 to 100 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

2.4.1.5. Filter loading

The recommended minimum filter loadings for the most common filter sizes are shown in the following table. For larger filter sizes, the minimum filter loading shall be 0.065 mg/1000 mm<sup>2</sup> filter area.

<i>Filter diameter (mm)</i>	<i>Recommended stain diameter (mm)</i>	<i>Recommended minimum loading (mg)</i>
47	37	0.11
70	60	0.25
90	80	0.41
110	100	0.62

2.4.2. Weighing chamber and analytical balance specifications

2.4.2.1. Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295 K (22 °C) ± 3 K during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of 282.5 (9.5 °C) ± 3 K and a relative humidity of 45 ± 8 per cent.

2.4.2.2. Reference filter weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilization. Disturbances to weighing room specifications as outlined in paragraph 2.4.2.1. will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personnel entrance into the weighing room. At least two unused reference filters or reference filter pairs shall be weighed within four hours of, but preferably at the same time as the sample filter (pair) weighing. They shall be the same size and material as the sample filters.

If the average weight of the reference filters (reference filter pairs) changes between sample filter weighing by more than 10 µg, then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in paragraph 2.4.2.1. are not met, but the reference filter (pair) weighing meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and re-running the test.

2.4.2.3. Analytical balance

The analytical balance used to determine the weights of all filters shall have a precision (standard deviation) of 2 µg and a resolution of 1 µg (1 digit = 1 µg) specified by the balance manufacturer.

2.4.2.4. Elimination of static electricity effects

To eliminate the effects of static electricity, the filters shall be neutralized prior to weighing, for example, by a Polonium neutralizer or a device having similar effect.

2.4.3. Additional specifications for particulate measurement

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition or alteration of the particulates. 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.

## Annex 4A - Appendix 2

### Calibration procedure (NRSC, NRTC<sup>1</sup>)

1. Calibration of the analytical instruments

1.1. Introduction

Each analyser shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method that shall be used is described in this paragraph for the analysers indicated in Appendix 1, paragraph 1.4.3.

At the request of the manufacturer and with the agreement of the approval authority the methods described in Annex 4B, paragraphs 8.1. and 8.2. may be used as an alternative to those in paragraph 1. of this appendix.

1.2. Calibration gases

The shelf life of all calibration gases shall be respected.

The expiry date of the calibration gases stated by the manufacturer shall be recorded.

1.2.1. Pure gases

The required purity of the gases is defined by the contamination limits given below. The following gases shall be available for operation:

(a) Purified nitrogen

(contamination  $\leq 1$  ppm C,  $\leq 1$  ppm CO,  $\leq 400$  ppm CO<sub>2</sub>,  $\leq 0.1$  ppm NO)

(b) Purified oxygen

(purity  $> 99.5$  per cent vol O<sub>2</sub>)

(c) Hydrogen-helium mixture

( $40 \pm 2$  per cent hydrogen, balance helium)

(contamination  $\leq 1$  ppm C,  $\leq 400$  ppm CO<sub>2</sub>)

(d) Purified synthetic air

(contamination  $\leq 1$  ppm C,  $\leq 1$  ppm CO,  $\leq 400$  ppm CO<sub>2</sub>,  $\leq 0.1$  ppm NO)

(oxygen content between 18 – 21 per cent vol)

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<sup>1</sup> The calibration procedure is common for both NRSC and NRTC tests, with the exception of the requirements specified in paragraphs 1.11. and 2.6.

1.2.2. Calibration and span gases

Mixtures of gases having the following chemical compositions shall be available:

- (a) C<sub>3</sub>H<sub>8</sub> and purified synthetic air (see paragraph 1.2.1.);
- (b) CO and purified nitrogen;
- (c) NO and purified nitrogen (the amount of NO<sub>2</sub> contained in this calibration gas shall not exceed 5 per cent of the NO content);
- (d) O<sub>2</sub> and purified nitrogen;
- (e) CO<sub>2</sub> and purified nitrogen;
- (f) CH<sub>4</sub> and purified synthetic air;
- (g) C<sub>2</sub>H<sub>6</sub> and purified synthetic air.

*Note:* other gas combinations are allowed provided the gases do not react with one another.

The true concentration of a calibration and span gas shall be within  $\pm 2$  per cent of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume per cent or volume ppm).

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N<sub>2</sub> or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the diluted calibration gases may be determined to within  $\pm 2$  per cent.

This accuracy implies that primary gases used for blending shall be known to have an accuracy of at least  $\pm 1$  per cent, traceable to national or international gas standards. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a blending device. An additional verification may be performed using another calibration gas, if the first verification has failed.

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 blending device shall be checked at the used settings and the nominal value shall be compared to the measured concentration of the instrument. This difference shall in each point be within  $\pm 1$  per cent of the nominal value.

Other methods may be used based on good engineering practice and with the prior agreement of the parties involved.

*Note:* A precision gas divider of accuracy is within  $\pm 1$  per cent, is recommended for establishing the accurate analyser calibration curve. The gas divider shall be calibrated by the instrument manufacturer.

1.3. Operating procedure for analysers and sampling system

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in paragraphs 1.4. to 1.9. shall be included.

1.4. Leakage test

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilization period all flow-meters should read zero. If not, the sampling lines shall be checked and the fault corrected. The maximum allowable leakage rate on the vacuum side shall be 0.5 per cent of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas.

If after an adequate period of time the reading shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

1.5. Calibration procedure

1.5.1. Instrument assembly

The instrument assembly shall be calibrated and calibration curves checked against standard gases. The same gas flow rates shall be used as when sampling exhaust.

1.5.2. Warming-up time

The warming-up time should be according to the recommendations of the manufacturer. If not specified, a minimum of two hours is recommended for warming-up the analysers.

1.5.3. NDIR and HFID analyser

The NDIR analyser shall be tuned, as necessary, and the combustion flame of the HFID analyser shall be optimized (paragraph 1.8.1.).

1.5.4. Calibration

Each normally used operating range shall be calibrated.

Using purified synthetic air (or nitrogen), the CO, CO<sub>2</sub>, NO<sub>x</sub>, HC and O<sub>2</sub> analysers shall be set at zero.

The appropriate calibration gases shall be introduced to the analysers, the values recorded, and the calibration curve established according to paragraph 1.5.6.

The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

1.5.5. Establishment of the calibration curve

1.5.5.1. General guidelines

The analyser calibration curve is established by at least six calibration points (excluding zero) spaced as uniformly as possible. The highest nominal concentration shall be equal to or higher than 90 per cent of full scale.

The calibration curve is calculated by the method of least squares. If the resulting polynomial degree is greater than three, the number of calibration points (zero included) shall be at least equal to this polynomial degree plus two.

The calibration curve shall not differ by more than  $\pm 2$  per cent from the nominal value of each calibration point and by more than  $\pm 0.3$  per cent of full scale at zero.

From the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser shall be indicated, particularly:

- (a) The measuring range;
- (b) The sensitivity;
- (c) The date of carrying out the calibration.

1.5.5.2. Calibration below 15 per cent of full scale

The analyser calibration curve is established by at least ten calibration points (excluding zero) spaced so that 50 per cent of the calibration points are below 10 per cent of full scale.

The calibration curve is calculated by the method of least squares.

The calibration curve shall not differ by more than  $\pm 4$  per cent from the nominal value of each calibration point and by more than  $\pm 0.3$  per cent of full scale at zero.

1.5.5.3. Alternative methods

If it can be shown that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.

1.6. Verification of the calibration

Each normally used operating range shall be checked prior to each analysis in accordance with the following procedure.

The calibration is checked by using a zero gas and a span gas whose nominal value is more than 80 per cent of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than  $\pm 4$  per cent of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with paragraph 1.5.4.

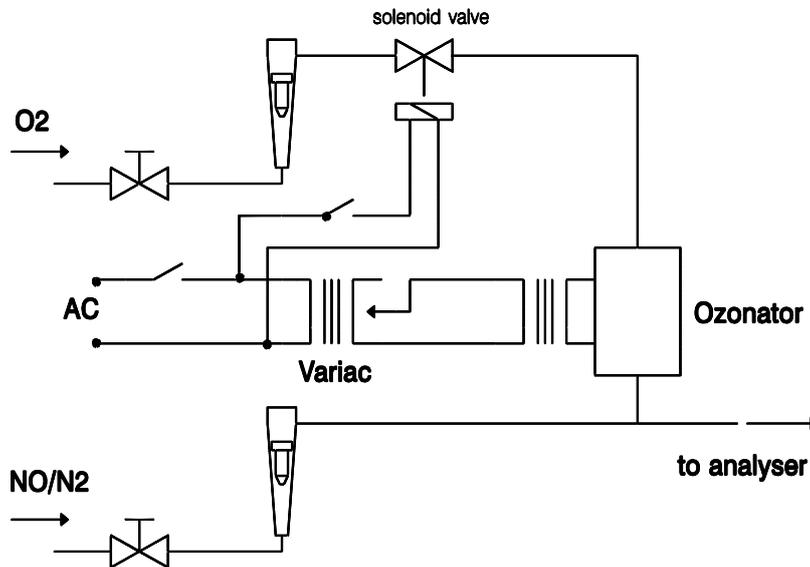
1.7. Efficiency test of the NO<sub>x</sub> converter

The efficiency of the converter used for the conversion of NO<sub>2</sub> into NO is tested as given in paragraphs 1.7.1. to 1.7.8. (Figure 1).

1.7.1. Test set-up

Using the test set-up as shown in Figure 1 (see also Appendix 1, paragraph 1.4.3.5.) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

Figure 1  
**Schematic of NO<sub>2</sub> converter efficiency device**



1.7.2. Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which shall amount to about 80 per cent of the operating range and the NO<sub>2</sub> concentration of the gas mixture to less than 5 per cent of the NO concentration). The NO<sub>x</sub> analyser shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3. Calculation

The efficiency of the NO<sub>x</sub> converter is calculated as follows:

$$\text{Efficiency (\%)} = \left(1 + \frac{a - b}{c - d}\right) \cdot 100$$

where:

- a* = NO<sub>x</sub> concentration according to paragraph 1.7.6.
- b* = NO<sub>x</sub> concentration according to paragraph 1.7.7.
- c* = NO concentration according to paragraph 1.7.4.
- d* = NO concentration according to paragraph 1.7.5.

1.7.4. Adding of oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 per cent less than the indicated calibration concentration given in paragraph 1.7.2. (The analyser is in the NO mode.)

- The indicated concentration  $c$  shall be recorded. The ozonator is kept de-activated throughout the process.
- 1.7.5. Activation of the ozonator
- The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20 per cent (minimum 10 per cent) of the calibration concentration given in paragraph 1.7.2. The indicated concentration  $d$  shall be recorded. (The analyser is in the NO mode.)
- 1.7.6. NO<sub>x</sub> mode
- The NO analyser is then switched to the NO<sub>x</sub> mode so that the gas mixture (consisting of NO, NO<sub>2</sub>, O<sub>2</sub> and N<sub>2</sub>) now passes through the converter. The indicated concentration  $a$  shall be recorded. (The analyser is in the NO<sub>x</sub> mode.)
- 1.7.7. De-activation of the ozonator
- The ozonator is now de-activated. The mixture of gases described in paragraph 1.7.6. passes through the converter into the detector. The indicated concentration  $b$  shall be recorded. (The analyser is in the NO<sub>x</sub> mode.)
- 1.7.8. NO mode
- Switched to NO mode with the ozonator de-activated, the flow of oxygen or synthetic air is also shut off. The NO<sub>x</sub> reading of the analyser shall not deviate by more than  $\pm 5$  per cent from the value measured according to paragraph 1.7.2. (The analyser is in the NO mode.)
- 1.7.9. Test interval
- The efficiency of the converter shall be tested prior to each calibration of the NO<sub>x</sub> analyser.
- 1.7.10. Efficiency requirement
- The efficiency of the converter shall not be less than 90 per cent, but a higher efficiency of 95 per cent is strongly recommended.
- Note:* If, with the analyser in the most common range, the ozonator cannot give a reduction from 80 per cent to 20 per cent according to paragraph 1.7.5., then the highest range which will give the reduction shall be used.
- 1.8. Adjustment of the FID
- 1.8.1. Optimization of the detector response
- The HFID shall be adjusted as specified by the instrument manufacturer. A propane in air span gas should be used to optimize the response on the most common operating range.
- With the fuel and air flow rates set at the manufacturer's recommendations, a  $350 \pm 75$  ppm C span gas shall be introduced to the analyser. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. 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. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve.

1.8.2. Hydrocarbon response factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to paragraph 1.5.

Response factors shall be determined when introducing an analyser into service and after major service intervals. The response factor ( $R_f$ ) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppm C1.

The concentration of the test gas shall be at a level to give a response of approximately 80 per cent of full scale. The concentration shall be known to an accuracy of  $\pm 2$  per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be pre-conditioned for 24 hours at a temperature of 298 K (25 °C)  $\pm 5$  K.

The test gases to be used and the recommended relative response factor ranges are as follows:

Methane and purified synthetic air:  $1.00 \leq R_f \leq 1.15$

Propylene and purified synthetic air:  $0.90 \leq R_f \leq 1.1$

Toluene and purified synthetic air:  $0.90 \leq R_f \leq 1.10$

These values are relative to the response factor ( $R_f$ ) of 1.00 for propane and purified synthetic air.

1.8.3. Oxygen interference check

The oxygen interference check shall be determined when introducing an analyser into service and after major service intervals.

A range shall be chosen where the oxygen interference check gases will fall within the upper 50 per cent. The test shall be conducted with the oven temperature set as required.

1.8.3.1. Oxygen interference gases

Oxygen interference check gases shall contain propane with 350 ppmC to 75 ppmC hydrocarbon. The concentration value shall be determined to calibration gas tolerances by chromatographic analysis of total hydrocarbons plus impurities or by dynamic blending. Nitrogen shall be the predominant diluent with the balance oxygen. Blends required for Diesel engine testing are:

O <sub>2</sub> concentration	Balance
21 (20 to 22)	Nitrogen
10 (9 to 11)	Nitrogen
5 (4 to 6)	Nitrogen

1.8.3.2. Procedure

- (a) The analyser shall be zeroed.
- (b) The analyser shall be spanned with the 21 per cent oxygen blend.
- (c) The zero response shall be rechecked. If it has changed more than 0.5 per cent of full scale sub-paragraphs (a) and (b) shall be repeated.

- (d) The 5 per cent and 10 per cent oxygen interference check gases shall be introduced.
- (e) The zero response shall be rechecked. If it has changed more than  $\pm 1$  per cent of full scale, the test shall be repeated.
- (f) The oxygen interference ( $\%O_2I$ ) shall be calculated for each mixture in (d) as follows:

$$\%O_2I = \frac{(B-C)}{B} \cdot 100$$

A = hydrocarbon concentration (ppmC) of the span gas used in (b)

B = hydrocarbon concentration (ppmC) of the oxygen interference check gases used in (d)

C = analyser response

$$(ppmC) = \frac{A}{D}$$

D = per cent of full scale analyser response due to A.

- (g) The per cent of oxygen interference ( $\%O_2I$ ) shall be less than  $\pm 3.0$  per cent for all required oxygen interference check gases prior to testing.
- (h) If the oxygen interference is greater than  $\pm 3.0$  per cent, the air flow above and below the manufacturer's specifications shall be incrementally adjusted, repeating paragraph 1.8.1. for each flow.
- (i) If the oxygen interference is greater than  $\pm 3.0$  per cent after adjusting the air flow, the fuel flow and thereafter the sample flow shall be varied, repeating paragraph 1.8.1. for each new setting.
- (j) If the oxygen interference is still greater than  $\pm 3.0$  per cent, the analyser, FID fuel, or burner air shall be repaired or replaced prior to testing. This paragraph shall then be repeated with the repaired or replaced equipment or gases.

#### 1.9. Interference effects with NDIR and CLD analysers

Gases present in the exhaust other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in paragraphs 1.9.1. and 1.9.2. shall be performed prior to an analyser's initial use and after major service intervals.

##### 1.9.1. CO analyser interference check

Water and CO<sub>2</sub> can interfere with the CO analyser performance. Therefore a CO<sub>2</sub> span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 1 per cent of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

1.9.2. NO<sub>x</sub> analyser quench checks

The two gases of concern for CLD (and HCLD) analysers are CO<sub>2</sub> and water vapour. Quench responses of these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

1.9.2.1. CO<sub>2</sub> quench check

A CO<sub>2</sub> span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO<sub>2</sub> value recorded as A. It shall then be diluted approximately 50 per cent with NO span gas and passed through the NDIR and (H)CLD with the CO<sub>2</sub> and NO values recorded as B and C, respectively. The CO<sub>2</sub> shall be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as D.

The quench shall be calculated as follows:

$$\% CO_2 \text{ Quench} = \left[ 1 - \left( \frac{C \cdot A}{(D \cdot A) - (D \cdot B)} \right) \right] \cdot 100$$

and shall not be greater than 3 per cent of full scale.

where:

A = undiluted CO<sub>2</sub> concentration measured with NDIR per cent

B = diluted CO<sub>2</sub> concentration measured with NDIR per cent

C = diluted NO concentration measured with CLD ppm

D = undiluted NO concentration measured with CLD ppm

1.9.2.2. Water quench check

This check applies to wet gas concentration measurements only. Calculation of water quench shall consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing. A NO span gas having a concentration of 80 to 100 per cent of full scale to the normal operating range shall be passed through the (H)CLD and the NO value recorded as D. The NO gas shall be bubbled through water at room temperature and passed through the (H)CLD and NO value recorded as C. The water temperature shall be determined and recorded as F. The mixture's saturation vapour pressure that corresponds to the bubbler water temperature (F) shall be determined and recorded as G. The water vapour concentration (in per cent) of the mixture shall be calculated as follows:

$$H = 100 \cdot \left( \frac{G}{p_B} \right)$$

and recorded as H. The expected diluted NO span gas (in water vapour) concentration shall be calculated as follows:

$$De = D \cdot \left( 1 - \frac{H}{100} \right)$$

and recorded as De. For diesel exhaust, the maximum exhaust water vapour concentration (in per cent) expected during testing shall be estimated, under the

assumption of a fuel atom H/C ratio of 1.8 to 1.0, from the maximum CO<sub>2</sub> concentration in the exhaust gas or from the undiluted CO<sub>2</sub> span gas concentration (A, as measured in paragraph 1.9.2.1.) as follows:

$$Hm = (0.9 \cdot A)$$

and recorded as Hm.

The water quench shall be calculated as follows:

$$\% H_2O \text{ Quench} = 100 \cdot \left( \frac{De - C}{De} \right) \cdot \left( \frac{Hm}{H} \right)$$

and shall not be greater than 3 per cent of full scale.

*De* = expected diluted NO concentration (ppm)

*C* = diluted NO concentration (ppm)

*Hm* = maximum water vapour concentration (per cent)

*H* = actual water vapour concentration (per cent)

*Note:* It is important that the NO span gas contains minimal NO<sub>2</sub> concentration for this check, since absorption of NO<sub>2</sub> in water has not been accounted for in the quench calculations.

1.10. Calibration intervals

The analysers shall be calibrated according to paragraph 1.5. at least every three months or whenever a system repair or change is made that could influence calibration.

1.11. Additional calibration requirements for raw exhaust measurements over NRTC test

1.11.1. Response time check of the analytical system

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 gas switching shall be done in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent FS.

The concentration trace of each single gas component shall be recorded. The response time is defined as the difference in time between the gas switching and the appropriate change of the recorded concentration. The system response time ( $t_{90}$ ) consists of the delay time to the measuring detector and the rise time of the detector. The delay time is defined as the time from the change ( $t_0$ ) until the response is 10 per cent of the final reading ( $t_{10}$ ). The rise time is defined as the time between 10 and 90 per cent response of the final reading ( $t_{90} - t_{10}$ ).

For time alignment of the analyser and exhaust flow signals in the case of raw measurement, the transformation time is defined as the time from the change ( $t_0$ ) until the response is 50 per cent of the final reading ( $t_{50}$ ).

The system response time shall be  $\leq 10$  s with a rise time  $\leq 2.5$  s for all limited components (CO, NO<sub>x</sub>, HC) and all ranges used.

1.11.2. Calibration of tracer gas analyser for exhaust flow measurement

The analyser for measurement of the tracer gas concentration, if used, shall be calibrated using the standard gas.

The calibration curve shall be established by at least 10 calibration points (excluding zero) spaced so that a half of the calibration points are placed between 4 to 20 per cent of analyser's full scale and the rest are in between 20 to 100 per cent of the full scale. The calibration curve is calculated by the method of least squares.

The calibration curve shall not differ by more than  $\pm 1$  per cent of the full scale from the nominal value of each calibration point, in the range from 20 to 100 per cent of the full scale. It shall also not differ by more than  $\pm 2$  per cent from the nominal value in the range from 4 to 20 per cent of the full scale.

The analyser shall be set at zero and spanned prior to the test run using a zero gas and a span gas whose nominal value is more than 80 per cent of the analyser full scale.

2. Calibration of the particulate measuring system

2.1. Introduction

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this Regulation. The calibration method to be used is described in this paragraph for the components indicated in Annex 4A, Appendix 1, paragraph 1.5. and Appendix 4.

At the request of the manufacturer and with the agreement of the approval authority the methods described in Annex 4B, paragraphs 8.1. and 8.2. may be used as an alternative to those in paragraph 2. of this appendix.

2.2. Flow measurement

The calibration of gas flow-meters or flow measurement instrumentation shall be traceable to national and/or international standards.

The maximum error of the measured value shall be within  $\pm 2$  per cent of reading.

For partial flow dilution systems, the accuracy of the sample flow  $G_{SE}$  is of special concern, if not measured directly, but determined by differential flow measurement:

$$G_{SE} = G_{TOTW} - G_{DILW}$$

In this case an accuracy of  $\pm 2$  per cent for  $G_{TOTW}$  and  $G_{DILW}$  is not sufficient to guarantee acceptable accuracies of  $G_{SE}$ . If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of  $G_{SE}$  is within  $\pm 5$  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.

2.3. Checking the dilution ratio

When using particulate sampling systems without EGA (Annex 4A, Appendix 4, paragraph 1.2.1.1.), the dilution ratio shall be checked for each new engine installation with the engine running and the use of either the  $CO_2$  or  $NO_x$  concentration measurements in the raw and dilute exhaust.

The measured dilution ratio shall be within  $\pm 10$  per cent of the calculated dilution ratio from  $\text{CO}_2$  or  $\text{NO}_x$  concentration measurement.

2.4. Checking the partial flow conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of Annex 4A, Appendix 4, paragraph 1.2.1.1., EP, if applicable.

2.5. Calibration intervals

The flow measurement instrumentation shall be calibrated at least every three months, or whenever a system change is made that could influence calibration.

2.6. Additional calibration requirements for partial flow dilution systems

2.6.1. Periodical calibration

If the sample gas flow is determined by differential flow measurement the flow-meter or the flow measurement instrumentation shall be calibrated by one of the following procedures, such that the probe flow  $G_{SE}$  into the tunnel fulfils the accuracy requirements of Annex 4A, Appendix 1, paragraph 2.4.:

The flow-meter for  $G_{DILW}$  is connected in series to the flow-meter for  $G_{TOTW}$ , the difference between the two flow-meters is calibrated for at least five set points with flow values equally spaced between the lowest  $G_{DILW}$  value used during the test and the value of  $G_{TOTW}$  used during the test. The dilution tunnel may be bypassed.

A calibrated mass flow device is connected in series to the flow-meter for  $G_{TOTW}$  and the accuracy is checked for the value used for the test. Then the calibrated mass flow device is connected in series to the flow-meter for  $G_{DILW}$ , and the accuracy is checked for at least five settings corresponding to the dilution ratio between 3 and 50, relative to  $G_{TOTW}$  used during the test.

The transfer tube TT is disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure  $G_{SE}$  is connected to the transfer tube. Then  $G_{TOTW}$  is set to the value used during the test, and  $G_{DILW}$  is sequentially set to at least five values corresponding to dilution ratios  $q$  between 3 and 50. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and dilution air flow through the corresponding meters are maintained as in the actual test.

A tracer gas is fed into the transfer tube TT. This tracer gas may be a component of the exhaust gas, like  $\text{CO}_2$  or  $\text{NO}_x$ . After dilution in the tunnel the tracer gas component is measured. This shall be carried out for five dilution ratios between 3 and 50. The accuracy of the sample flow is determined from the dilution ratio  $q$ :

$$G_{SE} = G_{TOTW} / q$$

The accuracies of the gas analysers shall be taken into account to guarantee the accuracy of  $G_{SE}$ .

2.6.2. Carbon flow check

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 dilution 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<sub>2</sub>. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

2.6.3. Pre-test check

A pre-test check shall be performed within two 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 for at least two points, including flow values of  $G_{DILW}$  that correspond to dilution ratios between five and 15 for the  $G_{TOTW}$  value used during the test.

If it can be demonstrated by records of the calibration procedure described above that the flow-meter calibration is stable over a longer period of time, the pre-test check may be omitted.

2.6.4. Determination of the transformation time

The system settings for the transformation time evaluation shall be exactly the same as during measurement of the test run. The transformation time 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 not to affect the dynamic performance of the partial flow dilution system, and consistent with good engineering practice.

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 should be the same one as that 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  $G_{SE}$  signal of the partial flow dilution system and of the  $G_{EXHW}$  signal of the exhaust flow-meter shall be determined. These signals are used in the regression checks performed after each test (Annex 4A, Appendix 1, paragraph 2.4.).

The calculation shall be repeated for at least five 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. This is the 'look-ahead' value of the partial flow dilution system, which shall be applied in accordance with Annex 4A, Appendix 1, paragraph 2.4.

3. Calibration of the CVS system

3.1. General

The CVS system shall be calibrated by using an accurate flow-meter and means to change operating conditions.

The flow through the system shall be measured at different flow operating 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.

At the request of the manufacturer and with the agreement of the approval authority the methods described in Annex 4B, paragraphs 8.1. and 8.2. may be used as an alternative to those in paragraph 3. of this appendix.

3.2. Calibration of the 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<sup>3</sup>/min at pump inlet, absolute pressure and temperature) shall be plotted against 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).

3.2.1. Data analysis

The air flowrate ( $Q_s$ ) at each restriction setting (minimum 6 settings) shall be calculated in standard m<sup>3</sup>/min. from the flow-meter data using the manufacturer's prescribed method. The air flow rate shall then be converted to pump flow ( $V_0$ ) in m<sup>3</sup>/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{Q_s}{n} \cdot \frac{T}{273} \cdot \frac{101.3}{P_A}$$

where:

$Q_s$  = air flow rate at standard conditions (101.3 kPa, 273 K) (m<sup>3</sup>/s)

$T$  = temperature at pump inlet (K)

$p_A$  = absolute pressure at pump inlet ( $p_B - p_1$ ) (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 ( $X_0$ ) between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$X_0 = \frac{1}{n} \cdot \sqrt{\frac{\Delta p_p}{p_A}}$$

where,

$\Delta p_p$  = pressure differential from pump inlet to pump outlet (kPa)

$p_A$  = absolute outlet pressure at pump outlet (kPa)

A linear least-square fit shall be performed to generate the calibration equation as follows:

$$V_0 = D_0 - m \cdot (X_0)$$

$D_0$  and  $m$  are the intercept and slope constants, respectively, describing the regression lines.

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 values calculated by the equation shall be within  $\pm 0.5$  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 (paragraph 3.5.) indicates a change in the slip rate.

### 3.3. Calibration of the critical flow venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature, as shown below:

$$Q_s = \frac{K_v \cdot p_A}{\sqrt{T}}$$

where,

$K_v$  = calibration coefficient

$p_A$  = absolute pressure at venturi inlet (kPa)

$T$  = temperature at venturi inlet (K)

#### 3.3.1. Data analysis

The air flow rate ( $Q_s$ ) at each restriction setting (minimum 8 settings) shall be calculated in standard  $m^3/min.$  from the flow-meter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$K_v = \frac{Q_s \cdot \sqrt{T}}{p_A}$$

where:

$Q_s$  = air flow rate at standard conditions (101.3 kPa, 273 K) ( $m^3/s$ )

$T$  = temperature at the venturi inlet (K)

$p_A$  = absolute pressure at venturi inlet (kPa)

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.

For a minimum of eight points in the region of critical flow, the average  $K_v$  and the standard deviation shall be calculated. The standard deviation shall not exceed  $\pm 0.3$  per cent of the average  $K_v$ .

### 3.4. Calibration of the 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 below:

$$Q_{SSV} = A_0 d^2 C_d P_A \sqrt{\left[ \frac{1}{T} \left( r^{1.4286} - r^{1.7143} \right) \left( \frac{1}{1 - \beta^4 r^{1.4286}} \right) \right]}$$

where:

$A_0$  = collection of constants and units conversions =

$$0.006111 \text{ in SI units } \left( \frac{m^3}{\text{min}} \right) \left( \frac{K^{\frac{1}{2}}}{kPa} \right) \left( \frac{1}{mm^2} \right)$$

$d$  = diameter of the SSV throat (m)

$C_d$  = discharge coefficient of the SSV

$P_A$  = absolute pressure at venturi inlet (kPa)

$T$  = temperature at the venturi inlet (K)

$r$  = ratio of the SSV throat to inlet absolute, static pressure =  $1 - \frac{\Delta P}{P_A}$

$\beta$  = ratio of the SSV throat diameter,  $d$ , to the inlet pipe inner diameter =  $\frac{d}{D}$

#### 3.4.1. Data analysis

The air flow rate ( $Q_{SSV}$ ) at each flow setting (minimum 16 settings) shall be calculated in standard  $m^3/\text{min}$  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:

$$C_d = \frac{Q_{SSV}}{A_0 d^2 P_A \sqrt{\left[ \frac{1}{T} \left( r^{1.4286} - r^{1.7143} \right) \left( \frac{1}{1 - \beta^4 r^{1.4286}} \right) \right]}}$$

where:

- $Q_{SSV}$  = air flow rate at standard conditions (101.3 kPa, 273 K),  $m^3/s$   
 $T$  = temperature at the venturi inlet (K)  
 $d$  = diameter of the SSV throat (m)  
 $r$  = ratio of the SSV throat to inlet absolute, static pressure =  

$$1 - \frac{\Delta P}{P_A}$$
  
 $\beta$  = ratio of the SSV throat diameter,  $d$ , to the inlet pipe inner diameter =  $\frac{d}{D}$

To determine the range of subsonic flow,  $C_d$  shall be plotted as a function of Reynolds number, at the SSV throat. The  $Re$  at the SSV throat is calculated with the following formula:

$$Re = A_1 \frac{Q_{SSV}}{d\mu}$$

where:

- $A_1$  = a collection of constants and units conversions =  

$$25.55152 \left( \frac{1}{m^3} \right) \left( \frac{\min}{s} \right) \left( \frac{mm}{m} \right)$$
  
 $Q_{SSV}$  = air flow rate at standard conditions (101.3 kPa, 273 K) ( $m^3/s$ )  
 $d$  = diameter of the SSV throat (m)  
 $\mu$  = absolute or dynamic viscosity of the gas, calculated with the following formula:

$$\mu = \frac{bT^{3/2}}{S + T} = \frac{bT^{1/2}}{1 + \frac{S}{T}} \text{ kg/m}\cdot\text{s}$$

where:

- $b$  = empirical constant =  $1.458 \cdot 10^6 \frac{\text{kg}}{\text{msK}^2}$   
 $S$  = empirical constant = 104.4 K

Because  $Q_{SSV}$  is an input to the  $Re$  formula, the calculations shall be started with an initial guess for  $Q_{SSV}$  or  $C_d$  of the calibration venturi, and repeated until  $Q_{SSV}$  converges. The convergence method shall be accurate to 0.1 per cent or better.

For a minimum of sixteen points in the subsonic flow region, the calculated values of  $C_d$  from the resulting calibration curve fit equation shall be within  $\pm 0.5$  per cent of the measured  $C_d$  for each calibration point.

3.5. Total system verification

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 4A, Appendix 3, paragraph 2.4.1. except in the case of propane where a factor of 0.000472 is used in place of 0.000479 for HC. Either of the following two techniques shall be used.

3.5.1. Metering with a critical flow orifice

A known quantity of pure gas (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 five 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. The mass so determined shall be within  $\pm 3$  per cent of the known mass of the gas injected.

3.5.2. Metering by means of a gravimetric technique

The weight of a small cylinder filled with propane shall be determined with a precision of  $\pm 0.01$  g. For about five 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. The mass so determined shall be within  $\pm 3$  per cent of the known mass of the gas injected.

## Annex 4A - Appendix 3

### Data evaluation and calculations

1. Data evaluation and calculations – NRSC test
  - 1.1. Gaseous emissions data evaluation

For the evaluation of the gaseous emissions, the chart reading of the last 60 s of each mode shall be averaged, and the average concentrations (*conc*) of HC, CO, NO<sub>x</sub> and CO<sub>2</sub> if the carbon balance method is used, during each mode shall be determined from the average chart readings and the corresponding calibration data. A different type of recording can be used if it ensures an equivalent data acquisition.

The average background concentrations (*conc<sub>d</sub>*) may be determined from the bag readings of the dilution air or from the continuous (non-bag) background reading and the corresponding calibration data.

If the ramped modal cycles of Annex 5, sub-paragraphs (a) or (b) of paragraph 1.2., respectively, are used, the data evaluation and calculation procedures of Annex 4B, paragraph 7.8.2.2., and the applicable sections of paragraphs A.8.2., A.8.3. and A.8.4. shall apply. The final test results shall be calculated according to equations A.8-60 and A.8-61 or A.7-49 and A.7-50, respectively.
  - 1.2. Particulate emissions

For the evaluation of the particulates, the total sample masses ( $M_{SAM,i}$ ) through the filters shall be recorded for each mode. The filters shall be returned to the weighing chamber and conditioned for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight (see paragraph 3.1., Annex 4A) subtracted. The particulate mass ( $M_f$  for single filter method;  $M_{f,i}$  for the multiple filter method) is the sum of the particulate masses collected on the primary and back-up filters. If background correction is to be applied, the dilution air mass ( $M_{DIL}$ ) through the filters and the particulate mass ( $M_d$ ) shall be recorded. If more than one measurement was made, the quotient  $M_d/M_{DIL}$  shall be calculated for each single measurement and the values averaged.

If the ramped modal cycles of Annex 5, sub-paragraphs (a) or (b) of paragraph 1.2., respectively, are used, the data evaluation and calculation procedures of Annex 4B, paragraph 7.8.2.2., and the applicable sections of paragraphs A.8.2., A.8.3. and A.8.4. shall apply. The final test results shall be calculated according to equation A.8-64 or A.7-53, respectively.
  - 1.3. Calculation of the gaseous emissions

The finally reported test results shall be derived through the following steps:

    - 1.3.1. Determination of the exhaust gas flow

The exhaust gas flow rate ( $G_{EXHW,i}$ ) shall be determined for each mode according to Annex 4A, Appendix 1, paragraphs 1.2.1. to 1.2.3.

When using a full flow dilution system, the total dilute exhaust gas flow rate ( $G_{TOTW,i}$ ) shall be determined for each mode according to Annex 4A, Appendix 1, paragraph 1.2.4.

1.3.2. Dry/wet correction

Dry/wet correction ( $G_{EXHW,i}$ ) shall be determined for each mode according to Annex 4A, Appendix 1, paragraphs 1.2.1. to 1.2.3.

When applying  $G_{EXHW}$  the measured concentration shall be converted to a wet basis according to the following formulae, if not already measured on a wet basis:

$$conc_{wet} = K_w \cdot conc_{dry}$$

For the raw exhaust gas:

$$K_{w,r} = \left( \frac{1}{1 + 1.88 \cdot 0.005 \cdot (\% CO[dry] + \% CO_2[dry])} \right) \cdot K_{w1}$$

$$K_{w1} = \frac{1.608 \cdot H_a}{1000 + (1.608 \cdot H_a)}$$

$$H_a = \frac{6.22 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

For the diluted gas:

$$K_{w,e,1} = \left( 1 - \frac{1.88 \cdot CO_2 \%(wet)}{200} \right) \cdot K_{w2}$$

or:

$$K_{w,e,2} = \left( 1 + \frac{1 - K_{w2}}{1 + \frac{1.88 \cdot CO_2 \%(dry)}{200}} \right)$$

$$K_{w2} = \frac{1.608 \cdot [H_d \cdot (1 - 1/DF) + H_a \cdot (1/DF)]}{1000 + 1.608 \cdot [H_d \cdot (1 - 1/DF) + H_a \cdot (1/DF)]}$$

For the dilution air:

$$K_{w,d} = 1 - K_{w3}$$

$$K_{w3} = \frac{1.608 \cdot H_d}{1000 + (1.608 \cdot H_d)}$$

$$H_d = \frac{6.22 \cdot R_d \cdot p_d}{p_B - p_d \cdot R_d \cdot 10^{-2}}$$

For the intake air (if different from the dilution air):

$$K_{w,a} = 1 - K_{w2}$$

$$K_{w2} = \frac{1.608 \cdot H_a}{1000 + (1.608 \cdot H_a)}$$

$$H_a = \frac{6.22 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

- $H_a$  = absolute humidity of the intake air (g water per kg dry air)  
 $H_d$  = absolute humidity of the dilution air (g water per kg dry air)  
 $R_d$  = relative humidity of the dilution air (per cent)  
 $R_a$  = relative humidity of the intake air (per cent)  
 $p_d$  = saturation vapour pressure of the dilution air (kPa)  
 $p_a$  = saturation vapour pressure of the intake air (kPa)  
 $p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  and  $H_d$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

### 1.3.3. Humidity correction for NO<sub>x</sub>

As the NO<sub>x</sub> emission depends on ambient air conditions, the NO<sub>x</sub> concentration shall be corrected for ambient air temperature and humidity by the factors  $K_H$  given in the following formula:

$$K_H = \frac{1}{1 + A \left( \frac{H_a}{10.71} \right) (B - 29.8)}$$

where:

- $A$  =  $0.309 G_{\text{Fuel}} / G_{\text{AIRD}} - 0.0266$   
 $B$  =  $-0.209 G_{\text{Fuel}} / G_{\text{AIRD}} + 0.00954$

$\frac{G_{\text{FUEL}}}{G_{\text{AIRD}}}$  = Fuel air ratio (dry air basis)

- $T_a$  = temperatures of the air in (K)  
 $H_a$  = humidity of the intake air (g water per kg dry air):

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

- $R_a$  = relative humidity of the intake air (per cent)  
 $p_a$  = saturation vapour pressure of the intake air (kPa)  
 $p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

1.3.4. Calculation of emission mass flow rates

The emission mass flow rates for each mode shall be calculated as follows:

- (a) For the raw exhaust gas<sup>1</sup>:

$$Gas_{mass} = u \cdot conc \cdot G_{EXHW}$$

- (b) For the dilute exhaust gas<sup>2</sup>:

$$Gas_{mass} = u \cdot conc_c \cdot G_{TOTW}$$

where:

$conc_c$  is the background corrected concentration

$$conc_c = conc - conc_d \cdot (1 - (1 / DF))$$

$$DF = 13.4 / (conc_{CO_2} + (conc_{CO} + conc_{HC}) \cdot 10^{-4})$$

or:

$$DF = 13.4 / conc_{CO_2}$$

The coefficients  $u$  – wet shall be used according to Table 5:

Table 5

**Values of the coefficient  $u$  – wet for various exhaust components**

Gas	$u$	conc
NO <sub>x</sub>	0.001587	ppm
CO	0.000966	ppm
HC	0.000479	ppm
CO <sub>2</sub>	15.19	per cent

The density of HC is based upon an average carbon to hydrogen ratio of 1:1.85.

1.3.5. Calculation of the specific emissions

The specific emission (g/kWh) shall be calculated for all individual components in the following way:

$$Individual\ gas = \frac{\sum_{i=1}^n Gas\ mass_i \cdot WF_i}{\sum_{i=1}^n P_i \cdot WF_i}$$

where  $P_i = P_{m,i} + P_{AE,i}$ .

<sup>1</sup> In the case of NO<sub>x</sub>, the NO<sub>x</sub> concentration (NO<sub>x</sub>conc or NO<sub>x</sub>conc<sub>c</sub>) has to be multiplied by  $K_{HNOx}$  (humidity correction factor for NO<sub>x</sub> quoted in section 1.3.3) as follows:  $K_{HNOx} \cdot conc$  or  $K_{HNOx} \cdot conc_c$

<sup>2</sup> In the case of NO<sub>x</sub>, the NO<sub>x</sub> concentration (NO<sub>x</sub>conc or NO<sub>x</sub>conc<sub>c</sub>) has to be multiplied by  $K_{HNOx}$  (humidity correction factor for NO<sub>x</sub> quoted in section 1.3.3) as follows:  $K_{HNOx} \cdot conc$  or  $K_{HNOx} \cdot conc_c$

The weighing factors and the number of modes (n) used in the above calculation are according to Annex 4A, paragraph 3.7.1.

1.4. Calculation of the particulate emission

The particulate emission shall be calculated in the following way:

1.4.1. Humidity correction factor for particulates

As the particulate emission of diesel engines depends on ambient air conditions, the particulate mass flow rate shall be corrected for ambient air humidity with the factor  $K_p$  given in the following formula:

$$K_p = 1 / (1 + 0.0133 \cdot (H_a - 10.71))$$

where:

$H_a$  = humidity of the intake air, gram of water per kg dry air

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$  = relative humidity of the intake air (per cent)

$p_a$  = saturation vapour pressure of the intake air (kPa)

$p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

1.4.2. Partial flow dilution system

The final reported test results of the particulate emission shall be derived through the following steps. Since various types of dilution rate control may be used, different calculation methods for equivalent diluted exhaust gas mass flow rate  $G_{EDF}$  apply. All calculations shall be based upon the average values of the individual modes (i) during the sampling period.

1.4.2.1. Isokinetic systems

$$G_{EDFW,i} = G_{EXHW,i} \cdot q_i$$

$$q_i = \frac{G_{DILW,i} + (G_{EXHW,i} \cdot r)}{(G_{EXHW,i} \cdot r)}$$

where  $r$  corresponds to the ratio of the cross sectional areas of the isokinetic probe  $A_p$  and exhaust pipe  $A_T$ :

$$r = \frac{A_p}{A_T}$$

1.4.2.2. Systems with measurement of CO<sub>2</sub> or NO<sub>x</sub> concentration

$$G_{EDFW,i} = G_{EXHW,i} \cdot q_i$$

$$q_i = \frac{Conc_{E,i} - Conc_{A,i}}{Conc_{D,i} - Conc_{A,i}}$$

where:

$Conc_E$  = wet concentration of the tracer gas in raw exhaust

$Conc_D$  = wet concentration of the tracer gas in the diluted exhaust

$Conc_A$  = wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis shall be converted to a wet basis according to paragraph 1.3.2.

1.4.2.3. Systems with CO<sub>2</sub> measurement and carbon balance method

$$G_{EDFW,i} = \frac{206.6 \cdot G_{FUEL,i}}{CO_{2D,i} - CO_{2A,i}}$$

where:

$CO_{2D}$  = CO<sub>2</sub> concentration of the diluted exhaust

$CO_{2A}$  = CO<sub>2</sub> concentration of the dilution air

(concentrations in volume per cent on wet basis)

This equation is based upon the carbon balance assumption (carbon atoms supplied to the engine are emitted as CO<sub>2</sub>) and derived through the following steps:

$$G_{EDFW,i} = G_{EXHW,i} \cdot q_i$$

and:

$$q_i = \frac{206.6 \cdot G_{FUEL,i}}{G_{EXHW,i} \cdot (CO_{2D,i} - CO_{2A,i})}$$

1.4.2.4. Systems with flow measurement

$$G_{EDFW,i} = G_{EXHW,i} \cdot q_i$$

$$q_i = \frac{G_{TOTW,i}}{(G_{TOTW,i} - G_{DILW,i})}$$

1.4.3. Full flow dilution system

The final reported test results of the particulate emission shall be derived through the following steps.

All calculations shall be based upon the average values of the individual modes (*i*) during the sampling period.

$$G_{EDFW,i} = G_{TOTW,i}$$

1.4.4. Calculation of the particulate mass flow rate

The particulate mass flow rate shall be calculated as follows:

For the single filter method:

$$PT_{mass} = \frac{M_f \cdot (G_{EDFW})_{aver}}{M_{SAM} \cdot 1000}$$

where:

$(G_{EDFW})_{aver}$  over the test cycle shall be determined by summation of the average values of the individual modes during the sampling period:

$$(G_{EDFW})_{aver} = \sum_{i=1}^n G_{EDFW,i} \cdot WF_i$$

$$M_{SAM} = \sum_{i=1}^n M_{SAM,i}$$

where  $i = 1, \dots, n$

For the multiple filter method:

$$PT_{mass,i} = \frac{M_{f,i} \cdot (G_{EDFW,i})_{aver}}{M_{SAM,i} \cdot 1000}$$

where  $i = 1, \dots, n$

The particulate mass flow rate may be background corrected as follows:

For single filter method:

$$PT_{mass} = \left[ \frac{M_f}{M_{SAM}} - \left( \frac{M_d}{M_{DIL}} \cdot \left( \sum_{i=1}^n \left( 1 - \frac{1}{DF_i} \right) \cdot WF_i \right) \right) \right] \cdot \frac{(G_{EDFW})_{aver}}{1000}$$

If more than one measurement is made,  $(M_d/M_{DIL})$  shall be replaced with  $(M_d/M_{DIL})_{aver}$

$$DF = \frac{13.4}{conc_{CO_2} + (conc_{CO} + conc_{HC}) \cdot 10^{-4}}$$

or:

$$DF = 13.4 / conc_{CO_2}$$

For multiple filter method:

$$PT_{mass,i} = \left[ \frac{M_{f,i}}{M_{SAM,i}} - \left( \frac{M_d}{M_{DIL}} \cdot \left( 1 - \frac{1}{DF} \right) \right) \right] \cdot \left[ \frac{G_{EDFW,i}}{1000} \right]$$

If more than one measurement is made,  $(M_d/M_{DIL})$  shall be replaced with  $(M_d/M_{DIL})_{aver}$

$$DF = \frac{13.4}{conc_{CO_2} + (conc_{CO} + conc_{HC}) \cdot 10^{-4}}$$

or:

$$DF = 13.4 / conc_{CO_2}$$

1.4.5. Calculation of the specific emissions

The specific emission of particulates  $PT$  (g/kWh) shall be calculated in the following way<sup>3</sup>:

For the single filter method:

$$PT = \frac{PT_{\text{mass}}}{\sum_{i=1}^n P_i \cdot WF_i}$$

For the multiple filter method:

$$PT = \frac{\sum_{i=1}^n PT_{\text{mass},i} \cdot WF_i}{\sum_{i=1}^n P_i \cdot WF_i}$$

1.4.6. Effective weighing factor

For the single filter method, the effective weighing factor  $WF_{E,i}$  for each mode shall be calculated in the following way:

$$WF_{E,i} = \frac{M_{\text{SAM},i} \cdot (G_{\text{EDF}})_{\text{aver}}}{M_{\text{SAM}} \cdot (G_{\text{EDFW},i})}$$

where  $i = 1, \dots, n$ .

The value of the effective weighing factors shall be within  $\pm 0,005$  (absolute value) of the weighing factors listed in Annex 4A, paragraph 3.7.1.

2. Data evaluation and calculations (NRTC test)

The two following measurement principles that can be used for the evaluation of pollutant emissions over the NRTC cycle are described in this paragraph:

- (a) The gaseous components are measured in the raw exhaust gas on a real-time basis, and the particulates are determined using a partial flow dilution system;
- (b) The gaseous components and the particulates are determined using a full flow dilution system (CVS system).

2.1. Calculation of gaseous emissions in the raw exhaust gas and of the particulate emissions with a partial flow dilution system

2.1.1. Introduction

The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly, or calculated using the methods described in Annex 4A, Appendix 1, paragraph 2.2.3. (intake air and fuel flow measurement, tracer

<sup>3</sup> The particulate mass flow rate  $PT_{\text{mass}}$  has to be multiplied by  $K_p$  (humidity correction factor for particulates quoted in section 1.4.1).

method, intake air and air/fuel ratio measurement). Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals.

For particulates, the exhaust mass flow rate signals are used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality is checked by applying a regression analysis between sample and exhaust flow as described in Annex 4A, Appendix 1, paragraph 2.4.

2.1.2. Determination of the gaseous components

2.1.2.1. Calculation of mass emission

The mass of the pollutants  $M_{\text{gas}}$  (g/test) shall be determined by calculating the instantaneous mass emissions from the raw concentrations of the pollutants, the  $u$  values from Table 6 (see also paragraph 1.3.4.) and the exhaust mass flow, aligned for the transformation time and integrating the instantaneous values over the cycle. Preferably, the concentrations should be measured on a wet basis. If measured on a dry basis, the dry/wet correction as described here below shall be applied to the instantaneous concentration values before any further calculation is done.

Table 6  
**Values of the coefficient  $u$  – wet for various exhaust components**

<i>Gas</i>	<i>u</i>	<i>conc</i>
NO <sub>x</sub>	0.001587	ppm
CO	0.000966	ppm
HC	0.000479	ppm
CO <sub>2</sub>	15.19	per cent

The density of HC is based upon an average carbon to hydrogen ratio of 1:1.85.

The following formula shall be applied:

$$M_{\text{gas}} = \sum_{i=1}^n u \cdot \text{conc}_i \cdot G_{\text{EXHW},i} \cdot \frac{1}{f} \quad (\text{in g/test})$$

where:

$u$  = ratio between density of exhaust component and density of exhaust gas

$\text{conc}_i$  = instantaneous concentration of the respective component in the raw exhaust gas (ppm)

$G_{\text{EXHW},i}$  = instantaneous exhaust mass flow (kg/s)

$f$  = data sampling rate (Hz)

$n$  = number of measurements

For the calculation of NO<sub>x</sub>, the humidity correction factor  $k_H$ , as described here below, shall be used.

The instantaneously measured concentration shall be converted to a wet basis as described here below, if not already measured on a wet basis

2.1.2.2. Dry/wet correction

If the instantaneously measured concentration is measured on a dry basis, it shall be converted to a wet basis according to the following formulae:

$$conc_{wet} = K_W \cdot conc_{dry}$$

where:

$$K_{w,t} = \left( \frac{1}{1 + 1.88 \cdot 0.005 \cdot (conc_{CO} + conc_{CO_2})} \right) - K_{W2}$$

with:

$$K_{W2} = \frac{1.608 \cdot H_a}{1000 + (1.608 \cdot H_a)}$$

where:

$conc_{CO_2}$  = dry CO<sub>2</sub> concentration (per cent)

$conc_{CO}$  = dry CO concentration (per cent)

$H_a$  = intake air humidity, (g water per kg dry air)

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$  = relative humidity of the intake air (per cent)

$p_a$  = saturation vapour pressure of the intake air (kPa)

$p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

2.1.2.3. NO<sub>x</sub> correction for humidity and temperature

As the NO<sub>x</sub> emission depends on ambient air conditions, the NO<sub>x</sub> concentration shall be corrected for humidity and ambient air temperature with the factors given in the following formula:

$$k_H = \frac{1}{1 - 0.0182 \cdot (H_a - 10.71) + 0.0045 \cdot (T_a - 298)}$$

with:

$T_a$  = temperature of the intake air, K

$H_a$  = humidity of the intake air, g water per kg dry air

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$	=	relative humidity of the intake air (per cent)
$p_a$	=	saturation vapour pressure of the intake air (kPa)
$p_B$	=	total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

#### 2.1.2.4. Calculation of the specific emissions

The specific emissions (g/kWh) shall be calculated for each individual component in the following way:

$$\text{Individual Gas} = \frac{(1/10)M_{\text{gas,cold}} + (9/10)M_{\text{gas,hot}}}{(1/10)W_{\text{gas,cold}} + (9/10)W_{\text{gas,hot}}}$$

where:

$M_{\text{gas,cold}}$	=	total mass of gaseous pollutant over the cold start cycle (g)
$M_{\text{gas,hot}}$	=	total mass of gaseous pollutant over the hot start cycle (g)
$W_{\text{act,cold}}$	=	actual cycle work over the cold start cycle as determined in Annex 4A, paragraph 4.6.2. (kWh)
$W_{\text{act,hot}}$	=	actual cycle work over the hot start cycle as determined in Annex 4A, paragraph 4.6.2. (kWh)

#### 2.1.3. Particulate determination

##### 2.1.3.1. Calculation of mass emission

The particulate masses  $M_{\text{PT,cold}}$  and  $M_{\text{PT,hot}}$  (g/test) shall be calculated by either of the following methods:

$$(a) \quad M_{\text{PT}} = \frac{M_f}{M_{\text{SAM}}} \cdot \frac{M_{\text{EDFW}}}{1000}$$

where:

$M_{\text{PT}}$	=	$M_{\text{PT,cold}}$ for the cold start cycle
$M_{\text{PT}}$	=	$M_{\text{PT,hot}}$ for the hot start cycle
$M_f$	=	particulate mass sampled over the cycle (mg)
$M_{\text{EDFW}}$	=	mass of equivalent diluted exhaust gas over the cycle (kg)
$M_{\text{SAM}}$	=	mass of diluted exhaust gas passing the particulate collection filters (kg)

The total mass of equivalent diluted exhaust gas mass over the cycle shall be determined as follows:

$$M_{\text{EDFW}} = \sum_{i=1}^n G_{\text{EDFW},i} \cdot \frac{1}{f}$$

$$G_{\text{EDFW},i} = G_{\text{EXHW},i} \cdot q_i$$

$$q_i = \frac{G_{\text{TOTW},i}}{(G_{\text{TOTW},i} - G_{\text{DILW},i})}$$

where:

$G_{\text{EDFW},i}$  = instantaneous equivalent diluted exhaust mass flow rate (kg/s)

$G_{\text{EXHW},i}$  = instantaneous exhaust mass flow rate (kg/s)

$q_i$  = instantaneous dilution ratio

$G_{\text{TOTW},i}$  = instantaneous diluted exhaust mass flow rate through dilution tunnel (kg/s)

$G_{\text{DILW},i}$  = instantaneous dilution air mass flow rate (kg/s)

$f$  = data sampling rate (Hz)

$n$  = number of measurements

$$(b) \quad M_{\text{PT}} = \frac{M_f}{r_s \cdot 1000}$$

where:

$M_{\text{PT}}$  =  $M_{\text{PT,cold}}$  for the cold start cycle

$M_{\text{PT}}$  =  $M_{\text{PT,hot}}$  for the hot start cycle

$M_f$  = particulate mass sampled over the cycle (mg)

$r_s$  = average sample ratio over the test cycle

where:

$$r_s = \frac{M_{\text{SE}}}{M_{\text{EXHW}}} \cdot \frac{M_{\text{SAM}}}{M_{\text{TOTW}}}$$

$M_{\text{SE}}$  = sampled exhaust mass over the cycle (kg)

$M_{\text{EXHW}}$  = total exhaust mass flow over the cycle (kg)

$M_{\text{SAM}}$  = mass of diluted exhaust gas passing the particulate collection filters (kg)

$M_{\text{TOTW}}$  = mass of diluted exhaust gas passing the dilution tunnel (kg)

*Note:* In case of the total sampling type system,  $M_{\text{SAM}}$  and  $M_{\text{TOTW}}$  are identical

#### 2.1.3.2. Particulate correction factor for humidity

As the particulate emission of diesel engines depends on ambient air conditions, the particulate concentration shall be corrected for ambient air humidity with the factor  $k_p$  given in the following formulae.

$$k_p = \frac{1}{(1 + 0.0133 \cdot (H_a - 10.71))}$$

where:

$H_a$  = humidity of the intake air in g water per kg dry air

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$  = relative humidity of the intake air (per cent)

$p_a$  = saturation vapour pressure of the intake air (kPa)

$p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

### 2.1.3.3. Calculation of the specific emissions

The specific emissions (g/kWh) shall be calculated for in the following way:

$$PT = \frac{(1/10) K_{p,cold} \cdot M_{PT,cold} + (9/10) K_{p,hot} \cdot M_{PT,hot}}{(1/10) W_{act,cold} + (9/10) W_{act,hot}}$$

where:

$M_{PT,cold}$  = particulate mass over the cold start cycle (g/test)

$M_{PT,hot}$  = particulate mass over the hot start cycle (g/test)

$K_{p,cold}$  = humidity correction factor for particulate over the cold start cycle

$K_{p,hot}$  = humidity correction factor for particulate over the hot start cycle

$W_{act,cold}$  = actual cycle work over the cold start cycle as determined in paragraph 4.6.2. of Annex 4A, (kWh)

$W_{act,hot}$  = actual cycle work over the hot start cycle as determined in paragraph 4.6.2. of Annex 4A, (kWh)

### 2.2. Determination of gaseous and particulate components with a full flow dilution system

For calculation of the emissions in the diluted exhaust gas, it is necessary to know the diluted exhaust gas mass flow rate. The total diluted exhaust gas flow over the cycle  $M_{TOTW}$  (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device ( $V_0$  for PDP,  $K_V$  for CFV,  $C_d$  for SSV): the corresponding methods described in paragraph 2.2.1. may be used. If the total sample mass of particulates ( $M_{SAM}$ ) and gaseous pollutants exceeds 0.5 per cent of the total CVS flow ( $M_{TOTW}$ ), the CVS flow shall be corrected for  $M_{SAM}$  or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

2.2.1. Determination of the diluted exhaust gas flow

PDP-CVS system

The calculation of the mass flow over the cycle, if the temperature of the diluted exhaust is kept within  $\pm 6$  K over the cycle by using a heat exchanger, is as follows:

$$M_{\text{TOTW}} = 1.293 \cdot V_0 \cdot N_P \cdot (p_B - p_1) \cdot 273 / (101.3 \cdot T)$$

where:

- $M_{\text{TOTW}}$  = mass of the diluted exhaust gas on wet basis over the cycle  
 $V_0$  = volume of gas pumped per revolution under test conditions (m<sup>3</sup>/rev)  
 $N_P$  = total revolutions of pump per test  
 $p_B$  = atmospheric pressure in the test cell (kPa)  
 $p_1$  = pressure drop below atmospheric at the pump inlet (kPa)  
 $T$  = average temperature of the diluted exhaust gas at pump inlet over the cycle (K)

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$M_{\text{TOTW},i} = 1.293 \cdot V_0 \cdot N_{P,i} \cdot (p_B - p_1) \cdot 273 / (101.3 \cdot T)$$

where:

- $N_{P,i}$  = total revolutions of pump per time interval

CFV-CVS system

The calculation of the mass flow over the cycle, if the temperature of the diluted exhaust gas is kept within  $\pm 11$  K over the cycle by using a heat exchanger, is as follows:

$$M_{\text{TOTW}} = 1.293 \cdot t \cdot K_V \cdot p_A / T^{0.5}$$

where:

- $M_{\text{TOTW}}$  = mass of the diluted exhaust gas on wet basis over the cycle  
 $t$  = cycle time (s)  
 $K_V$  = calibration coefficient of the critical flow venturi for standard conditions,  
 $p_A$  = absolute pressure at venturi inlet (kPa)  
 $T$  = absolute temperature at venturi inlet (K)

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$M_{\text{TOTW},i} = 1.293 \cdot \Delta t_i \cdot K_V \cdot p_A / T^{0.5}$$

where:

$\Delta t_i$  = time interval(s)

SSV-CVS system

The calculation of the mass flow over the cycle is as follows if the temperature of the diluted exhaust is kept within  $\pm 11$  K over the cycle by using a heat exchanger:

$$M_{TOTW} = 1.293 \cdot Q_{SSV} \cdot \Delta t$$

where:

$$Q_{SSV} = A_0 d^2 C_d P_A \sqrt{\left[ \frac{1}{T} (r^{1.4286} - r^{1.7143}) \cdot \left( \frac{1}{1 - \beta^4 r^{1.4286}} \right) \right]}$$

$A_0$  = collection of constants and units conversions

$$= 0.006111 \text{ in SI units } \left( \frac{m^3}{\text{min}} \right) \left( \frac{K^{\frac{1}{2}}}{kPa} \right) \left( \frac{1}{mm^2} \right)$$

$d$  = diameter of the SSV throat (m)

$C_d$  = discharge coefficient of the SSV

$P_A$  = absolute pressure at venturi inlet (kPa)

$T$  = temperature at the venturi inlet (K)

$r$  = ratio of the SSV throat to inlet absolute, static pressure =  
 $1 - \frac{\Delta P}{P_A}$

$\beta$  = ratio of the SSV throat diameter,  $d$ , to the inlet pipe inner diameter =  
 $\frac{d}{D}$

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows:

$$M_{TOTW,i} = 1.293 \cdot Q_{SSV} \cdot \Delta t_i$$

where:

$$Q_{SSV} = A_0 d^2 C_d P_A \times \sqrt{\left[ \frac{1}{T} (r^{1.4286} - r^{1.7143}) \left( \frac{1}{1 - \beta^4 r^{1.4286}} \right) \right]}$$

$\Delta t_i$  = time interval (s)

The real time calculation shall be initialised with either a reasonable value for  $C_d$ , such as 0.98, or a reasonable value of  $Q_{SSV}$ . If the calculation is initialised with  $Q_{SSV}$ , the initial value of  $Q_{SSV}$  shall be used to evaluate  $Re$ .

During all emissions tests, the Reynolds number at the SSV throat shall be in the range of Reynolds numbers used to derive the calibration curve developed in Appendix 2, paragraph 3.2.

2.2.2.  $NO_x$  correction for humidity

As the  $NO_x$  emission depends on ambient air conditions, the  $NO_x$  concentration shall be corrected for ambient air humidity with the factors given in the following formulae.

$$k_H = \frac{1}{1 - 0.0182 \cdot (H_a - 10.71) + 0.0045 \cdot (T_a - 298)}$$

where:

$T_a$  = temperature of the air (K)

$H_a$  = humidity of the intake air (g water per kg dry air)

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$  = relative humidity of the intake air (per cent)

$p_a$  = saturation vapour pressure of the intake air (kPa)

$p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

2.2.3. Calculation of the emission mass flow

2.2.3.1. Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants  $M_{GAS}$  (g/test) shall be determined from the following equation:

$$M_{gas} = u \cdot conc \cdot M_{TOTW}$$

where:

$u$  = ratio between density of the exhaust component and density of diluted exhaust gas, as reported in Table 6, paragraph 2.1.2.1.

$conc$  = average background corrected concentrations over the cycle from integration (mandatory for  $NO_x$  and HC) or bag measurement (ppm)

$M_{TOTW}$  = total mass of diluted exhaust gas over the cycle as determined in paragraph 2.2.1. (kg)

As the NO<sub>x</sub> emission depends on ambient air conditions, the NO<sub>x</sub> concentration shall be corrected for ambient air humidity with the factor  $k_H$ , as described in paragraph 2.2.2.

Concentrations measured on a dry basis shall be converted to a wet basis in accordance with paragraph 1.3.2.

2.2.3.1.1. Determination of the background corrected concentrations

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 formula shall be used.

$$conc = conc_e - conc_d \cdot (1 - (1 / DF))$$

where:

$conc$  = concentration of the respective pollutant in the diluted exhaust gas, corrected by the amount of the respective pollutant contained in the dilution air (ppm)

$conc_e$  = concentration of the respective pollutant measured in the diluted exhaust gas (ppm)

$conc_d$  = concentration of the respective pollutant measured in the dilution air (ppm)

$DF$  = dilution factor

The dilution factor shall be calculated as follows:

$$DF = \frac{13.4}{conc_{eCO_2} + (conc_{eHC} + conc_{eCO}) \cdot 10^{-4}}$$

2.2.3.2. Systems with flow compensation

For systems without heat exchanger, the mass of the pollutants  $M_{GAS}$  (g/test) shall be determined by calculating the instantaneous mass emissions and integrating the instantaneous values over the cycle. Also, the background correction shall be applied directly to the instantaneous concentration value. The following formulae shall be applied:

$$M_{GAS} = \sum_{i=1}^n ((M_{TOTW,i} \cdot conc_{e,i} \cdot u) - (M_{TOTW} \cdot conc_d \cdot (1 - \frac{1}{DF}) \cdot u))$$

where:

$conc_{e,i}$  = instantaneous concentration of the respective pollutant measured in the diluted exhaust gas (ppm)

$conc_d$  = concentration of the respective pollutant measured in the dilution air (ppm)

$u$  = ratio between density of the exhaust component and density of diluted exhaust gas, as reported in Table 6, paragraph 2.1.2.1.

$M_{TOTW,i}$  = instantaneous mass of the diluted exhaust gas (paragraph 2.2.1.) (kg)

$M_{TOTW}$  = total mass of diluted exhaust gas over the cycle (paragraph 2.2.1.) (kg)

$DF$  = dilution factor as determined in paragraph 2.2.3.1.1.

As the  $NO_x$  emission depends on ambient air conditions, the  $NO_x$  concentration shall be corrected for ambient air humidity with the factor  $k_H$ , as described in paragraph 2.2.2.

#### 2.2.4. Calculation of the specific emissions

The specific emissions (g/kWh) shall be calculated for each individual component in the following way:

$$Individual\ Gas = \frac{(1/10)M_{gas,cold} + (9/10)M_{gas,hot}}{(1/10)W_{gas,cold} + (9/10)W_{gas,hot}}$$

where:

$M_{gas,cold}$  = total mass of gaseous pollutant over the cold start cycle (g)

$M_{gas,hot}$  = total mass of gaseous pollutant over the hot start cycle (g)

$W_{act,cold}$  = actual cycle work over the cold start cycle as determined in paragraph 4.6.2. of Annex 4A (kWh)

$W_{act,hot}$  = actual cycle work over the hot start cycle as determined in paragraph 4.6.2. of Annex 4A. (kWh)

#### 2.2.5. Calculation of the particulate emission

##### 2.2.5.1. Calculation of the mass flow

The particulate masses  $M_{PT,cold}$  and  $M_{PT,hot}$  (g/test) shall be calculated as follows:

$$M_{PT} = \frac{M_f}{M_{SAM}} \cdot \frac{M_{TOTW}}{1000}$$

where:

$M_{PT}$  =  $M_{PT,cold}$  for the cold start cycle

$M_{PT}$  =  $M_{PT,hot}$  for the hot start cycle

$M_f$  = particulate mass sampled over the cycle (mg)

$M_{TOTW}$  = total mass of diluted exhaust gas over the cycle as determined in paragraph 2.2.1. (kg)

$M_{SAM}$  = mass of diluted exhaust gas taken from the dilution tunnel for collecting particulates (kg)

and

$M_f$  =  $M_{f,p} + M_{f,b}$ , if weighed separately (mg)

$M_{f,p}$  = particulate mass collected on the primary filter (mg)

$M_{f,b}$  = particulate mass collected on the back-up filter (mg)

If a double dilution system is used, the mass of the secondary dilution air shall be subtracted from the total mass of the double diluted exhaust gas sampled through the particulate filters.

$$M_{\text{SAM}} = M_{\text{TOT}} - M_{\text{SEC}}$$

where:

$M_{\text{TOT}}$  = mass of double diluted exhaust gas through particulate filter (kg)

$M_{\text{SEC}}$  = mass of secondary dilution air (kg)

If the particulate background level of the dilution air is determined in accordance with paragraph 4.4.4. of Annex 4A, the particulate mass may be background corrected. In this case, the particulate masses  $M_{\text{PT,cold}}$  and  $M_{\text{PT,hot}}$  (g/test) shall be calculated as follows:

$$M_{\text{PT}} = \left( \frac{M_f}{M_{\text{SAM}}} - \left( \frac{M_d}{M_{\text{DIL}}} \cdot \left( 1 - \frac{1}{DF} \right) \right) \right) \cdot \frac{M_{\text{TOTW}}}{1000}$$

where:

$M_{\text{PT}}$  =  $M_{\text{PT,cold}}$  for the cold start cycle

$M_{\text{PT}}$  =  $M_{\text{PT,hot}}$  for the hot start cycle

$M_f, M_{\text{SAM}}, M_{\text{TOTW}}$  = see above

$M_{\text{DIL}}$  = mass of primary dilution air sampled by background particulate sampler (kg)

$M_d$  = mass of the collected background particulates of the primary dilution air (mg)

$DF$  = dilution factor as determined in paragraph 2.2.3.1.1.

#### 2.2.5.2. Particulate correction factor for humidity

As the particulate emission of diesel engines depends on ambient air conditions, the particulate concentration shall be corrected for ambient air humidity with the factor  $k_p$  given in the following formula.

$$k_p = \frac{1}{(1 + 0.0133 \cdot (H_a - 10.71))}$$

where:

$H_a$  = humidity of the intake air (g water per kg dry air)

$$H_a = \frac{6.220 \cdot R_a \cdot p_a}{p_B - p_a \cdot R_a \cdot 10^{-2}}$$

where:

$R_a$  = relative humidity of the intake air (per cent)

$p_a$  = saturation vapour pressure of the intake air (kPa)

$p_B$  = total barometric pressure (kPa).

*Note:*  $H_a$  may be derived from relative humidity measurement, as described above, or from dewpoint measurement, vapour pressure measurement or dry/wet bulb measurement using the generally accepted formulae.

2.2.5.3. Calculation of the specific emissions

The specific emissions (g/kWh) shall be calculated for in the following way:

$$PT = \frac{(1/10) K_{p,cold} \cdot M_{PT,cold} + (9/10) K_{p,hot} \cdot M_{PT,hot}}{(1/10) W_{act,cold} + (9/10) W_{act,hot}}$$

where:

- $M_{PT,cold}$  = particulate mass over the cold start cycle of NRTC, (g/test)
- $M_{PT,hot}$  = particulate mass over the hot start cycle of NRTC, (g/test)
- $K_{p,cold}$  = humidity correction factor for particulate over the cold start cycle
- $K_{p,hot}$  = humidity correction factor for particulate over the hot start cycle
- $W_{act,cold}$  = actual cycle work over the cold start cycle as determined in paragraph 4.6.2. of Annex 4A, (kWh)
- $W_{act,hot}$  = actual cycle work over the hot start cycle as determined in paragraph 4.6.2. of Annex 4A, (kWh)

## Annex 4A - Appendix 4

### Analytical and sampling system

#### 1. Gaseous and particulate sampling systems

<i>Figure number</i>	<i>Description</i>
2	Exhaust gas analysis system for raw exhaust
3	Exhaust gas analysis system for dilute exhaust
4	Partial flow, isokinetic flow, suction blower control, fractional sampling
5	Partial flow, isokinetic flow, pressure blower control, fractional sampling
6	Partial flow, CO <sub>2</sub> or NO <sub>x</sub> control, fractional sampling
7	Partial flow, CO <sub>2</sub> or carbon balance, total sampling
8	Partial flow, single venturi and concentration measurement, fractional sampling
9	Partial flow, twin venturi or orifice and concentration measurement, fractional sampling
10	Partial flow, multiple tube splitting and concentration measurement, fractional sampling
11	Partial flow, flow control, total sampling
12	Partial flow, flow control, fractional sampling
13	Full flow, positive displacement pump or critical flow venturi, fractional sampling
14	Particulate sampling system
15	Dilution system for full flow system

#### 1.1. Determination of the gaseous emissions

Paragraph 1.1.1. and Figures 2 and 3 contain detailed descriptions of the recommended sampling and analysing systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems may be excluded if their exclusion is based upon good engineering judgement.

#### 1.1.1. Gaseous exhaust components CO, CO<sub>2</sub>, HC, NO<sub>x</sub>

An analytical system for the determination of the gaseous emissions in the raw or diluted exhaust gas is described based on the use of:

- HFID analyser for the measurement of hydrocarbons;

- NDIR analysers for the measurement of carbon monoxide and carbon dioxide;
- HCLD or equivalent analyser for the measurement of nitrogen oxide.

For the raw exhaust gas (Figure 2), the sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

For the diluted exhaust gas (Figure 3), the sample for the hydrocarbons shall be taken with another sampling probe than the sample for the other components. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

Figure 2  
 Flow diagram of exhaust gas analysis system for CO, NO<sub>x</sub> and HC

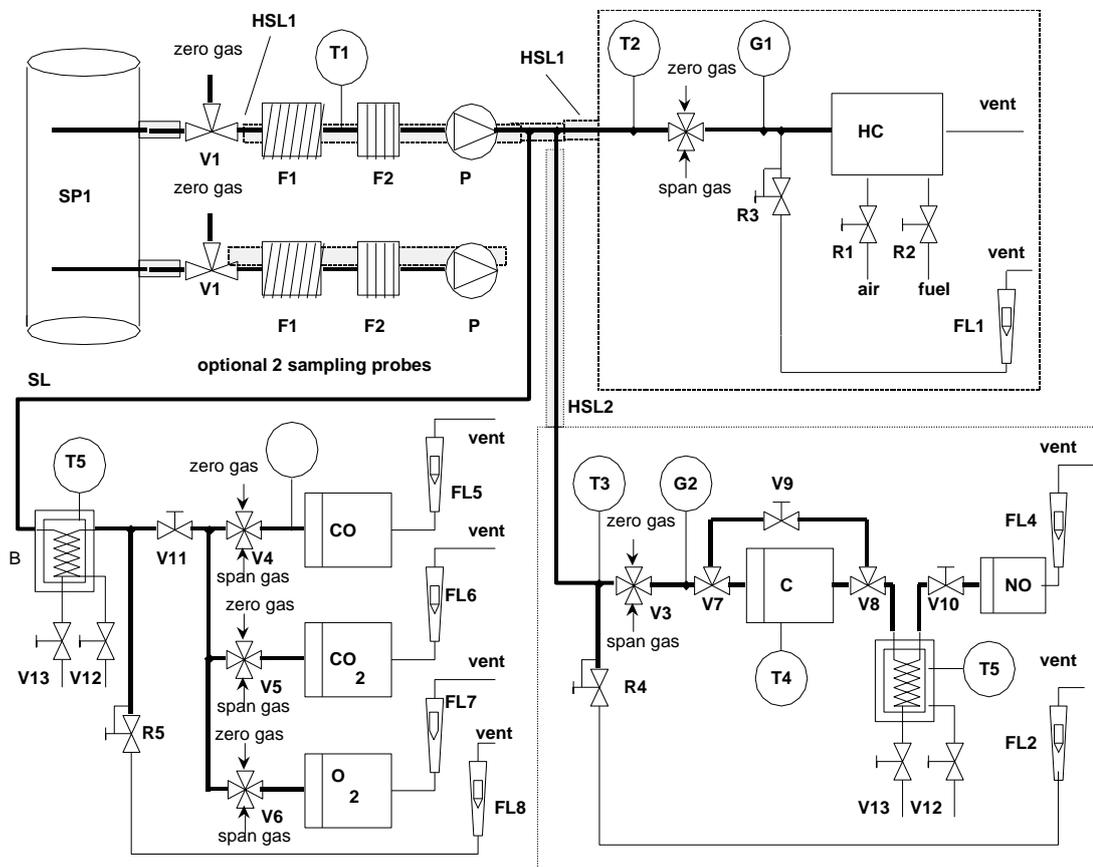
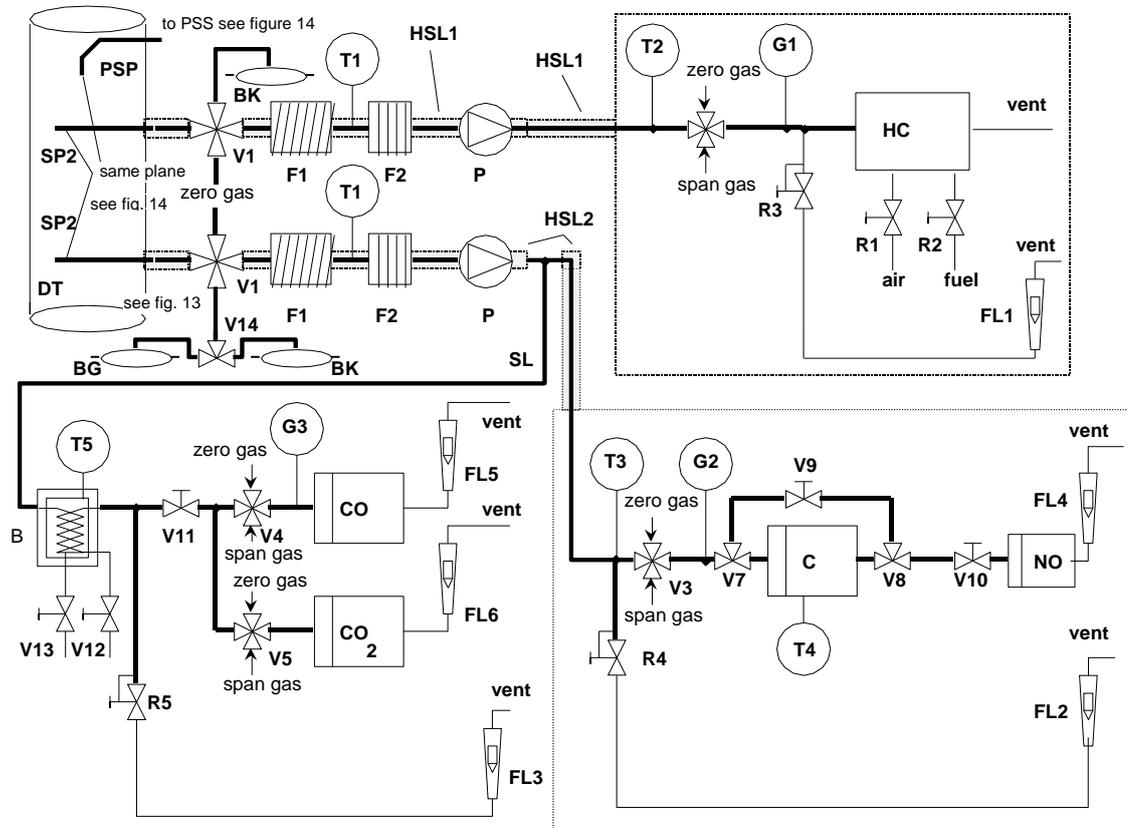


Figure 3  
 Flow diagram of dilute exhaust gas analysis system for CO, CO<sub>2</sub>, NO<sub>x</sub> and HC



Descriptions — Figures 2 and 3

General statement:

All components in the sampling gas path shall be maintained at the temperature specified for the respective systems.

— SP1 raw exhaust gas sampling probe (Figure 2 only)

A stainless steel straight closed and multihole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of three holes in three different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 per cent of the diameter of the exhaust pipe.

— SP2 dilute exhaust gas HC sampling probe (Figure 3 only)

The probe shall:

- Be defined as the first 254 mm to 762 mm of the hydrocarbon sampling line (HSL3);
- Have a 5 mm minimum inside diameter;

- Be installed in the dilution tunnel DT (paragraph 1.2.1.2.) at a point where the dilution air and exhaust gas are well mixed (i.e. approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);
- Be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- Be heated so as to increase the gas stream temperature to 463 K (190 °C) ± 10 K at the exit of the probe.

— SP3 dilute exhaust gas CO, CO<sub>2</sub>, NO<sub>x</sub> sampling probe (Figure 3 only)

The probe shall:

- Be in the same plane as SP2;
- Be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies;
- Be heated and insulated over its entire length to a minimum temperature of 328 K (55 °C) to prevent water condensation.

— HSL1 heated sampling line

The sampling line provides gas sampling from a single probe to the split point(s) and the HC analyser.

The sampling line shall:

- Have a 5 mm minimum and a 13.5 mm maximum inside diameter;
- Be made of stainless steel or PTFE;
- Maintain a wall temperature of 463 (190 °C) ± 10 K as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal or below 463 K (190 °C);
- Maintain a wall temperature greater than 453 K (180 °C) if the temperature of the exhaust gas at the sampling probe is above 463 K (190 °C);
- Maintain a gas temperature of 463 K (190 °C) ± 10 K immediately before the heated filter (F2) and the HFID.

— HSL2 heated NO<sub>x</sub> sampling line

The sampling line shall:

- Maintain a wall temperature of 328 to 473 K (55 to 200 °C) up to the converter when using a cooling bath, and up to the analyser when a cooling bath is not used;
- Be made of stainless steel or PTFE.

Since the sampling line need only be heated to prevent condensation of water and sulphuric acid, the sampling line temperature will depend on the sulphur content of the fuel.

— SL sampling line for CO (CO<sub>2</sub>)

The line shall be made of PTFE or stainless steel. It may be heated or unheated.

— BK background bag (optional; Figure 3 only)

For the measurement of the background concentrations.

— BG sample bag (optional; Figure 3 CO and CO<sub>2</sub> only)

For the measurement of the sample concentrations.

— F1 heated pre-filter (optional)

The temperature shall be the same as HSL1.

— F2 heated filter

The filter shall extract any solid particles from the gas sample prior to the analyser. The temperature shall be the same as HSL1. The filter shall be changed as needed.

— P heated sampling pump

The pump shall be heated to the temperature of HSL1.

— HC

Heated flame ionization detector (HFID) for the determination of the hydrocarbons. The temperature shall be kept at 453 to 473 K (180 to 200 °C).

— CO, CO<sub>2</sub>

NDIR analysers for the determination of carbon monoxide and carbon dioxide.

— NO<sub>2</sub>

(H)CLD analyser for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 to 473 K (55 to 200 °C).

— C converter

A converter shall be used for the catalytic reduction of NO<sub>2</sub> to NO prior to analysis in the CLD or HCLD.

— B cooling bath

To cool and condense water from the exhaust sample. The bath shall be maintained at a temperature of 273 to 277 K (0 to 4 °C) by ice or refrigeration. It is optional if the analyser is free from water vapour interference as determined in Annex 4A, Appendix 2, paragraphs 1.9.1. and 1.9.2.

Chemical dryers are not allowed for removing water from the sample.

— T1, T2, T3 temperature sensor

To monitor the temperature of the gas stream.

— T4 temperature sensor

Temperature of the NO<sub>2</sub>-NO converter.

— T5 temperature sensor

To monitor the temperature of the cooling bath.

— G1, G2, G3 pressure gauge

To measure the pressure in the sampling lines.

— R1, R2 pressure regulator

To control the pressure of the air and the fuel, respectively, for the HFID.

— R3, R4, R5 pressure regulator

To control the pressure in the sampling lines and the flow to the analysers.

— FL1, FL2, FL3 flow-meter

To monitor the sample bypass flow.

— FL4 to FL7 flow-meter (optional)

To monitor the flow rate through the analysers.

— V1 to V6 selector valve

Suitable valving for selecting sample, span gas or zero gas flow to the analyser.

— V7, V8 solenoid valve

To bypass the NO<sub>2</sub>-NO converter.

— V9 needle valve

To balance the flow through the NO<sub>2</sub>-NO converter and the bypass.

— V10, V11 needle valve

To regulate the flows to the analysers.

— V12, V13 toggle valve

To drain the condensate from the bath B.

— V14 selector valve

Selecting the sample or background bag.

## 1.2. Determination of the particulates

Paragraphs 1.2.1. and 1.2.2. and Figures 4 to 15 contain detailed descriptions of the recommended dilution and sampling systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. Additional components such as instruments, valve, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems may be excluded if their exclusion is based on good engineering judgement.

### 1.2.1. Dilution system

#### 1.2.1.1. Partial flow dilution system (Figures 4 to 12)<sup>1</sup>

A dilution system is described based on the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust

<sup>1</sup> Figures 4 to 12 show many types of partial flow dilution systems, which normally can be used for the steady-state test (NRSC). But, because of very severe constraints of the transient tests, only those partial flow dilution systems (Figures 4 to 12) able to fulfill all the requirements quoted in paragraph 2.4. Appendix 1, Annex 4A - Partial flow dilution system specifications -, are accepted for the transient test (NRTC).

gas may be passed to the particulate sampling system (paragraph 1.2.2., Figure 14). The first method is referred to as total sampling type, the second method as fractional sampling type.

The calculation of the dilution ratio depends on the type of system used.

The following types are recommended:

— isokinetic systems (Figures 4 and 5)

With these systems, the flow into the transfer tube is matched to the bulk exhaust flow in terms of gas velocity and/or pressure, thus requiring an undisturbed and uniform exhaust flow at the sampling probe. This is usually achieved by using a resonator and a straight approach tube upstream of the sampling point. The split ratio is then calculated from easily measurable values like tube diameters. It should be noted that isokinesis is only used for matching the flow conditions and not for matching the size distribution. The latter is typically not necessary, as the particles are sufficiently small as to follow the fluid streamlines,

— flow controlled systems with concentration measurement (Figures 6 to 10)

With these systems, a sample is taken from the bulk exhaust stream by adjusting the dilution air flow and the total dilution exhaust flow. The dilution ratio is determined from the concentrations of tracer gases, such as CO<sub>2</sub> or NO<sub>x</sub>, naturally occurring in the engine exhaust. The concentrations in the dilution exhaust gas and in the dilution air are measured, whereas the concentration in the raw exhaust gas can be either measured directly or determined from fuel flow and the carbon balance equation, if the fuel composition is known. The systems may be controlled by the calculated dilution ratio (Figures 6 and 7) or by the flow into the transfer tube (Figures 8, 9 and 10),

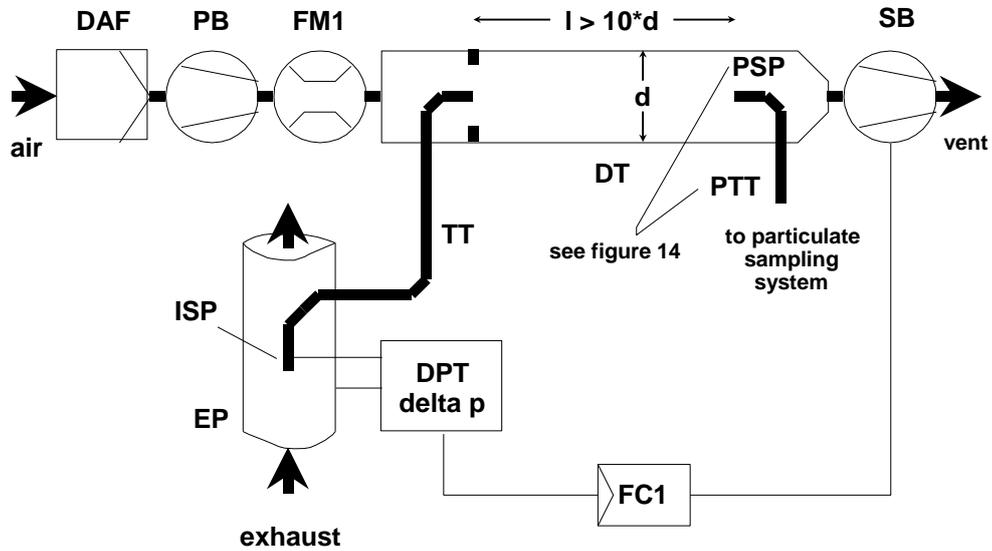
— flow controlled systems with flow measurement (Figures 11 and 12)

With these systems, a sample is taken from the bulk exhaust stream by setting the dilution air flow and the total dilution exhaust flow. The dilution ratio is determined from the difference of the two flow rates. Accurate calibration of the flow-meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios. Flow control is very straightforward by keeping the dilute exhaust flow rate constant and varying the dilution air flow rate, if needed.

In order to realize the advantages of the partial flow dilution systems, attention shall be paid to avoiding the potential problems of loss of particulates in the transfer tube, ensuring that a representative sample is taken from the engine exhaust, and determination of the split ratio.

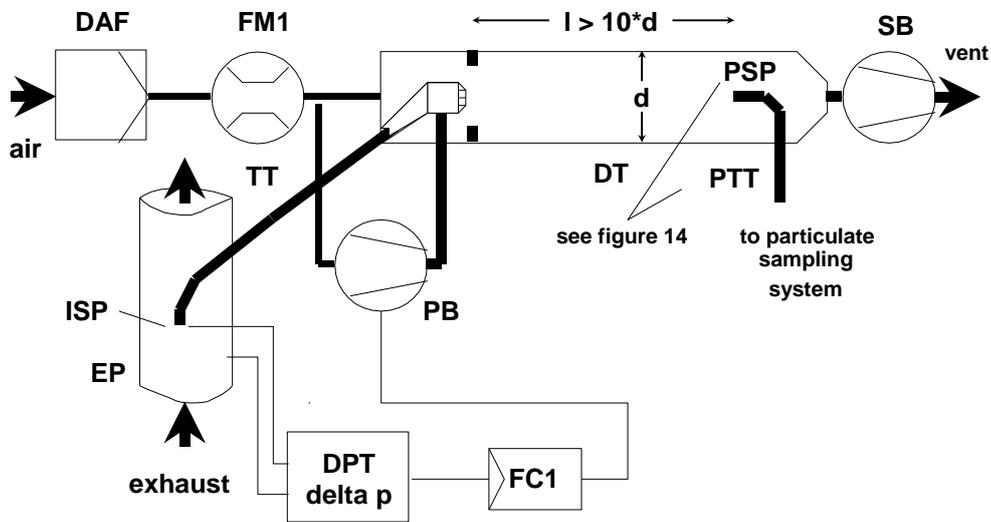
The systems described pay attention to these critical areas.

Figure 4  
 Partial flow dilution system with isokinetic probe and fractional sampling (SB control)



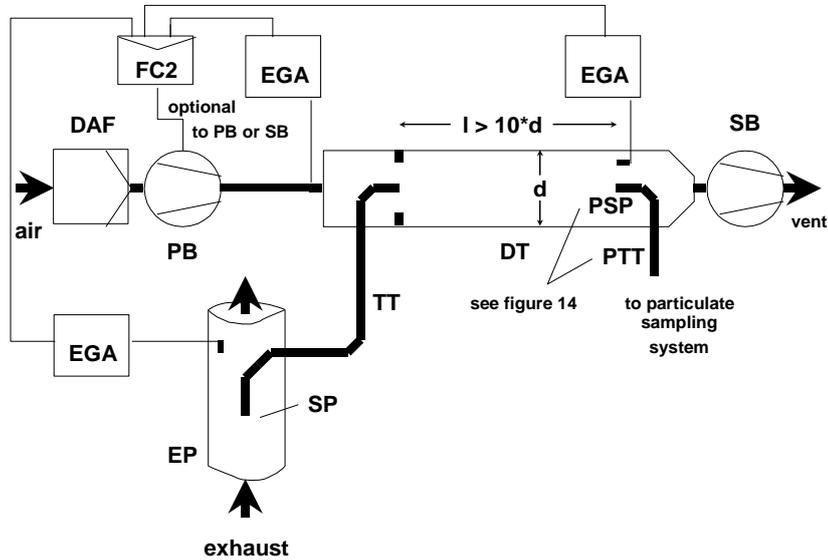
Raw exhaust gas is transferred from the exhaust pipe to EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted to the flow controller FC1 that controls the suction blower SB to maintain a differential pressure of zero at the tip of the probe. Under these conditions, exhaust gas velocities in EP and ISP are identical, and the flow through ISP and TT is a constant fraction (split) of the exhaust gas flow. The split ratio is determined from the cross sectional areas of EP and ISP. The dilution air flow rate is measured with the flow measurement device FM1. The dilution ratio is calculated from the dilution air flow rate and the split ratio.

Figure 5  
 Partial flow dilution system with isokinetic probe and fractional sampling (PB control)



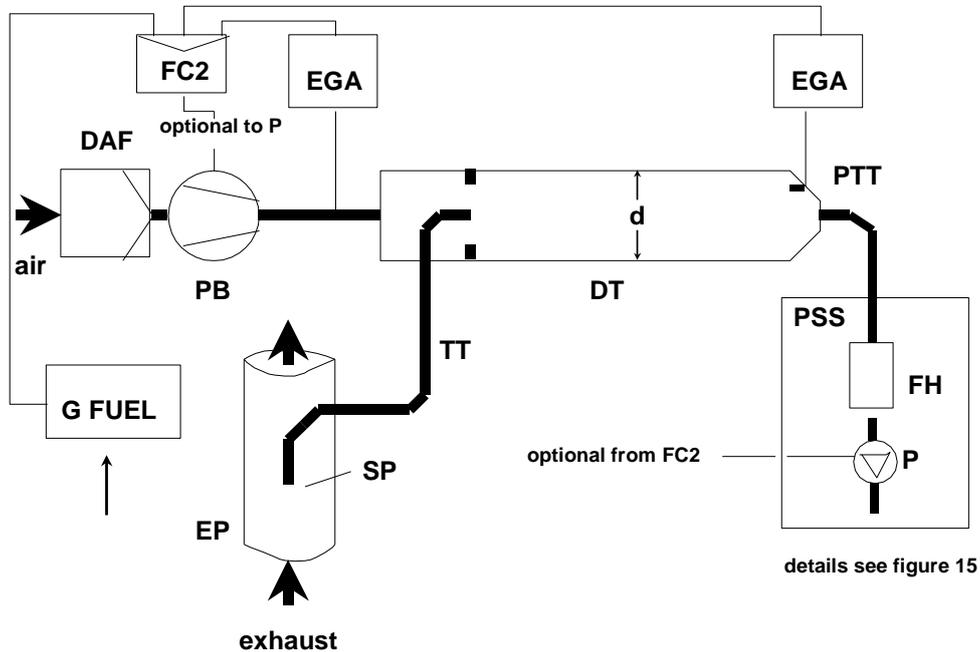
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the isokinetic sampling probe ISP. The differential pressure of the exhaust gas between exhaust pipe and inlet to the probe is measured with the pressure transducer DPT. This signal is transmitted to the flow controller FC1 that controls the pressure blower PB to maintain a differential pressure of zero at the tip of the probe. This is done by taking a small fraction of the dilution air whose flow rate has already been measured with the flow measurement device FM1, and feeding it to TT by means of a pneumatic orifice. Under these conditions, exhaust gas velocities in EP and ISP are identical, and the flow through ISP and TT is a constant fraction (split) of the exhaust gas flow. The split ratio is determined from the cross sectional areas of EP and ISP. The dilution air is sucked through DT by the suction blower SB, and the flow rate is measured with FM1 at the inlet to DT. The dilution ratio is calculated from the dilution air flow rate and the split ratio.

Figure 6  
**Partial flow dilution system with CO<sub>2</sub> or NO<sub>x</sub> concentration measurement and fractional sampling**



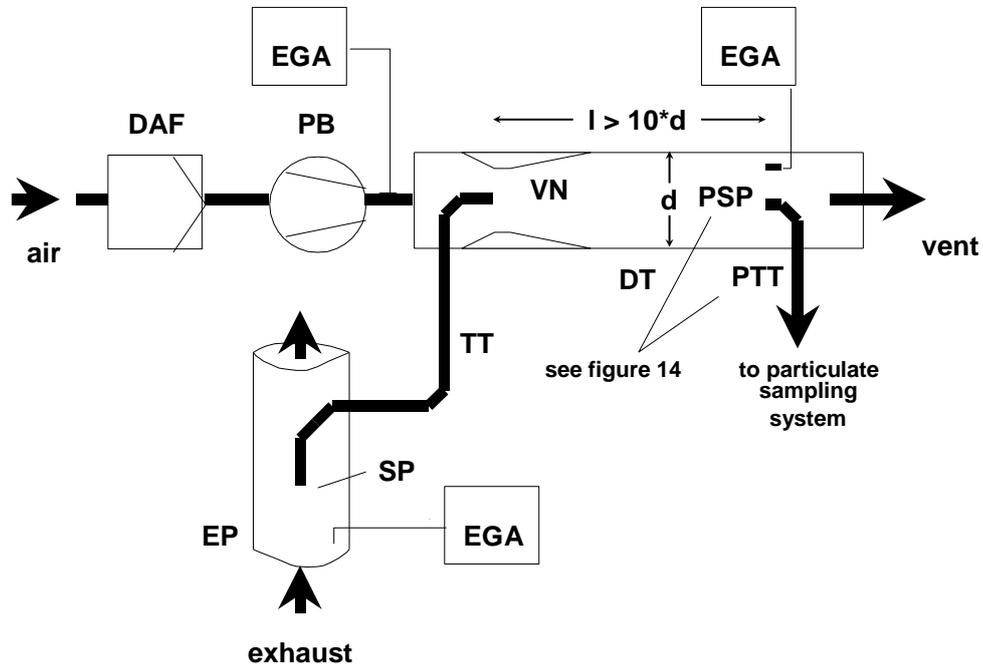
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The concentrations of a tracer gas (CO<sub>2</sub> or NO<sub>x</sub>) are measured in the raw and diluted exhaust gas as well as in the dilution air with the exhaust gas analyser(s) EGA. These signals are transmitted to the flow controller FC2 that controls either the pressure blower PB or the suction blower SB to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the tracer gas concentrations in the raw exhaust gas, the diluted exhaust gas, and the dilution air.

Figure 7  
**Partial flow dilution system with CO<sub>2</sub> concentration measurement, carbon balance and total sampling**



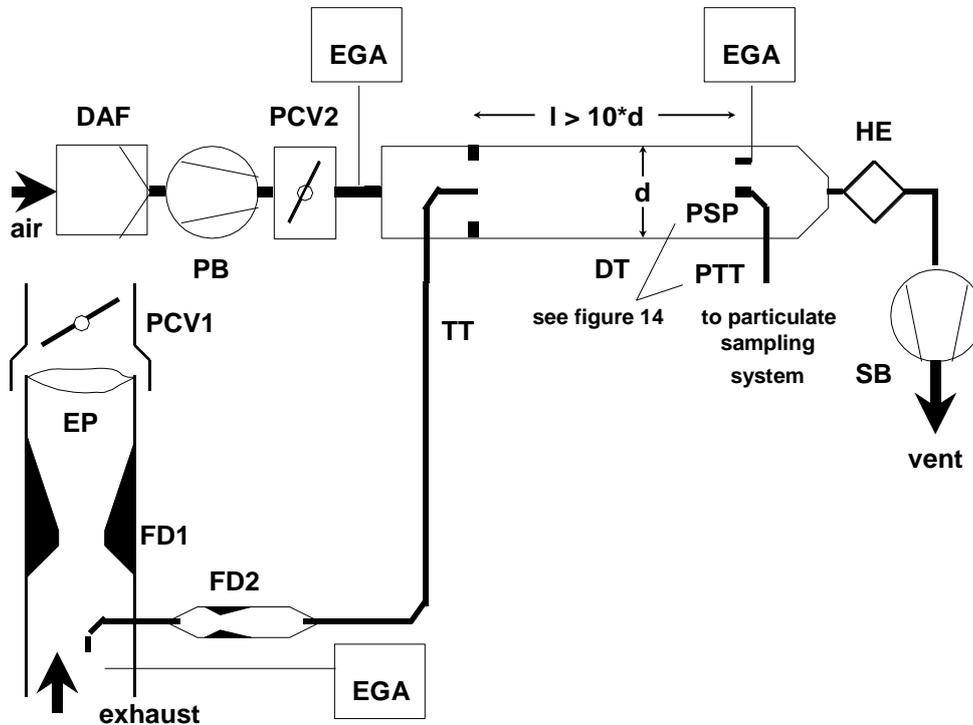
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The CO<sub>2</sub> concentrations are measured in the diluted exhaust gas and in the dilution air with the exhaust gas analyser(s) EGA. The CO<sub>2</sub> and fuel flow  $G_{\text{FUEL}}$  signals are transmitted either to the flow controller FC2, or to the flow controller FC3 of the particulate sampling system (Figure 14). FC2 controls the pressure blower PB, while FC3 controls the particulate sampling system (Figure 14), thereby adjusting the flows into and out of the system so as to maintain the desired exhaust split and dilution ratio in DT. The dilution ratio is calculated from the CO<sub>2</sub> concentrations and  $G_{\text{FUEL}}$  using the carbon balance assumption.

Figure 8  
**Partial flow dilution system with single venturi, concentration measurement and fractional sampling**



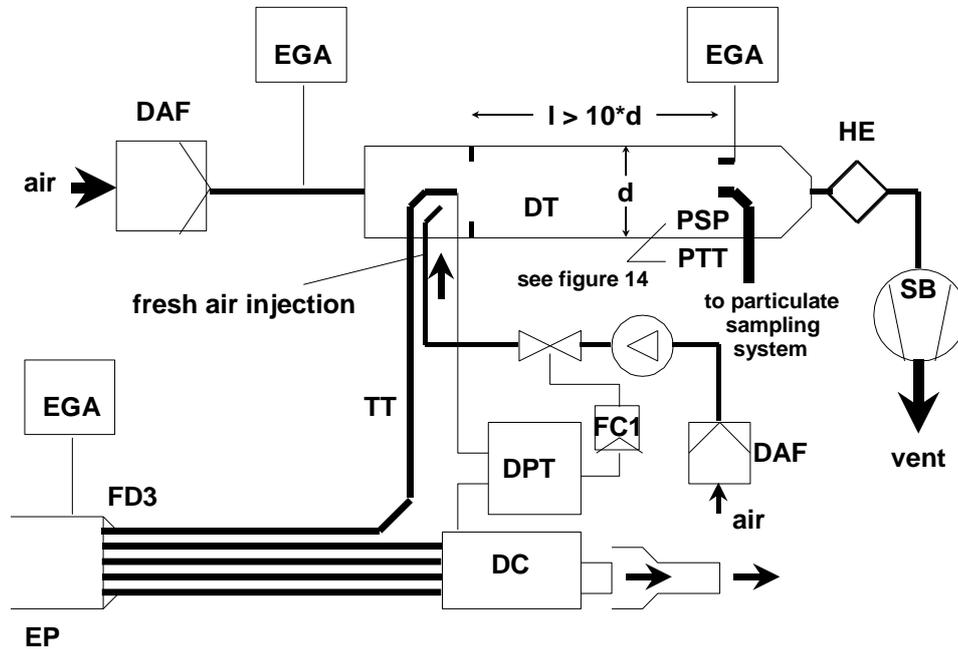
Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT due to the negative pressure created by the venturi VN in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone, and is therefore affected by the absolute temperature of the gas at the exit of TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. The tracer gas concentrations ( $\text{CO}_2$  or  $\text{NO}_x$ ) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA, and the dilution ratio is calculated from the values so measured.

Figure 9  
 Partial flow dilution system twin venturi or twin orifice, concentration measurement  
 and fractional sampling



Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT by a flow divider that contains a set of orifices or venturis. The first one (FD1) is located in EP, the second one (FD2) in TT. Additionally, two pressure control valves (PCV1 and PCV2) are necessary to maintain a constant exhaust split by controlling the backpressure in EP and the pressure in DT. PCV1 is located downstream of SP in EP, PCV2 between the pressure blower PB and DT. The tracer gas concentrations ( $\text{CO}_2$  or  $\text{NO}_x$ ) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split, and may be used to adjust PCV1 and PCV2 for precise split control. The dilution ratio is calculated from the tracer gas concentrations.

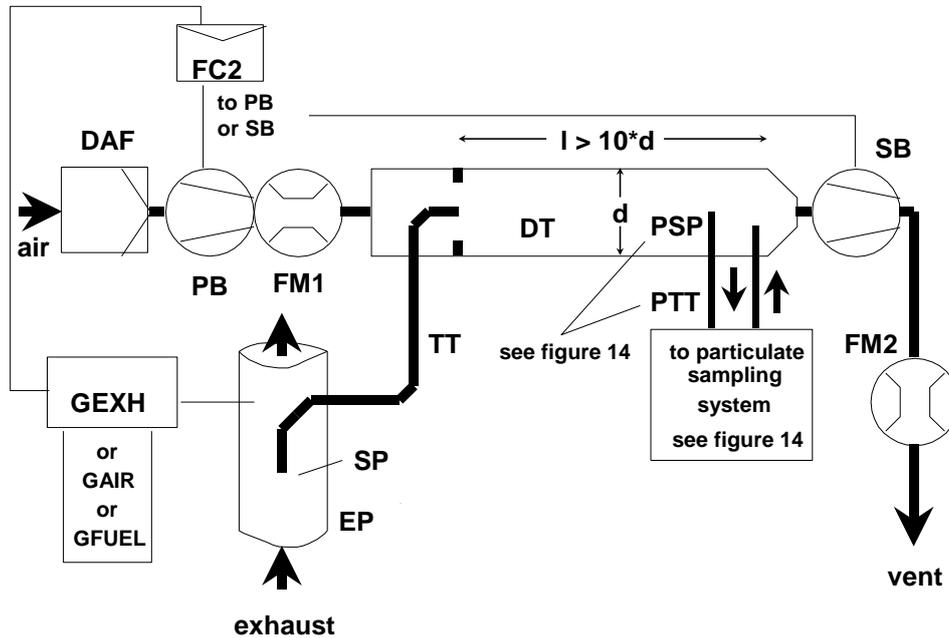
Figure 10  
**Partial flow dilution system with multiple tube splitting, concentration measurement and fractional sampling**



Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the transfer tube TT by the flow divider FD3 that consists of a number of tubes of the same dimensions (same diameter, length and bed radius) installed in EP. The exhaust gas through one of these tubes is lead to DT, and the exhaust gas through the rest of the tubes is passed through the damping chamber DC. Thus, the exhaust split is determined by the total number of tubes. A constant split control requires a differential pressure of zero between DC and the outlet of TT, which is measured with the differential pressure transducer DPT. A differential pressure of zero is achieved by injecting fresh air into DT at the outlet of TT. The tracer gas concentrations ( $\text{CO}_2$  or  $\text{NO}_x$ ) are measured in the raw exhaust gas, the diluted exhaust gas, and the dilution air with the exhaust gas analyser(s) EGA. They are necessary for checking the exhaust split and may be used to control the injection air flow rate for precise split control. The dilution ratio is calculated from the tracer gas concentrations.



Figure 12  
 Partial flow dilution system with flow control and fractional sampling



Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The exhaust split and the flow into DT is controlled by the flow controller FC2 that adjusts the flows (or speeds) of the pressure blower PB and the suction blower SB, accordingly. This is possible since the sample taken with the particulate sampling system is returned into DT.  $G_{EXH}$ ,  $G_{AIR}$  or  $G_{FUEL}$  may be used as command signals for FC2. The dilution air flow rate is measured with the flow measurement device FM1, the total flow with the flow measurement device FM2. The dilution ratio is calculated from these two flow rates.

Description – Figures 4 to 12

— EP exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less. Bends will be minimized to reduce inertial deposition. If the system includes a test bed silencer, the silencer may also be insulated.

For an isokinetic system, the exhaust pipe shall be free of elbows, bends and sudden diameter changes for at least six pipe diameters upstream and three pipe diameters downstream of the tip of the probe. The gas velocity at the sampling zone shall be higher than 10 m/s except at idle mode. Pressure oscillations of the exhaust gas shall not exceed  $\pm 500$  Pa on the average. Any steps to reduce pressure oscillations beyond using a chassis-type exhaust system (including silencer and after-treatment device) shall not alter engine performance nor cause the deposition of particulates.

For systems without isokinetic probes, it is recommended to have a straight pipe of six pipe diameters upstream and three pipe diameters downstream of the tip of the probe.

— SP sampling probe (Figures 6 to 12)

The minimum inside diameter shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be four. The probe shall be an open tube facing upstream on the exhaust pipe centre-line, or a multiple hole probe as described under SP1 in paragraph 1.1.1.

— ISP isokinetic sampling probe (Figures 4 and 5)

The isokinetic sampling probe shall be installed facing upstream on the exhaust pipe centre-line where the flow conditions in section EP are met, and designed to provide a proportional sample of the raw exhaust gas. The minimum inside diameter shall be 12 mm.

A control system is necessary for isokinetic exhaust splitting by maintaining a differential pressure of zero between EP and ISP. Under these conditions exhaust gas velocities in EP and ISP are identical and the mass flow through ISP is a constant fraction of the exhaust gas flow. The ISP has to be connected to a differential pressure transducer. The control to provide a differential pressure of zero between EP and ISP is done with blower speed or flow controller.

— FD1, FD2 flow divider (Figure 9)

A set of venturis or orifices is installed in the exhaust pipe EP and in the transfer tube TT, respectively, to provide a proportional sample of the raw exhaust gas. A control system consisting of two pressure control valves PCV1 and PCV2 is necessary for proportional splitting by controlling the pressures in EP and DT.

— FD3 flow divider (Figure 10)

A set of tubes (multiple tube unit) is installed in the exhaust pipe EP to provide a proportional sample of the raw exhaust gas. One of the tubes feeds exhaust gas to the dilution tunnel DT, whereas the other tubes exit exhaust gas to a damping chamber DC. The tubes shall have the same dimensions (same diameter, length, bend radius), so that the exhaust split depends on the total number of tubes. A control system is necessary for proportional splitting by maintaining a differential pressure of zero between the exit of the multiple tube unit into DC and the exit of TT. Under these conditions, exhaust gas velocities in EP and FD3 are proportional, and the flow TT is a constant fraction of the exhaust gas flow. The two points have to be connected to a differential pressure transducer DPT. The control to provide a differential pressure of zero is done with the flow controller FC1.

— EGA exhaust gas analyser (Figures 6 to 10)

CO<sub>2</sub> or NO<sub>x</sub> analysers may be used (with carbon balance method CO<sub>2</sub> only). The analysers shall be calibrated like the analysers for the measurement of the gaseous emissions. One or several analysers may be used to determine the concentration differences.

The accuracy of the measuring systems has to be such that the accuracy of  $G_{EDFW,i}$  is within  $\pm 4$  per cent.

— TT transfer tube (Figures 4 to 12)

The particulate sample transfer tube shall be:

- As short as possible, but not more than 5 m in length;
- Equal to or greater than the probe diameter, but not more than 25 mm in diameter;
- Exiting on the centre-line of the dilution tunnel and pointing downstream.

If the tube is 1 metre or less in length, it is to be insulated with material with a maximum thermal conductivity of 0.05 W/(m · K) with a radial insulation thickness corresponding to the diameter of the probe. If the tube is longer than 1 metre, it shall be insulated and heated to a minimum wall temperature of 523 K (250 °C).

Alternatively, the transfer tube wall temperatures required may be determined through standard heat transfer calculations.

— DPT differential pressure transducer (Figures 4, 5 and 10)

The differential pressure transducer shall have a range of  $\pm 500$  Pa or less.

— FC1 flow controller (Figures 4, 5 and 10)

For the isokinetic systems (Figures 4 and 5) a flow controller is necessary to maintain a differential pressure of zero between EP and ISP. The adjustment can be done by:

- (a) Controlling the speed or flow of the suction blower (SB) and keeping the speed of the pressure blower (PB) constant during each mode (Figure 4); or
- (b) Adjusting the suction blower (SB) to a constant mass flow of the diluted exhaust and controlling the flow of the pressure blower PB, and therefore the exhaust sample flow in a region at the end of the transfer tube (TT) (Figure 5).

In the case of a pressure controlled system the remaining error in the control loop shall not exceed  $\pm 3$  Pa. The pressure oscillations in the dilution tunnel shall not exceed  $\pm 250$  Pa on average.

For a multi-tube system (Figure 10) a flow controller is necessary for proportional exhaust splitting to maintain a differential pressure of zero between the outlet of the multi-tube unit and the exit of TT. The adjustment can be done by controlling the injection air flow rate into DT at the exit of TT.

— PCV1, PCV2 pressure control valve (Figure 9)

Two pressure control valves are necessary for the twin venturi/twin orifice system for proportional flow splitting by controlling the backpressure of EP and the pressure in DT. The valves shall be located downstream of SP in EP and between PB and DT.

— DC damping chamber (Figure 10)

A damping chamber shall be installed at the exit of the multiple tube unit to minimize the pressure oscillations in the exhaust pipe EP.

— VN venturi (Figure 8)

A venturi is installed in the dilution tunnel DT to create a negative pressure in the region of the exit of the transfer tube TT. The gas flow rate through TT is determined by the momentum exchange at the venturi zone, and is basically proportional to the flow rate of the pressure blower PB leading to a constant dilution ratio. Since the momentum exchange is affected by the temperature at the exit of TT and the pressure difference between EP and DT, the actual dilution ratio is slightly lower at low load than at high load.

— FC2 flow controller (Figures 6, 7, 11 and 12; optional)

A flow controller may be used to control the flow of the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust flow or fuel flow signal and/or to the CO<sub>2</sub> or NO<sub>x</sub> differential signal.

When using a pressurised air supply (Figure 11) FC2 directly controls the air flow.

— FM1 flow measurement device (Figures 6, 7, 11 and 12)

Gas meter or other flow instrumentation to measure the dilution air flow. FM1 is optional if PB is calibrated to measure the flow.

— FM2 flow measurement device (Figure 12)

Gas meter or other flow instrumentation to measure the diluted exhaust gas flow. FM2 is optional if the suction blower SB is calibrated to measure the flow.

— PB pressure blower (Figures 4, 5, 6, 7, 8, 9 and 12)

To control the dilution air flow rate, PB may be connected to the flow controllers FC1 or FC2. PB is not required when using a butterfly valve. PB may be used to measure the dilution air flow, if calibrated.

— SB suction blower (Figures 4, 5, 6, 9, 10 and 12)

For fractional sampling systems only. SB may be used to measure the dilute exhaust gas flow, if calibrated.

— DAF dilution air filter (Figures 4 to 12)

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. The dilution air shall have a temperature of 298 K (25 °C) ± 5 K.

At the manufacturer's request the dilution air shall be sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

— PSP particulate sampling probe (Figures 4, 5, 6, 8, 9, 10 and 12)

The probe is the leading section of PTT and

- Shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, i.e. on the dilution tunnel DT centre-line of the dilution systems approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- Shall be 12 mm in minimum inside diameter;

- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

— DT dilution tunnel (Figures 4 to 12)

The dilution tunnel:

- Shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions;
- Shall be constructed of stainless steel with:
  - A thickness to diameter ratio of 0.025 or less for dilution tunnels of greater than 75 mm inside diameter;
  - A nominal wall thickness of not less than 1.5 mm for dilution tunnels of equal to or less than 75 mm inside diameter;
- Shall be at least 75 mm in diameter for the fractional sampling type;
- Is recommended to be at least 25 mm in diameter for the total sampling type;
- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

The engine exhaust shall be thoroughly mixed with the dilution air. For fractional sampling systems, the mixing quality shall be checked after introduction into service by means of a CO<sub>2</sub> profile of the tunnel with the engine running (at least four equally spaced measuring points). If necessary, a mixing orifice may be used.

*Note:* If the ambient temperature in the vicinity of the dilution tunnel (DT) is below 293 K (20 °C), precautions should be taken to avoid particle losses onto the cool walls of the dilution tunnel. Therefore, heating and/or insulating the tunnel within the limits given above is recommended.

At high engine loads, the tunnel may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 293 K (20 °C).

— HE heat exchanger (Figures 9 and 10)

The heat exchanger shall be of sufficient capacity to maintain the temperature at the inlet to the suction blower SB within  $\pm 11$  K of the average operating temperature observed during the test.

#### 1.2.1.2. Full flow dilution system (Figure 13)

A dilution system is described based upon the dilution of the total exhaust using the constant volume sampling (CVS) concept. The total volume of the mixture of exhaust and dilution air shall be measured. Either a PDP or a CFV or a SSV system may be used.

For subsequent collection of the particulates, a sample of the dilute exhaust gas is passed to the particulate sampling system (paragraph 1.2.2., Figures 14 and 15). If this is done directly, it is referred to as single dilution. If the sample is diluted once more in the secondary dilution tunnel, it is referred to as double dilution. This is useful, if the filter face temperature requirement cannot be met with single dilution. Although partly a dilution system, the double dilution system is described as a modification of a particulate sampling system in paragraph 1.2.2., (Figure 15), since it shares most of the parts with a typical particulate sampling system.

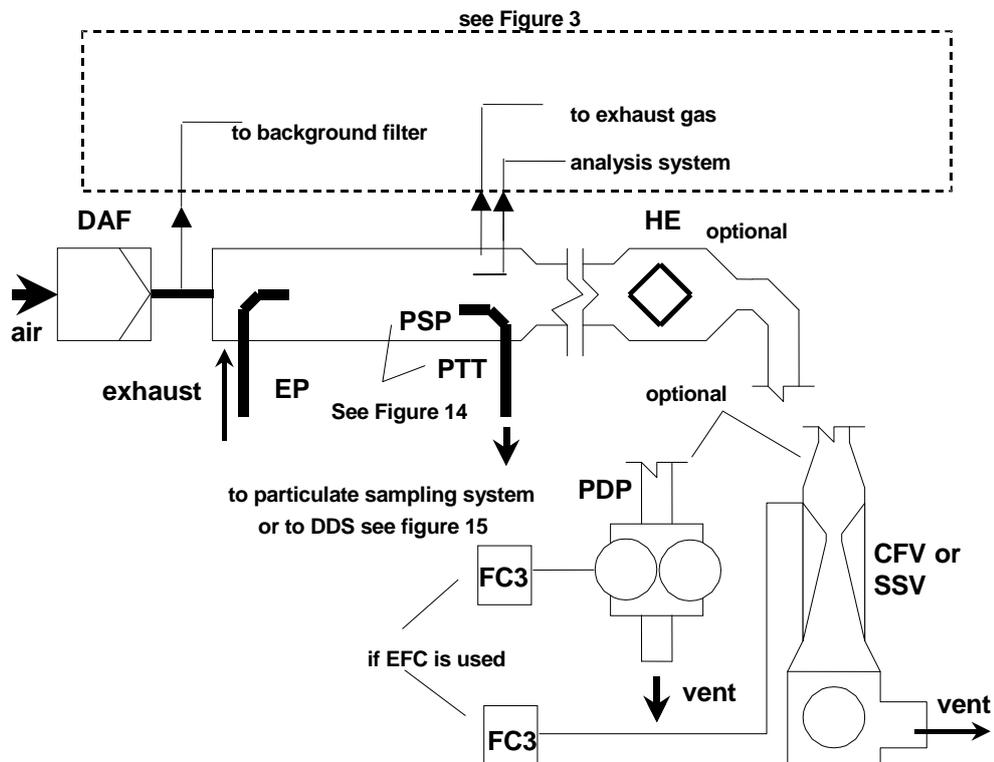
The gaseous emissions may also be determined in the dilution tunnel of a full flow dilution system. Therefore, the sampling probes for the gaseous components are shown in Figure 13 but do not appear in the description list. The respective requirements are described in paragraph 1.1.1.

Descriptions (Figure 13)

— EP exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel is required to be not more than 10 m. If the system exceeds 4 m in length, then all tubing in excess of 4 m shall be insulated, except for an in-line smoke-meter, if used. The radial thickness of the insulation shall be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than  $0.1 \text{ W}/(\text{m} \cdot \text{K})$  measured at 673 K (400 °C). To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less.

Figure 13  
**Full flow dilution system**



The total amount of raw exhaust gas is mixed in the dilution tunnel DT with the dilution air. The diluted exhaust gas flow rate is measured either with a positive displacement pump PDP or with a critical flow venturi CFV or with a sub-sonic venturi SSV. A heat exchanger HE or electronic flow compensation EFC may be used for proportional particulate sampling and for flow determination. Since particulate mass determination is based on the total diluted exhaust gas flow, the dilution ratio is not required to be calculated.

— PDP positive displacement pump

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system back pressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust back pressure measured with the CVS system operating shall remain within  $\pm 1,5$  kPa of the static pressure measured without connection to the CVS at identical engine speed and load.

The gas mixture temperature immediately ahead of the PDP shall be within  $\pm 6$  K of the average operating temperature observed during the test, when no flow compensation is used.

Flow compensation can only be used if the temperature at the inlet of the PDP does not exceed  $50$  °C (323 K).

— CFV critical flow venturi

CFV measures total diluted exhaust flow by maintaining the flow at choked conditions (critical flow). Static exhaust backpressure measured with the CFV system operating shall remain within  $\pm 1.5$  kPa of the static pressure measured without connection to the CFV at identical engine speed and load. The gas mixture temperature immediately ahead of the CFV shall be within  $\pm 11$  K of the average operating temperature observed during the test, when no flow compensation is used.

— SSV subsonic venturi

SSV measures total diluted exhaust flow as a function of inlet pressure, inlet temperature, pressure drop between the SSV inlet and throat. Static exhaust backpressure measured with the SSV system operating shall remain within  $\pm 1.5$  kPa of the static pressure measured without connection to the SSV at identical engine speed and load. The gas mixture temperature immediately ahead of the SSV shall be within  $\pm 11$  K of the average operating temperature observed during the test, when no flow compensation is used.

— HE heat exchanger (optional if EFC is used)

The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above.

— EFC electronic flow compensation (optional if HE is used)

If the temperature at the inlet to either the PDP or CFV or SSV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system. To that purpose, the continuously measured flow rate signals are used to correct the sample flow rate through the particulate filters of the particulate sampling system (Figures 14 and 15), accordingly.

— DT dilution tunnel

The dilution tunnel:

- Shall be small enough in diameter to cause turbulent flow (Reynolds number greater than 4,000) of sufficient length to cause complete mixing of the exhaust and dilution air. A mixing orifice may be used;
- Shall be at least 75 mm in diameter;
- May be insulated.

The engine exhaust shall be directed downstream at the point where it is introduced into the dilution tunnel, and thoroughly mixed.

When using single dilution, a sample from the dilution tunnel is transferred to the particulate sampling system (paragraph 1.2.2., Figure 14). The flow capacity of the PDP or CFV or SSV shall be sufficient to maintain the diluted exhaust at a temperature of less than or equal to 325 K (52 °C) immediately before the primary particulate filter.

When using double dilution, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (paragraph 1.2.2., Figure 15). The flow capacity of the PDP or CFV or SSV shall be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 464 K (191 °C) at the

sampling zone. The secondary dilution system shall provide sufficient secondary dilution air to maintain the doubly-diluted exhaust stream at a temperature of less than or equal to 325 K (52 °C) immediately before the primary particulate filter.

— DAF dilution air filter

It is recommended that the dilution air be filtered and charcoal scrubbed to eliminate background hydrocarbons. The dilution air shall have a temperature of 298 K (25 °C)  $\pm$  5 K. At the manufacturer's request the dilution air shall be sampled according to good engineering practice to determine the background particulate levels, which can then be subtracted from the values measured in the diluted exhaust.

— PSP particulate sampling probe

The probe is the leading section of PTT and

- Shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, i.e. on the dilution tunnel DT centre-line of the dilution systems approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- Shall be 12 mm in minimum inside diameter;
- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

#### 1.2.2. Particulate sampling system (Figures 14 and 15)

The particulate sampling system is required for collecting the particulates on the particulate filter. In the case of total sampling partial flow dilution, which consists of passing the entire dilute exhaust sample through the filters, dilution (paragraph 1.2.1.1., Figures 7 and 11) and sampling system usually form an integral unit. In the case of fractional sampling partial flow dilution or full flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution (paragraph 1.2.1.1, Figures 4, 5, 6, 8, 9, 10 and 12 and paragraph 1.2.1.2., Figure 13) and sampling systems usually form different units.

In this Regulation, the double dilution system DDS (Figure 15) of a full flow dilution system is considered as a specific modification of a typical particulate sampling system as shown in Figure 14. The double dilution system includes all important parts of the particulate sampling system, like filter holders and sampling pump, and additionally some dilution features, like a dilution air supply and a secondary dilution tunnel.

In order to avoid any impact on the control loops, it is recommended that the sample pump be running throughout the complete test procedure. For the single filter method, a bypass system shall be used for passing the sample through the sampling filters at the desired times. Interference of the switching procedure on the control loops shall be minimized.

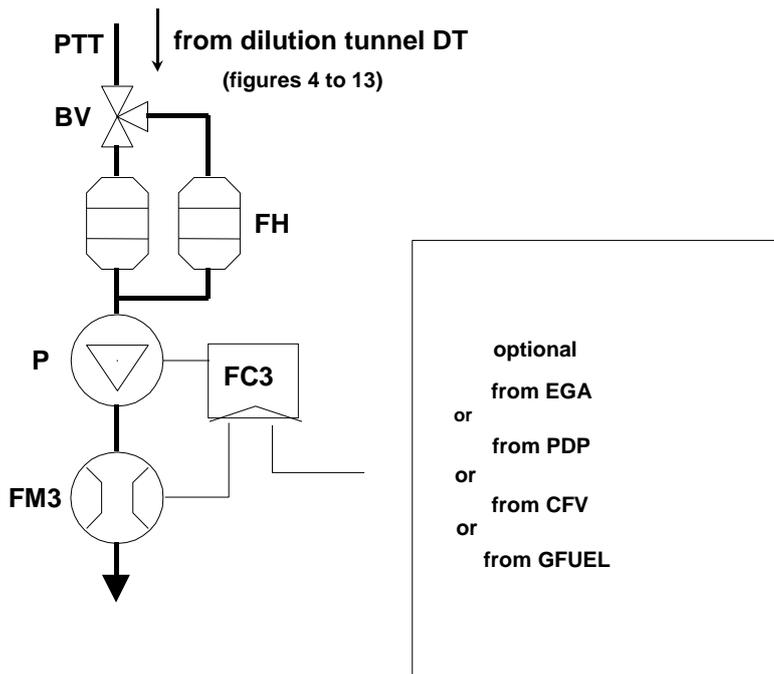
Descriptions – Figures 14 and 15

— PSP particulate sampling probe (Figures 14 and 15)

The particulate sampling probe shown in the figures is the leading section of the particulate transfer tube PTT. The probe:

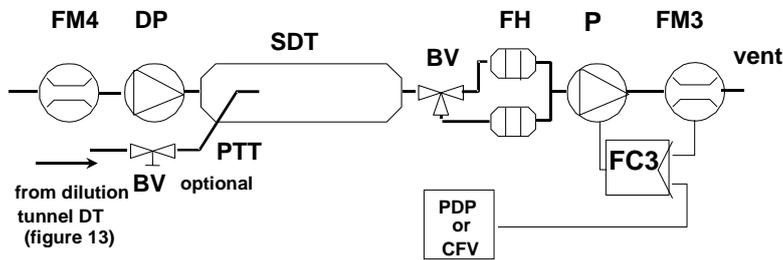
- Shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed, i.e. on the dilution tunnel DT centre-line of the dilution systems (paragraph 1.2.1.), approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel);
- Shall be 12 mm in minimum inside diameter;
- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

Figure 14  
**Particulate sampling system**



A sample of the diluted exhaust gas is taken from the dilution tunnel DT of a partial flow or full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the sampling pump P. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (Figure 13) is used, the diluted exhaust gas flow is used as command signal for FC3.

Figure 15  
**Dilution system (full flow system only)**



A sample of the diluted exhaust gas is transferred from the dilution tunnel DT of a full flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more. The sample is then passed through the filter holder(s) FH that contain the particulate sampling filters. The dilution air flow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (Figure 13) is used, the total diluted exhaust gas flow is used as command signal for FC3.

— PTT particulate transfer tube (Figures 14 and 15)

The particulate transfer tube shall not exceed 1020 mm in length, and shall be minimized in length whenever possible.

The dimensions are valid for:

- The partial flow dilution fractional sampling type and the full flow single dilution system from the probe tip to the filter holder;
- The partial flow dilution total sampling type from the end of the dilution tunnel to the filter holder;
- The full flow double dilution system from the probe tip to the secondary dilution tunnel.

The transfer tube:

- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

— SDT secondary dilution tunnel (Figure 15)

The secondary dilution tunnel should have a minimum diameter of 75 mm and should be sufficient length so as to provide a residence time of at least 0.25 s for the doubly-diluted sample. The primary filter holder, FH, shall be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel:

- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- May be insulated.

— FH filter holder(s) (Figures 14 and 15)

For primary and back-up filters one filter housing or separate filter housings may be used. The requirements of Annex 4A, Appendix 1, paragraph 1.5.1.3. have to be met.

The filter holder(s):

- May be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 325 K (52 °C);
- May be insulated.

— P sampling pump (Figures 14 and 15)

The particulate sampling pump shall be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant ( $\pm 3$  K), if flow correction by FC3 is not used.

— DP dilution air pump (Figure 15) (full flow double dilution only)

The dilution air pump shall be located so that the secondary dilution air is supplied at a temperature of 298 K (25 °C)  $\pm 5$  K.

— FC3 flow controller (Figures 14 and 15)

A flow controller shall be used to compensate the particulate sample flow rate for temperature and backpressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (Figure 13) is used.

— FM3 flow measurement device (Figures 14 and 15) (particulate sample flow)

The gas meter or flow instrumentation shall be located sufficiently distant from the sample pump so that the inlet gas temperature remains constant ( $\pm 3$  K), if flow correction by FC3 is not used.

— FM4 flow measurement device (Figure 15) (dilution air, full flow double dilution only)

The gas meter or flow instrumentation shall be located so that the inlet gas temperature remains at 298 K (25 °C)  $\pm 5$  K.

— BV ball valve (optional)

The ball valve shall have a diameter not less than the inside diameter of the sampling tube and a switching time of less than 0.5 s.

*Note:* If the ambient temperature in the vicinity of PSP, PTT, SDT, and FH is below 239 K (20 °C), precautions should be taken to avoid particle losses onto the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended. It is also recommended that the filter face temperature during sampling be not below 293 K (20 °C).

At high engine loads, the above parts may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 293 K (20 °C).

## Annex 4B

### Test procedure for compression-ignition 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

1. Reserved
2. Reserved
3. Definitions, symbols and abbreviations
  - 3.1. Definitions  
See paragraph 2.1. of this Regulation
  - 3.2. General symbols<sup>1</sup>

<i>Symbol</i>	<i>Unit</i>	<i>Term</i>
$a_0$	-	y intercept of the regression line
$a_1$	-	Slope of the regression line
$a_{sp}$	rad/s <sup>2</sup>	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 $\mu\text{mol/mol} = \text{ppm}$ )
$D$	-	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
$F$	-	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
$\lambda$	-	Excess air ratio

<sup>1</sup> Specific symbols are found in annexes.

<i>Symbol</i>	<i>Unit</i>	<i>Term</i>
$L$	-	Per cent torque
$M_a$	g/mol	Molar mass of the intake air
$M_e$	g/mol	Molar mass of the exhaust
$M_{\text{gas}}$	g/mol	Molar mass of gaseous components
$m$	kg	Mass
$m_{\text{gas}}$	g	Mass of gaseous emissions over the test cycle
$m_{\text{PM}}$	g	Mass of particulate emissions over the test cycle
$n$	min <sup>-1</sup>	Engine rotational speed
$n_{\text{hi}}$	min <sup>-1</sup>	High engine speed
$n_{\text{lo}}$	min <sup>-1</sup>	Low engine speed
$P$	kW	Power
$P_{\text{max}}$	kW	Maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer)
$P_{\text{AUX}}$	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
$q_{\text{maw}}$	kg/s	Intake air mass flow rate on wet basis
$q_{\text{mdw}}$	kg/s	Dilution air mass flow rate on wet basis
$q_{\text{mdew}}$	kg/s	Diluted exhaust gas mass flow rate on wet basis
$q_{\text{mew}}$	kg/s	Exhaust gas mass flow rate on wet basis
$q_{\text{mf}}$	kg/s	Fuel mass flow rate
$q_{\text{mp}}$	kg/s	Sample flow of exhaust gas into partial flow dilution system
$q_v$	m <sup>3</sup> /s	Volume flow rate
$RF$	-	Response factor
$r_d$	-	Dilution ratio
$r^2$	-	Coefficient of determination
$\rho$	kg/m <sup>3</sup>	Density
$\sigma$	-	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
$T_{\text{sp}}$	N·m	Demanded torque with "sp" set point
$u$	-	Ratio between densities of gas component and exhaust gas
$t$	s	Time
$\Delta t$	s	Time interval

<i>Symbol</i>	<i>Unit</i>	<i>Term</i>
$t_{10}$	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 <sup>3</sup>	Volume
$W$	kWh	Work
$y$		Generic variable
$\bar{y}$		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 paragraph 2.2.2. of this Regulation

- 3.5. Abbreviations

See paragraph 2.2.3. of this Regulation

4. General requirements

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

5. Performance requirements

- 5.1. General requirements

- 5.1.1. Reserved<sup>2</sup>

- 5.1.2. Emissions of gaseous and particulate pollutants

The pollutants are represented by:

- (a) Oxides of nitrogen, NO<sub>x</sub>;
- (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 paragraph 7. The measurement systems shall meet the calibration and performance checks of paragraph 8. with measurement equipment of paragraph 9.

Other systems or analysers may be approved by the Type Approval Authority if it is found that they yield equivalent results in accordance with paragraph 5.1.3.

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<sup>2</sup> The numbering of this annex is consistent with the numbering of the NRMM gtr 11. However, some sections of the NRMM gtr are not needed in 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 4B, 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 Type Approval Authority.

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:

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

Turbocharged engines with or without cooling of the intake air:

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

The temperature of intake air shall be maintained to  $(25 \pm 5)$  °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  $\pm 1$  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  $\pm 0.5$  °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  $\pm 5$  °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 authority. 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  $\pm 300$  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 paragraph 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 paragraph 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 paragraph 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 paragraph 7.8.2.1., the engine be soaked according to paragraph 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 paragraph 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  $\pm 25$  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 paragraph 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.

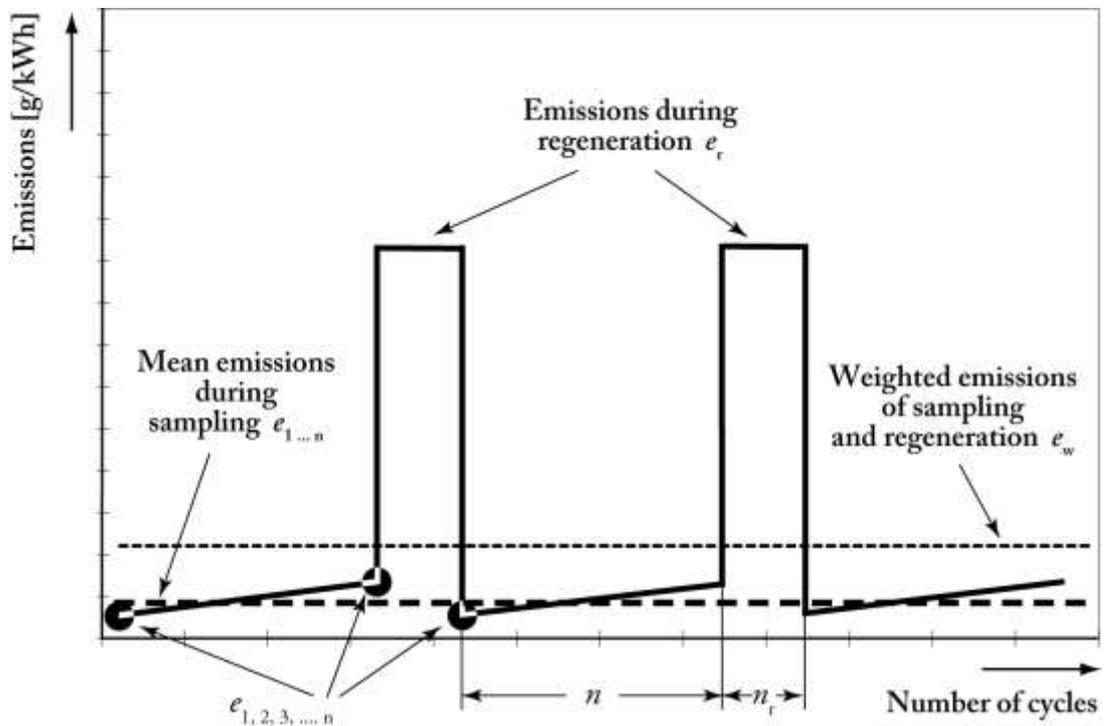
The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure, etc.). The manufacturer shall also provide the frequency of the regeneration event in terms of number of tests during which the regeneration occurs. The exact procedure to determine this frequency shall be agreed by the Type Approval Authority 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<sub>x</sub> 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  $\bar{e}_w$  [g/kWh] shall be weighted as follows (see Figure 6.1):

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

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

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

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

Additive

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

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

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 4B, 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 Type Approval Authority 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 authority may account for regeneration events differently than is provided in sub-paragraph (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-paragraph (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 reference fuel

The reference fuel is specified in Annex 6, Table 3.

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

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 paragraph, 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 paragraph 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 paragraph 5.2.

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 4B):

- (a) The laboratory configurations for measuring the brake specific emissions (paragraph 7.2.);
- (b) The pre-test and post-test verification procedures (paragraph 7.3.);
- (c) The test cycles (paragraph 7.4.);
- (d) The general test sequence (paragraph 7.5.);
- (e) The engine mapping (paragraph 7.6.);
- (f) The test cycle generation (paragraph 7.7.);
- (g) The specific test cycle running procedure (paragraph 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 paragraph 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<sub>x</sub> 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

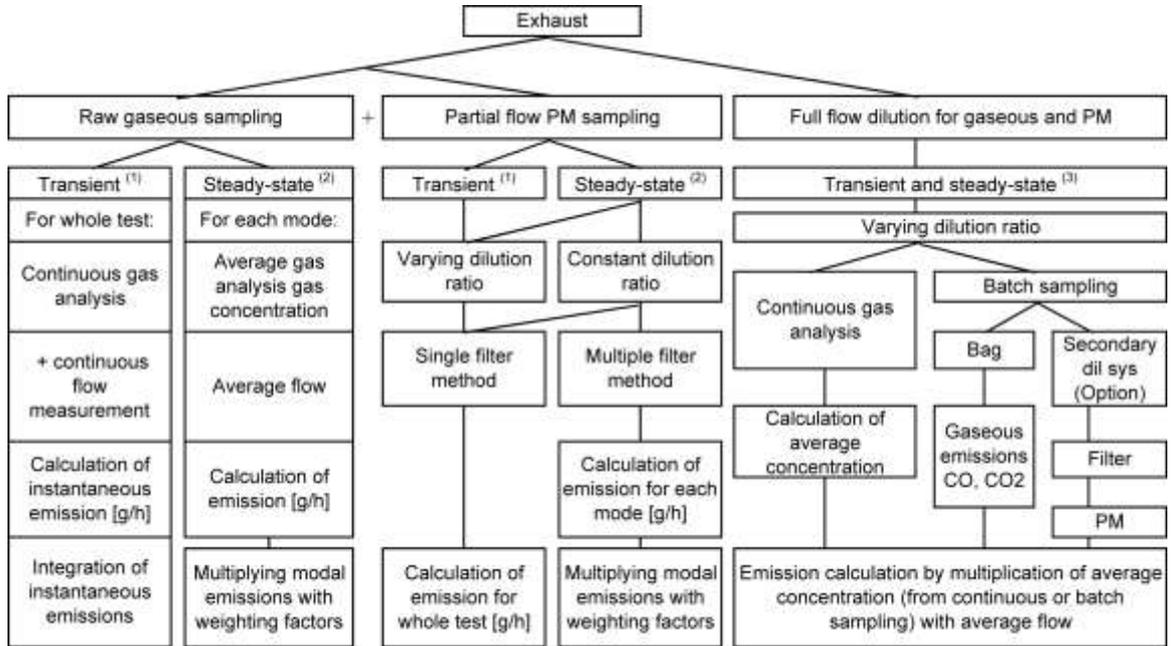
In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In principle 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).

Figure 7.1  
**Test procedures for emission measurement**



<sup>(1)</sup> Transient and Ramped Modal Test Cycle; <sup>(2)</sup> Discrete Mode Steady State Cycle; <sup>(3)</sup> 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.

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 paragraphs 7.3. and 7.4. The preconditioning for cooling down the engine in view of a cold start transient test is specially indicated in paragraph 7.4.2.

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 paragraph 8.1.8.7.;
- (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 paragraph 7.3.1.4.;
- (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 paragraph 9.5.1. 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 paragraph 8.2.3.

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 paragraph 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 paragraph 8.2.1. 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 paragraph 8.2.4. (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 paragraph 8.2.2.

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 paragraphs.

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 paragraph 7.8.2.1. 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  $20 \pm 1$  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 paragraph 7.7.2.).

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

The transient test cycle shall be run twice (see paragraph 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  $\pm$  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 4B Appendices A.7-A.8.

#### 7.5. General test sequence

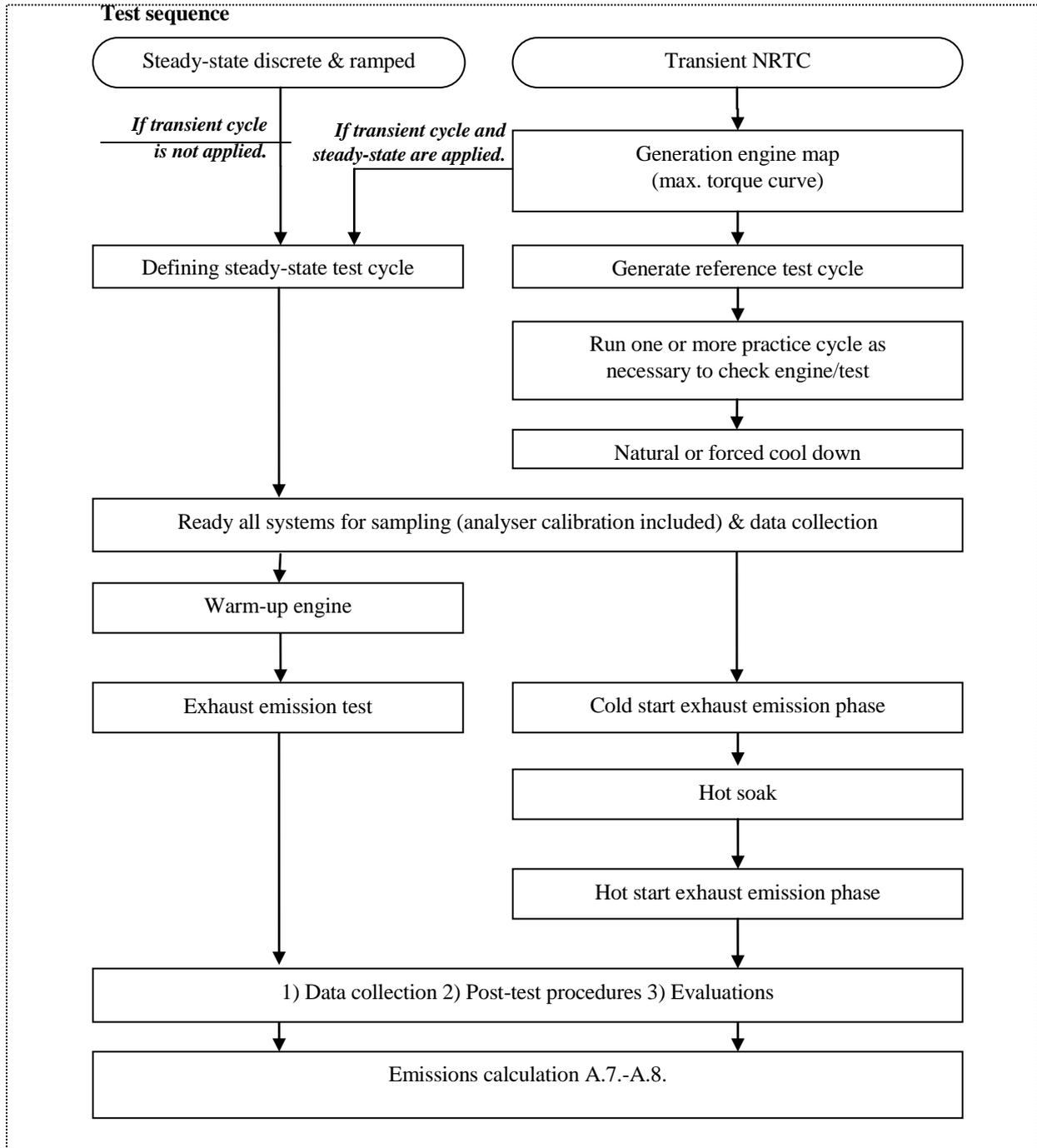
To measure engine emissions the following steps have to be performed:

- (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-paragraph (a) of paragraph 7.5.;
- (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- (paragraph 7.3.1.5.) and post-test (paragraph 7.3.2.2.) procedures;
- (i) Emission test results shall be evaluated.

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

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  $\pm 25$  per cent of its typical in-use cranking speed or start the engine by linearly increasing the dynamometer speed from zero to  $100 \text{ min}^{-1}$  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 paragraph 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 =  $n_{hi} \times 1.02$  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 setpoint, 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  $\pm 2.5$  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  $8 \pm 1 \text{ min}^{-1}/\text{s}$  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 paragraph for reasons of safety or representativeness shall be approved by the Type Approval Authority 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  $\pm 5$  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<sup>-1</sup>) 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

7.7.1.1. Rated speed

For engines that are tested with the steady state and also the transient schedule, the denormalization speed shall be calculated according to the transient procedure (paragraphs 7.6.2. and 7.7.2.1. and Figure 7.3.).

If the calculated denormalization speed ( $n_{denorm}$ ) is within  $\pm 2.5$  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. In case of the steady state cycle the calculated denormalization speed ( $n_{denorm}$ ) is tabled as rated speed.

For engines that are not tested with the transient schedule, the rated speed of tables in Annex 5 for the 8-mode discrete and the derived ramped mode cycle shall be calculated according to the procedure (paragraphs 7.6.1. and 7.7.2.1. and Figure 7.3.). The rated speed is defined in paragraph 3.1.53.

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 paragraph 3.1.32.).

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

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

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 paragraph 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 paragraph 7.6.1. or 7.6.2.). "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  $\pm 2.5$  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 paragraph 7.7.1.1.) 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<sup>3</sup> 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 paragraph 7.7.2.2.;
- (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 paragraph 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 Type Approval Authorities:

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

where:

- $n_{denorm}$  = denormalization speed
- $n_{hi}$  = high speed (see paragraph 3.1.30.)
- $n_{lo}$  = low speed (see paragraph 3.1.34.)

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

$$n_{denorm} = n_i \text{ at the maximum of } (n_{normi}^2 + P_{normi}^2) \quad (7-3)$$

where:

- $i$  = an indexing variable that represents one recorded value of an engine map
- $n_{normi}$  = an engine speed normalized by dividing it by  $n_{Pmax}$ .
- $P_{normi}$  = an engine power normalized by dividing it by  $P_{max}$ .

<sup>3</sup> For further understanding of the prime power definition, see figure 2 of ISO 8528-1:1993(E) standard.

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 type approval or certification authorities, 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  $\pm 3$  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:

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

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 paragraph 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 paragraph 7.6.2., as follows:

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

for the respective reference speed as determined in paragraph 7.7.2.2.

#### 7.7.2.4. Example of denormalization procedure

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

$$\%speed = 43 \text{ per cent}$$

$$\%torque = 82 \text{ per cent}$$

Given the following values:

$$n_{denorm} = 2200 \text{ min}^{-1}$$

$$n_{idle} = 600 \text{ min}^{-1}$$

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<sup>-1</sup>

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

- 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 paragraph 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 paragraph 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  $\pm 1$  per cent of rated speed or  $\pm 3 \text{ min}^{-1}$ , 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  $\pm 2$  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  $20 \pm 1 \text{ s}$  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  $20 \text{ s} \pm 1 \text{ s}$  following the tolerances prescribed in paragraph 7.8.2.4. (see Annex 5).

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 paragraph 7.4. shall be performed.

7.8.2.4. Validation criteria

RMC tests shall be validated using the regression analysis as described in paragraphs 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**

	<i>Speed</i>	<i>Torque</i>	<i>Power</i>
Standard error of estimate ( <i>SEE</i> ) 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, $a_0$	$\pm 1$ % of rated speed	$\pm 20$ Nm or 2 % of maximum torque, whichever is greater	$\pm 4$ 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 paragraph 7.8.1.3. For the 20 s linear speed and linear torque transitions between the RMC steady-state test modes (paragraph 7.4.1.2.) the following tolerances for speed and load shall be applied for the ramp, the speed shall be held linear within  $\pm 2$  per cent of rated speed. The torque shall be held linear within  $\pm 5$  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 paragraph 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 paragraph 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 paragraph 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 paragraph 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 4B 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:

$$y = a_1x + a_0 \quad (7-6)$$

where:

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

$a_1$  = slope of the regression line

$x$  = reference value of speed ( $\text{min}^{-1}$ ), 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 4B 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 of this paragraph shall be met.

Table 7.2  
**Regression line tolerances**

	<i>Speed</i>	<i>Torque</i>	<i>Power</i>
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 of this paragraph 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**

<i>Event</i>	<i>Conditions (n = engine speed, T = torque)</i>	<i>Permitted point deletions</i>
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 paragraph describes required calibrations and verifications of measurement systems. See paragraph 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 paragraph 8. and indicates when these have to be performed.

Table 8.1  
**Summary of Calibration and Verifications**

<i>Type of calibration or verification</i>	<i>Minimum frequency<sup>a</sup></i>
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.

<i>Type of calibration or verification</i>	<i>Minimum frequency<sup>a</sup></i>
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.
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 <sup>b</sup>	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 paragraph 7.1.
8.1.9.1.: CO <sub>2</sub> NDIR H <sub>2</sub> O interference	Upon initial installation and after major maintenance.
8.1.9.2.: CO NDIR CO <sub>2</sub> and H <sub>2</sub> O 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 <sub>4</sub> response: upon initial installation and after major maintenance.  Verify CH <sub>4</sub> response: upon initial installation, within 185 days before testing, and after major maintenance.
8.1.10.2.: Raw exhaust FID O <sub>2</sub> 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 <sub>2</sub> and H <sub>2</sub> O quench	Upon initial installation and after major maintenance.
8.1.11.3.: NDUV HC and H <sub>2</sub> O interference	Upon initial installation and after major maintenance.
8.1.11.4.: Cooling bath NO <sub>2</sub> penetration (chiller)	Upon initial installation and after major maintenance.
8.1.11.5.: NO <sub>2</sub> -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.

<sup>a</sup> Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

<sup>b</sup> The CVS verification is not required for systems that agree within  $\pm 2$  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 of this paragraph.
- 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 paragraph 9.5.1. 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 paragraph 9.5.1. 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-paragraph (b) of this paragraph. 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 paragraph 8.1.4.4. For gas analysers, gas concentrations known to be within the specifications of paragraph 9.5.1. 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,  $\bar{y}_i$  recorded;
- (j) Steps in sub-paragraphs (g) through (i) of this paragraph shall be repeated until all reference quantities are measured;
- (k) The arithmetic means  $\bar{y}_i$ , 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 4B Appendix A.2 paragraph A.2. shall be used.

#### 8.1.4.4. Reference signals

This paragraph describes recommended methods for generating reference values for the linearity-verification protocol in paragraph 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  $\pm 2$  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			
			$ x_{\min} \cdot (a_1 - 1) + a_0 $	$a$	SEE	$r^2$
Engine speed	$n$	Within 370 days before testing	$\leq 0.05 \% n_{\max}$	0.98-1.02	$\leq 2 \% n_{\max}$	$\geq 0.990$
Engine torque	$T$	Within 370 days before testing	$\leq 1 \% T_{\max}$	0.98-1.02	$\leq 2 \% T_{\max}$	$\geq 0.990$
Fuel flow rate	$q^m$	Within 370 days before testing	$\leq 1 \% q_{m, \max}$	0.98-1.02	$\leq 2 \% q_{m, \max}$	$\geq 0.990$
Intake-air flow rate	$q^v$	Within 370 days before testing	$\leq 1 \% q_{v, \max}$	0.98-1.02	$\leq 2 \% q_{v, \max}$	$\geq 0.990$
Dilution air flow rate	$q^v$	Within 370 days before testing	$\leq 1 \% q_{v, \max}$	0.98-1.02	$\leq 2 \% q_{v, \max}$	$\geq 0.990$
Diluted exhaust flow rate	$q^v$	Within 370 days before testing	$\leq 1 \% q_{v, \max}$	0.98-1.02	$\leq 2 \% q_{v, \max}$	$\geq 0.990$
Raw exhaust flow rate	$q^v$	Within 185 days before testing	$\leq 1 \% q_{v, \max}$	0.98-1.02	$\leq 2 \% q_{v, \max}$	$\geq 0.990$
Batch sampler flow rates	$q^v$	Within 370 days before testing	$\leq 1 \% q_{v, \max}$	0.98-1.02	$\leq 2 \% q_{v, \max}$	$\geq 0.990$
Gas dividers	$x/x_{\text{span}}$	Within 370 days before testing	$\leq 0.5 \% x_{\max}$	0.98-1.02	$\leq 2 \% x_{\max}$	$\geq 0.990$
Gas analysers	$x$	Within 35 days before testing	$\leq 0.5 \% x_{\max}$	0.99-1.01	$\leq 1 \% x_{\max}$	$\geq 0.998$
PM balance	$m$	Within 370 days before testing	$\leq 1 \% m_{\max}$	0.99-1.01	$\leq 1 \% m_{\max}$	$\geq 0.998$
Stand-alone pressures	$p$	Within 370 days before testing	$\leq 1 \% p_{\max}$	0.99-1.01	$\leq 1 \% p_{\max}$	$\geq 0.998$
Analog-to-digital conversion of stand-alone temperature signals	$T$	Within 370 days before testing	$\leq 1 \% T_{\max}$	0.99-1.01	$\leq 1 \% T_{\max}$	$\geq 0.998$

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 paragraph 8.1.6. 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  $\leq 10$  s with a rise time of  $\leq 2.5$  s or with a rise and fall time of  $\leq 5$  s each for all measured components (CO, NO<sub>x</sub>, CO<sub>2</sub> 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 Annexes 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<sub>2</sub> with span gases diluted in air;

Using a gas divider, an NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub> (balance N<sub>2</sub>) span gas shall be equally blended with a span gas of NO<sub>2</sub>, balance purified synthetic air. Standard binary span gases may be also be used, where applicable, in place of blended NO-CO-CO<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>-CH<sub>4</sub>, balance N<sub>2</sub> 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-paragraphs (c) (iv) through (vii) of this paragraph 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-paragraph (c) of paragraph 8.1.5.4. of this section 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-paragraphs (b) (i) of paragraph 8.1.5.3. of this section, 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 chosen to demonstrate compliance with sub-paragraphs (b) (ii) of paragraph 8.1.5.3. of this section, the demonstration of compliance with the requirements of sub-paragraphs (b) (ii) of paragraph 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<sub>4</sub> quoted in Annexes 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, paragraph 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-paragraph (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-paragraphs (b) (i) of paragraph 8.1.5.3.

8.1.6.4. Procedure

All procedures given in sub-paragraphs (a) - (c) of paragraph 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<sub>2</sub>) 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 °C 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 paragraph 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 paragraph 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  $\pm 1$  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 paragraph 8.1.8.4. refers to the molar based approach. For the corresponding sequence used in the mass based approach, see Annex 8 Appendix 1.

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  $\pm 2$  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,  $\bar{q}_{Vref}$  ;

- (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-paragraphs (f) and (g) of paragraph 8.1.8.4.2. 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 Annexes A.7-A.8;
- (j) The steps in sub-paragraphs (f) through (i) of this section shall be repeated for each speed at which the PDP is operated;
- (k) The equations in Annex 4B 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 paragraph 8.1.8.5.;
- (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  $\pm 2$  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,  $T_{\text{dew}}$ . See Annexes A.7-A.8 for permissible assumptions during emission measurements;
  - (iii) The mean temperature at the venturi inlet,  $T_{\text{in}}$ ;
  - (iv) The mean static absolute pressure at the venturi inlet,  $p_{\text{in}}$ ;
  - (v) The mean static differential pressure between the CFV inlet and the CFV outlet,  $\Delta p_{\text{CFV}}$ ;
- (g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the CFV,  $p_{\text{in}}$ ;
  - (h) The steps in sub-paragraphs (f) and (g) of this paragraph shall be repeated to record mean data at a minimum of ten restrictor positions, such that the fullest practical range of  $\Delta p_{\text{CFV}}$  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 paragraph 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 paragraph and Annexes A.7-A.8. See Annexes A.7-A.8 for instructions on calculating flow rates for this option;
    - (ii) Each CFV shall be calibrated according to this paragraph and Annexes A.7-A.8. See Annexes A.7-A.8 for instructions on calculating flow rates for this option.

#### 8.1.8.4.4. SSV calibration

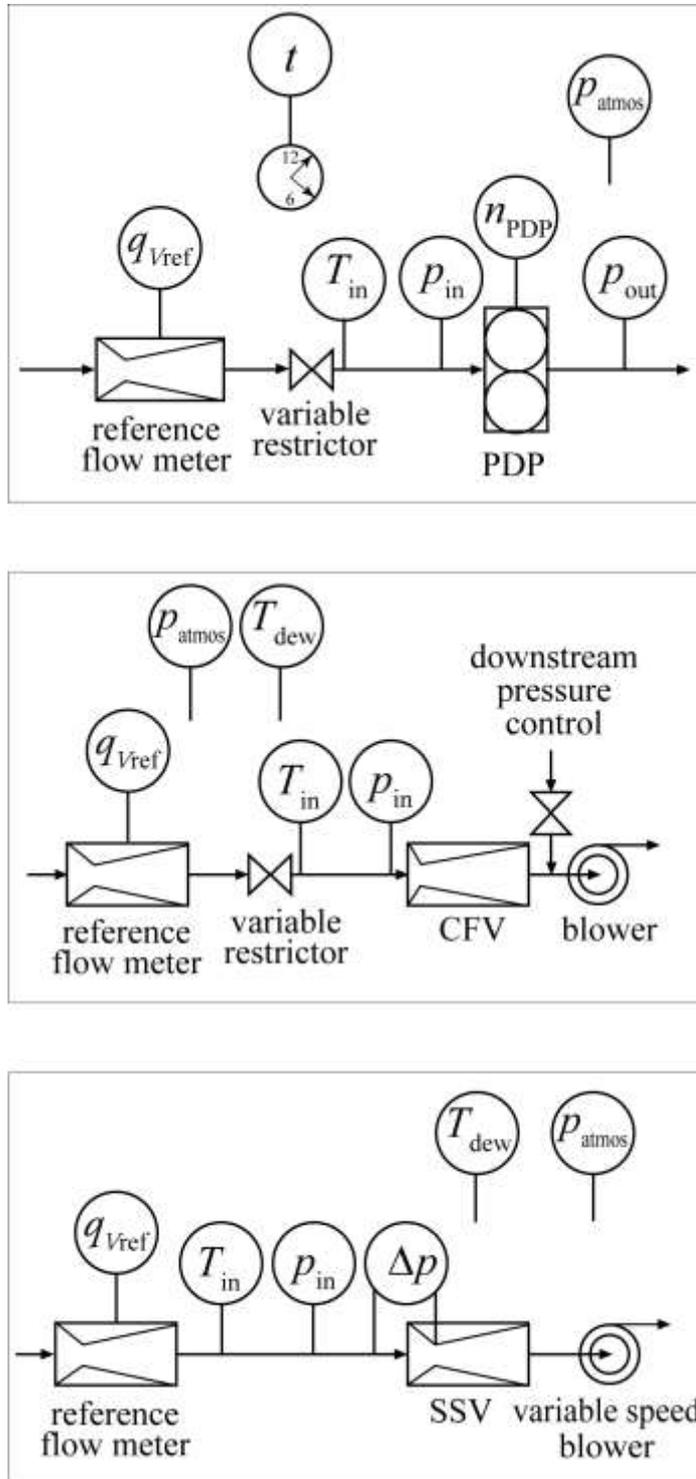
A subsonic venturi (SSV) shall be calibrated to determine its calibration coefficient,  $C_d$ , for the expected range of inlet pressures. An SSV flow-meter shall be calibrated as follows:

- (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  $\pm 2$  per cent of the mean absolute inlet temperature,  $T_{\text{in}}$ ;

- (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,  $\bar{q}_{Vref}$  ;
  - (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,  $\Delta p_{SSV}$ ;
- (g) The restrictor valve shall be incrementally closed or the blower speed decreased to decrease the flow rate;
- (h) The steps in sub-paragraphs (f) and (g) of this paragraph 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 paragraph 8.1.8.5. 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 4B Appendix A.7 (molar based approach) or Annex 4B 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-paragraph (f) of this paragraph. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO<sub>2</sub> 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 paragraph 8.1.8.7.;
- (iii) The verification for poor mixing shall be performed in accordance with paragraph 9.2.2.;
- (iv) The hydrocarbon contamination verification in the sample system shall be performed as described in paragraph 7.3.1.2.;
- (v) Change in CVS calibration. An in-situ calibration of the CVS flow-meter shall be performed as described in paragraph 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<sub>3</sub>H<sub>8</sub> as a tracer gas in a CVS. If a reference flow rate is used, any non-ideal gas behaviour of C<sub>3</sub>H<sub>8</sub> in the reference flow-meter shall be accounted for. See Annexes 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 paragraph 8.1.8.5. and Annexes A.7 or A.8. The propane check compares the calculated mass of injected C<sub>3</sub>H<sub>8</sub> 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  $\pm 0.5$  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-paragraph (g) of this paragraph. If this procedure is used, the HC contamination procedure in paragraph 7.3.1.2. may be used. If the vacuum side leak check is not performed according to sub-paragraph (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  $\mu\text{mol/mol}$ , 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  $\mu\text{mol/mol}$ , this value shall be recorded as  $x_{\text{HCmit}}$  and it shall be used to correct for HC contamination as described in Annex 4B Appendix A.7 (molar based approach) or Annex 4B 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)  $\text{C}_3\text{H}_8$  shall be released at the rate selected. If a reference flow rate of  $\text{C}_3\text{H}_8$  is used, the integration of this flow rate shall be started;
  - (vii)  $\text{C}_3\text{H}_8$  shall be continued to be released until at least enough  $\text{C}_3\text{H}_8$  has been released to ensure accurate quantification of the reference  $\text{C}_3\text{H}_8$  and the measured  $\text{C}_3\text{H}_8$ ;
  - (viii) The  $\text{C}_3\text{H}_8$  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 sub-paragraph (a) paragraph 8.1.8.5.5.;
- (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<sub>3</sub>H<sub>8</sub> 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<sub>3</sub>H<sub>8</sub> has been released to ensure accurate quantification of the reference C<sub>3</sub>H<sub>8</sub> and the measured C<sub>3</sub>H<sub>8</sub>;
- (viii) Any integrators shall be stopped;
- (ix) The C<sub>3</sub>H<sub>8</sub> 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<sub>3</sub>H<sub>8</sub> mass based on the CVS and HC data shall be calculated as described in Annexes A.7-A.8, using the molar mass of C<sub>3</sub>H<sub>8</sub>,  $M_{C_3H_8}$ , 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  $\pm 0.5$  per cent and the C<sub>3</sub>H<sub>8</sub> 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<sub>3</sub>H<sub>8</sub> mass shall be subtracted from the calculated mass. If this difference is within  $\pm 3.0$  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-paragraphs (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 paragraph, 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  $\pm 5$  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 paragraph 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 paragraph 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 °C 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-paragraphs (d) (vi) of this paragraph is less than the dew point

corresponding to the sample dryer specifications as determined in paragraph 9.3.2.3.1. plus 2 °C or if the mol fraction from subparagraphs (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:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (8-1)$$

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  $\pm 5$  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  $\pm 0.2$  per cent which guarantees an accuracy of  $q_{mp}$  of  $\leq 5$  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 paragraph 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<sub>2</sub>. Accuracies equivalent to method (a) for  $q_{mp}$  are required;
- (d) The absolute accuracy of  $q_{mdew}$  and  $q_{mdw}$  is within  $\pm 2$  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  $\pm 0.2$  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 paragraph 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<sub>2</sub> or NO<sub>x</sub>. 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  $r_d$ :

$$q_{mp} = q_{mdew} / r_d \quad (8-2)$$

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<sub>2</sub>. 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 4B Appendix A.4 shall be applied. The carbon flow rates shall be calculated according to equations of Annex 4B 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 paragraph 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 paragraph 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 3.1, 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 paragraph 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 paragraph 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 paragraph 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 Annexes 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 overflowed 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  $\pm 0.5$  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  $\pm 10$  per cent of its true volume.

For this test measurement instruments that meet the specifications of paragraphs 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:

$$q_{V\text{leak}} = \frac{V_{\text{vac}}}{R} \frac{\left( \frac{p_2}{T_2} - \frac{p_1}{T_1} \right)}{(t_2 - t_1)} \quad (8-3)$$

where:

- $q_{V\text{leak}}$  = vacuum-decay leak rate [mol/s]
- $V_{\text{vac}}$  = geometric volume of the vacuum-side of the sampling system [m<sup>3</sup>]
- $R$  = 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<sub>2</sub> measurements
- 8.1.9.1. H<sub>2</sub>O interference verification for CO<sub>2</sub> NDIR analysers
- 8.1.9.1.1. Scope and frequency  
If CO<sub>2</sub> is measured using an NDIR analyser, the amount of H<sub>2</sub>O interference shall be verified after initial analyser installation and after major maintenance.
- 8.1.9.1.2. Measurement principles  
H<sub>2</sub>O can interfere with an NDIR analyser's response to CO<sub>2</sub>. 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<sub>2</sub> NDIR analyser shall have an H<sub>2</sub>O interference that is within  $(0.0 \pm 0.4)$  mmol/mol (of the expected mean CO<sub>2</sub> concentration).
- 8.1.9.1.4. Procedure  
The interference verification shall be performed as follows:
- (a) The CO<sub>2</sub> 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 paragraph 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<sub>2</sub>O 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<sub>2</sub>O level at least as high as the level determined in paragraph 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,  $x_{\text{H}_2\text{O}}$ , of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point,  $T_{\text{dew}}$ , and absolute pressure  $p_{\text{total}}$ , shall be measured to calculate  $x_{\text{H}_2\text{O}}$ ;
  - (f) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}}$  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  $(0.0 \pm 0.4)$  mmol/mol

- 8.1.9.2. H<sub>2</sub>O and CO<sub>2</sub> 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<sub>2</sub>O and CO<sub>2</sub> interference shall be verified after initial analyser installation and after major maintenance.
- 8.1.9.2.2. Measurement principles
- H<sub>2</sub>O and CO<sub>2</sub> 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<sub>2</sub>O and CO<sub>2</sub> interference that is within  $\pm 2$  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<sub>2</sub> test gas shall be created by bubbling a CO<sub>2</sub> 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<sub>2</sub>O 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<sub>2</sub>O level at least as high as the level determined in paragraph 8.1.8.5.8. A CO<sub>2</sub> span gas concentration shall be used at least as high as the maximum expected during testing;
  - (c) The humidified CO<sub>2</sub> test gas shall be introduced into the sampling system. The humidified CO<sub>2</sub> test gas may be introduced downstream of any sample dryer, if one is used during testing;
  - (d) The water mole fraction,  $x_{\text{H}_2\text{O}}$ , of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point,  $T_{\text{dew}}$ , and absolute pressure  $p_{\text{total}}$ , shall be measured to calculate  $x_{\text{H}_2\text{O}}$ ;
  - (e) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{O}}$  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 subparagraph (g) of this section meets the tolerance in paragraph 8.1.9.2.3.;

- (i) Interference procedures for CO<sub>2</sub> and H<sub>2</sub>O may be also run separately. If the CO<sub>2</sub> and H<sub>2</sub>O 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<sub>2</sub>O (down to 0.025 mol/mol H<sub>2</sub>O content) that are lower than the maximum levels expected during testing may be run, but the observed H<sub>2</sub>O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H<sub>2</sub>O concentration value to the actual value used during this procedure. The sum of the two scaled interference values shall meet the tolerance in paragraph 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<sub>4</sub>) response factor shall be determined after initial analyser installation and after major maintenance as described in paragraph 8.1.10.1.4. of this section;
- (c) Methane (CH<sub>4</sub>) 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<sub>3</sub>H<sub>8</sub> calibration gases that meet the specifications of paragraph 9.5.1. For a FID that measures CH<sub>4</sub>, it shall be calibrated using CH<sub>4</sub> calibration gases that meet the specifications of paragraph 9.5.1. Regardless of the calibration gas composition, it shall be calibrated on a carbon number basis of one (C<sub>1</sub>).

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-paragraph (a) of paragraph 8.1.10.1.1. and paragraph 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-paragraph (a) of paragraph 8.1.10.1.1. and paragraph 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-paragraph (a) of paragraph 8.1.10.1.1. and paragraph 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<sub>4</sub> response factor determination

This procedure is only for FID analysers that measure HC. Since FID analysers generally have a different response to CH<sub>4</sub> versus C<sub>3</sub>H<sub>8</sub>, each THC FID analyser's CH<sub>4</sub> response factor,  $RF_{CH_4[THC-FID]}$  shall be determined, after FID optimization. The most recent  $RF_{CH_4[THC-FID]}$  measured according to this paragraph shall be used in the calculations for HC determination described in Annex 4B Appendix A.7 (molar based approach) or Annex 4B Appendix A.8 (mass based approach) to compensate for CH<sub>4</sub> response.  $RF_{CH_4[THC-FID]}$  shall be determined as follows, noting that  $RF_{CH_4[THC-FID]}$  is not determined for FIDs that are calibrated and spanned using CH<sub>4</sub> with a non-methane cutter:

- (a) A C<sub>3</sub>H<sub>8</sub> span gas concentration shall be selected to span the analyser before emission testing. Only span gases that meet the specifications of paragraph 9.5.1. shall be selected and the C<sub>3</sub>H<sub>8</sub> concentration of the gas shall be recorded;

- (b) A CH<sub>4</sub> span gas that meets the specifications of paragraph 9.5.1. shall be selected and the CH<sub>4</sub> 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<sub>3</sub>H<sub>8</sub>. Calibration shall be performed on a carbon number basis of one (C<sub>1</sub>);
- (e) The FID shall be zeroed with a zero gas used for emission testing;
- (f) The FID shall be spanned with the selected C<sub>3</sub>H<sub>8</sub> span gas;
- (g) The selected CH<sub>4</sub> span gas shall be introduced at the sample port of the FID analyser, the CH<sub>4</sub> span gas that has been selected under sub-paragraph (b) of this paragraph;
- (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<sub>4</sub> 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<sub>4</sub> calibration gas. The result is the FID analyser's response factor for CH<sub>4</sub>,  $RF_{CH_4[THC-FID]}$ .

8.1.10.1.5. HC FID methane (CH<sub>4</sub>) response verification

This procedure is only for FID analysers that measure HC. If the value of  $RF_{CH_4[THC-FID]}$  from paragraph 8.1.10.1.4. is within  $\pm 5.0$  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  $\pm 0.5$  per cent of their most recent previously recorded values, as described in paragraph 8.1.10.1.3. of this section. If these flow rates have to be adjusted, a new  $RF_{CH_4[THC-FID]}$  shall be determined as described in paragraph 8.1.10.1.4. of this section. It should be verified that the value of  $RF_{CH_4[THC-FID]}$  determined is within the tolerance specified in this paragraph 8.1.10.1.5.;
- (b) If  $RF_{CH_4[THC-FID]}$  is not within the tolerance specified in this paragraph 8.1.10.1.5., the FID response shall be re-optimized as described in paragraph 8.1.10.1.3. of this section;
- (c) A new  $RF_{CH_4[THC-FID]}$  shall be determined as described in paragraph 8.1.10.1.4. of this section. This new value of  $RF_{CH_4[THC-FID]}$  shall be used in the calculations for HC determination, as described in Annex 4B, Appendix A.7 (molar based approach) or Annex 4B, Appendix A.8 (mass based approach).

8.1.10.2. Non-stoichiometric raw exhaust FID O<sub>2</sub> interference verification

8.1.10.2.1. Scope and frequency

If FID analysers are used for raw exhaust measurements, the amount of FID O<sub>2</sub> interference shall be verified upon initial installation and after major maintenance.

8.1.10.2.2. Measurement principles

Changes in O<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> interference verification according to the procedure in this section.

8.1.10.2.4. Procedure

FID O<sub>2</sub> 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 paragraph 9.5.1. and contain C<sub>3</sub>H<sub>8</sub> concentration used to span the analysers before emissions testing. Only span gases that meet the specifications in paragraph 9.5.1. CH<sub>4</sub> span reference gases may be used for FIDs calibrated on CH<sub>4</sub> with a non-methane cutter. The three balance gas concentrations shall be selected such that the concentrations of O<sub>2</sub> and N<sub>2</sub> represent the minimum and maximum and intermediate O<sub>2</sub> concentrations expected during testing. The requirement for using the average O<sub>2</sub> 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 paragraph 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-paragraph (e) of this paragraph, otherwise the procedure shall be restarted at sub-paragraph (d) of this paragraph;
- (g) The analyser response shall be checked using the span gas that has the minimum concentration of O<sub>2</sub> expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as  $x_{O_2\min HC}$ ;
- (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-paragraph (e) of this paragraph, otherwise the procedure shall be restarted at sub-paragraph (d) of this paragraph;

- (i) The analyser response shall be checked using the span gas that has the average concentration of O<sub>2</sub> expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as  $x_{O_2\text{avgHC}}$ ;
- (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  $\pm 0.5$  per cent of the span reference value used in paragraph (e) of this paragraph, otherwise the procedure shall be restarted at paragraph (d) of this paragraph;
- (k) The analyser response shall be checked using the span gas that has the maximum concentration of O<sub>2</sub> expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as  $x_{O_2\text{maxHC}}$ ;
- (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  $\pm 0.5$  per cent of the span reference value used in paragraph (e) of this paragraph, otherwise the procedure at paragraph (d) of this paragraph shall be restarted;
- (m) The percent difference between  $x_{O_2\text{maxHC}}$  and its reference gas concentration shall be calculated. The percent difference between  $x_{O_2\text{avgHC}}$  and its reference gas concentration shall be calculated. The percent difference between  $x_{O_2\text{minHC}}$  and its reference gas concentration shall be calculated. The maximum percent difference of the three shall be determined. This is the O<sub>2</sub> interference;
- (n) If the O<sub>2</sub> interference is within  $\pm 3$  per cent, the FID passes the O<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> interference verification, the  $RF_{\text{CH}_4}$  shall be reset for the next  $RF_{\text{CH}_4}$  verification. The O<sub>2</sub> interference verification shall be repeated after adjustment and  $RF_{\text{CH}_4}$  shall be determined;
  - (iv) The FID shall be repaired or replaced and the O<sub>2</sub> 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<sub>4</sub>), the non-methane cutter's conversion efficiencies of methane,  $E_{\text{CH}_4}$ , and ethane,  $E_{\text{C}_2\text{H}_6}$  shall be determined. As detailed in this paragraph, 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  $E_{\text{CH}_4}$  [-] of 0 (that is, a methane penetration fraction,  $PF_{\text{CH}_4}$ , of 1.000), and the conversion efficiency for all other hydrocarbons would be 1.000, as represented by an ethane conversion efficiency  $E_{\text{C}_2\text{H}_6}$  [-] of 1 (that is, an ethane penetration fraction  $PF_{\text{C}_2\text{H}_6}$  [-] of 0). The emission calculations in Annex 4B, Appendix A.7 or Annex 4B, Appendix A.8 use this paragraph's measured values of conversion efficiencies  $E_{\text{CH}_4}$  and  $E_{\text{C}_2\text{H}_6}$  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  $E_{\text{CH}_4} < 0.15$  and a  $E_{\text{C}_2\text{H}_6} > 0.98$  ( $PF_{\text{CH}_4} > 0.85$  and  $PF_{\text{C}_2\text{H}_6} < 0.02$ ) as determined by paragraph 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 Annexes A.7-A.8 as applicable.

8.1.10.3.4. Procedure

Any one of the procedures specified in paragraphs 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  $\text{CH}_4$  with the NMC, then the FID shall be spanned with the NMC using a  $\text{CH}_4$  span gas, the product of that FID's  $\text{CH}_4$  response factor and  $\text{CH}_4$  penetration fraction,  $RFPF_{\text{CH}_4[\text{NMC-FID}]}$ , shall be set equal to 1.0 (i.e. efficiency  $E_{\text{CH}_4}$  [-] is set to 0) for all emission calculations, and the combined ethane ( $\text{C}_2\text{H}_6$ ) response factor and penetration fraction,  $RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  (and efficiency  $E_{\text{C}_2\text{H}_6}$  [-]) shall be determined as follows:

- (a) Both a  $\text{CH}_4$  gas mixture and a  $\text{C}_2\text{H}_6$  analytical gas mixture shall be selected meeting the specifications of paragraph 9.5.1. Both a  $\text{CH}_4$  concentration for spanning the FID during emission testing and a  $\text{C}_2\text{H}_6$  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 paragraph 8.1.10.1.;

- (d) The FID analyser shall be operated according to the manufacturer's instructions;
- (e) CH<sub>4</sub> span gas shall be used to span the FID with the cutter. The FID shall be spanned on a C<sub>1</sub> basis. For example, if the span gas has a CH<sub>4</sub> 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<sub>4</sub> molecule;
- (f) The C<sub>2</sub>H<sub>6</sub> 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<sub>2</sub>H<sub>6</sub>, converted to a C<sub>1</sub> basis. The result is the C<sub>2</sub>H<sub>6</sub> combined response factor and penetration fraction,  $RFPF_{C_2H_6[NMC-FID]}$ , equivalent to  $(1 - E_{C_2H_6} [-])$ . This combined response factor and penetration fraction and the product of the CH<sub>4</sub> response factor and CH<sub>4</sub> penetration fraction,  $RFPF_{CH_4[NMC-FID]}$ , which is set equal to 1.0, in emission calculations shall be used according to 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<sub>3</sub>H<sub>8</sub>, by bypassing the NMC, penetrations fractions  $PF_{C_2H_6[NMC-FID]}$  and  $PF_{CH_4[NMC-FID]}$  shall be determined as follows:

- (a) A CH<sub>4</sub> gas mixture and a C<sub>2</sub>H<sub>6</sub> analytical gas mixture shall be selected meeting the specifications of paragraph 9.5.1. with the CH<sub>4</sub> concentration typical of its peak concentration expected at the hydrocarbon standard and the C<sub>2</sub>H<sub>6</sub> 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 paragraph 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<sub>3</sub>H<sub>8</sub> span gas to span the FID. The FID shall be spanned on a C<sub>1</sub> basis;
- (f) The C<sub>2</sub>H<sub>6</sub> 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-paragraphs (g) through (h) of this paragraph 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,  $PF_{C_2H_6[NMC-FID]}$ , that is equivalent to  $(1 - E_{C_2H_6} [-])$ . This penetration fraction shall be used according to A.7 or A.8, as applicable;
- (k) The steps in sub-paragraphs (f) through (j) of this paragraph 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,  $PF_{CH_4[NMC-FID]}$  (equivalent to  $(1 - E_{CH_4} [-])$ ). This penetration fraction shall be used according to Annexes 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,  $RFPF_{C_2H_6[NMC-FID]}$ , as well as its  $CH_4$  penetration fraction,  $PF_{CH_4[NMC-FID]}$ , as follows:

- (a)  $CH_4$  and  $C_2H_6$  analytical gas mixtures shall be selected that meet the specifications of paragraph 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 paragraph 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  $\mu\text{mol/mol}$ , the correct FID response to that span gas is 100  $\mu\text{mol/mol}$  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<sub>2</sub>H<sub>6</sub> analytical gas mixture shall be introduced to the bypass, and the steps in sub-paragraphs (g) and (h) of this paragraph shall be repeated;
- (j) The mean C<sub>2</sub>H<sub>6</sub> 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<sub>2</sub>H<sub>6</sub> combined response factor and penetration fraction,  $RFPF_{C_2H_6[NMC-FID]}$ . This combined response factor and penetration fraction shall be used according to Annexes A.7 and A.8, as applicable;
- (k) The steps in sub-paragraphs (f) through (j) of this paragraph shall be repeated, but with the CH<sub>4</sub> analytical gas mixture instead of C<sub>2</sub>H<sub>6</sub>. The result will be the CH<sub>4</sub> penetration fraction,  $PF_{CH_4[NMC-FID]}$ . This penetration fraction shall be used according to Annexes A.7 and A.8, as applicable.

8.1.11. NO<sub>x</sub> measurements

8.1.11.1. CLD CO<sub>2</sub> and H<sub>2</sub>O quench verification

8.1.11.1.1. Scope and frequency

If a CLD analyser is used to measure NO<sub>x</sub>, the amount of H<sub>2</sub>O and CO<sub>2</sub> quench shall be verified after installing the CLD analyser and after major maintenance.

8.1.11.1.2. Measurement principles

H<sub>2</sub>O and CO<sub>2</sub> can negatively interfere with a CLD's NO<sub>x</sub> response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO<sub>x</sub>. This procedure and the calculations in paragraph 8.1.11.2.3. determine quench and scale the quench results to the maximum mole fraction of H<sub>2</sub>O and the maximum CO<sub>2</sub> concentration expected during emission testing. If the CLD analyser uses quench compensation algorithms that utilize H<sub>2</sub>O and/or CO<sub>2</sub> 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<sub>2</sub>O and CO<sub>2</sub> quench of ±2 per cent. For raw measurement a CLD analyser shall not exceed a combined H<sub>2</sub>O and CO<sub>2</sub> quench of ±2 per cent. Combined quench is the sum of the CO<sub>2</sub> quench determined as described in paragraph 8.1.11.1.4. and the H<sub>2</sub>O quench as determined in paragraph 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<sub>2</sub> quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine CO<sub>2</sub> quench by using a gas divider that

blends binary span gases with zero gas as the diluent and meets the specifications in paragraph 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<sub>x</sub>, the CLD analyser shall be operated in the NO-only operating mode;
- (d) A CO<sub>2</sub> span gas that meets the specifications of paragraph 9.5.1. and a concentration that is approximately twice the maximum CO<sub>2</sub> concentration expected during emission testing shall be used;
- (e) An NO span gas that meets the specifications of paragraph 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 paragraph (e) of this paragraph 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-paragraph (b) of this paragraph; 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<sub>2</sub> 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<sub>2</sub> through the gas divider, the output of the gas divider shall be stabilized. The CO<sub>2</sub> concentration from the gas divider output shall be determined, applying gas property correction as necessary to ensure accurate gas division. This concentration,  $x_{\text{CO}_2\text{act}}$ , shall be recorded and it shall be used in the quench verification calculations in paragraph 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<sub>2</sub> 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<sub>2</sub> span gas from sub-paragraph (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<sub>2</sub> 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,  $x_{\text{NOmeas}}$ ,  $x_{\text{NOmeas}}$  shall be recorded and it shall be used in the quench verification calculations in paragraph 8.1.11.2.3.;
- (k) The actual NO concentration shall be calculated at the gas divider's outlet,  $x_{\text{NOact}}$ , based on the span gas concentrations and  $x_{\text{CO2act}}$  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 paragraphs 8.1.11.1.4. and 8.1.11.1.5. of this section shall be used to calculate quench as described in paragraph 8.1.11.2.3.

8.1.11.1.5. H<sub>2</sub>O quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine H<sub>2</sub>O 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<sub>x</sub>, 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 paragraph 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 paragraph (c) of this paragraph, the span gas concentration shall be recorded as  $x_{\text{NOdry}}$ , and it shall be used in the quench verification calculations in paragraph 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<sub>2</sub>O level approximately equal to the maximum mole fraction of H<sub>2</sub>O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in paragraph 8.1.11.2.3. scale the measured H<sub>2</sub>O quench to the highest mole fraction of H<sub>2</sub>O 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<sub>2</sub>O level at least as high as the level determined in paragraph 9.3.2.3.1. For this case, the quench verification calculations in paragraph 8.1.11.2.3. do not scale the measured H<sub>2</sub>O 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-paragraph (e) shall be selected. Note that the sample dryer shall meet the sample dryer verification check in paragraph 8.1.8.5.8.;
- (g) The mole fraction of H<sub>2</sub>O in the humidified NO span gas shall be measured. In case a sample dryer is used, the mole fraction of H<sub>2</sub>O in the humidified NO span gas shall be measured downstream of the sample dryer,  $x_{\text{H}_2\text{Omeas}}$ . It is recommended to measure  $x_{\text{H}_2\text{Omeas}}$  as close as possible to the CLD analyser inlet.  $x_{\text{H}_2\text{Omeas}}$  may be calculated from measurements of dew point,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ ;
- (h) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where  $x_{\text{H}_2\text{Omeas}}$  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  $x_{\text{H}_2\text{Omeas}}$  is measured to the analyser are at least 5 °C 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,  $x_{\text{NOwet}}$ .  $x_{\text{NOwet}}$  shall be recorded and used in the quench verification calculations in paragraph 8.1.11.2.3.

#### 8.1.11.2. CLD quench verification calculations

CLD quench-check calculations shall be performed as described in this paragraph.

##### 8.1.11.2.1. Amount of water expected during testing

The maximum expected mole fraction of water during emission testing,  $x_{\text{H}_2\text{Oexp}}$  shall be estimated. This estimate shall be made where the humidified NO span gas was introduced in sub-paragraph (f) of paragraph 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  $x_{\text{H}_2\text{Oexp}}$  shall be set equal to  $x_{\text{H}_2\text{Omeas}}$ .

##### 8.1.11.2.2. Amount of CO<sub>2</sub> expected during testing

The maximum expected CO<sub>2</sub> concentration during emission testing,  $x_{\text{CO}_2\text{exp}}$  shall be estimated. This estimate shall be made at the sample system location where the blended NO and CO<sub>2</sub> span gases are introduced according to sub-paragraph (j) of paragraph 8.1.11.1.4. When estimating the maximum expected

CO<sub>2</sub> concentration, the maximum expected CO<sub>2</sub> content in fuel combustion products and dilution air shall be considered.

8.1.11.2.3. Combined H<sub>2</sub>O and CO<sub>2</sub> quench calculations

Combined H<sub>2</sub>O and CO<sub>2</sub> quench shall be calculated as follows:

$$quench = \left[ \left( \frac{x_{NOwet}}{1 - x_{H2Omeas}} - 1 \right) \cdot \frac{x_{H2Oexp}}{x_{H2Omeas}} + \left( \frac{x_{NOmeas}}{x_{NOact}} - 1 \right) \cdot \frac{x_{CO2exp}}{x_{CO2act}} \right] \cdot 100\% \quad (8-4)$$

where:

*quench* = amount of CLD quench

*x*<sub>NOdry</sub> = measured concentration of NO upstream of a bubbler, according to sub-paragraph (d) of paragraph 8.1.11.1.5.

*x*<sub>NOwet</sub> = measured concentration of NO downstream of a bubbler, according to sub-paragraph (i) of paragraph 8.1.11.1.5.

*x*<sub>H2Oexp</sub> = maximum expected mole fraction of water during emission testing according to paragraph 8.1.11.2.1.

*x*<sub>H2Omeas</sub> = measured mole fraction of water during the quench verification according to sub-paragraph (g) of paragraph 8.1.11.1.5.

*x*<sub>NOmeas</sub> = measured concentration of NO when NO span gas is blended with CO<sub>2</sub> span gas, according to sub-paragraph (j) of paragraph 8.1.11.1.4.

*x*<sub>NOact</sub> = actual concentration of NO when NO span gas is blended with CO<sub>2</sub> span gas, according to sub-paragraph (k) of paragraph 8.1.11.1.4. and calculated according to equation (8-5)

*x*<sub>CO2exp</sub> = maximum expected concentration of CO<sub>2</sub> during emission testing, according to paragraph 8.1.11.2.2.

*x*<sub>CO2act</sub> = actual concentration of CO<sub>2</sub> when NO span gas is blended with CO<sub>2</sub> span gas, according to sub-paragraph (i) of paragraph 8.1.11.1.4.

$$x_{NOact} = \left( 1 - \frac{x_{CO2act}}{x_{CO2span}} \right) \cdot x_{NOspan} \quad (8-5)$$

where:

*x*<sub>NOspan</sub> = the NO span gas concentration input to the gas divider, according to sub-paragraph (e) of paragraph 8.1.11.1.4.

*x*<sub>CO2span</sub> = the CO<sub>2</sub> span gas concentration input to the gas divider, according to sub-paragraph (d) of paragraph 8.1.11.1.4.

8.1.11.3. NDUV analyser HC and H<sub>2</sub>O interference verification

8.1.11.3.1. Scope and frequency

If NO<sub>x</sub> is measured using an NDUV analyser, the amount of H<sub>2</sub>O and hydrocarbon interference shall be verified after initial analyser installation and after major maintenance.

8.1.11.3.2. Measurement principles

Hydrocarbons and H<sub>2</sub>O can positively interfere with a NDUV analyser by causing a response similar to NO<sub>x</sub>. 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<sub>x</sub> NDUV analyser shall have combined H<sub>2</sub>O and HC interference within ±2 per cent of the mean concentration of NO<sub>x</sub>.

8.1.11.3.4. Procedure

The interference verification shall be performed as follows:

- (a) The NO<sub>x</sub> 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 paragraph 9.4. to quantify NO<sub>x</sub> 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 paragraph 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 paragraph if this result is within ±2 per cent of the NO<sub>x</sub> concentration expected at the standard:

$$\left| \bar{x}_{\text{NO}_x, \text{CLD, meas}} - \bar{x}_{\text{NO}_x, \text{NDUV, meas}} \right| \cdot \left( \frac{\bar{x}_{\text{HC, exp}}}{\bar{x}_{\text{HC, meas}}} \right) \leq 2\% \cdot (\bar{x}_{\text{NO}_x, \text{exp}}) \quad (8-6)$$

where:

$\bar{x}_{\text{NO}_x, \text{CLD}, \text{meas}}$	=	the mean concentration of NO <sub>x</sub> measured by CLD [μmol/mol] or [ppm]
$\bar{x}_{\text{NO}_x, \text{NDUV}, \text{meas}}$	=	the mean concentration of NO <sub>x</sub> measured by NDUV [μmol/mol] or [ppm]
$\bar{x}_{\text{HC}, \text{meas}}$	=	the mean concentration of HC measured [μmol/mol] or [ppm]
$\bar{x}_{\text{HC}, \text{exp}}$	=	the mean concentration of HC expected at the standard [μmol/mol] or [ppm]
$\bar{x}_{\text{NO}_x, \text{exp}}$	=	the mean concentration of NO <sub>x</sub> 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<sub>2</sub>O), 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<sub>2</sub> penetration

##### 8.1.11.4.1. Scope and frequency

If a cooling bath (chiller) is used to dry a sample upstream of a NO<sub>x</sub> measurement instrument, but no NO<sub>2</sub>-to-NO converter is used upstream of the cooling bath, this verification shall be performed for cooling bath NO<sub>2</sub> 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<sub>x</sub> measurement. However, liquid water remaining in an improperly designed cooling bath can remove NO<sub>2</sub> from the sample. If a cooling bath is used without an NO<sub>2</sub>-to-NO converter upstream, it could therefore remove NO<sub>2</sub> from the sample prior NO<sub>x</sub> measurement.

##### 8.1.11.4.3. System requirements

The chiller shall allow for measuring at least 95 per cent of the total NO<sub>2</sub> at the maximum expected concentration of NO<sub>2</sub>.

##### 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<sub>x</sub> gas analyser(s) shall be zeroed and spanned as it would be before emission testing;
  - (ii) NO<sub>2</sub> calibration gas (balance gas of dry air) that has an NO<sub>2</sub> 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<sub>2</sub> 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<sub>x</sub> response, accounting only for transport delays and instrument response;
  - (iv) The mean of 30 s of recorded total NO<sub>x</sub> data shall be calculated and this value recorded as  $x_{\text{NOxref}}$ ;
  - (v) The flowing the NO<sub>2</sub> 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<sub>2</sub> calibration gas used to establish  $x_{\text{NOxref}}$ . It shall be allowed for stabilization of the total NO<sub>x</sub> response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO<sub>x</sub> data shall be calculated and this value recorded as  $x_{\text{NOxmeas}}$ ;
  - (viii)  $x_{\text{NOxmeas}}$  shall be corrected to  $x_{\text{NOxdry}}$  based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure;
- (c) Performance evaluation. If  $x_{\text{NOxdry}}$  is less than 95 per cent of  $x_{\text{NOxref}}$ , the chiller shall be repaired or replaced.

8.1.11.5. NO<sub>2</sub>-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<sub>x</sub>, an NO<sub>2</sub>-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<sub>2</sub>-to-NO converter has not deteriorated.

8.1.11.5.2. Measurement principles

An NO<sub>2</sub>-to-NO converter allows an analyser that measures only NO to determine total NO<sub>x</sub> by converting the NO<sub>2</sub> in exhaust to NO.

8.1.11.5.3. System requirements

An NO<sub>2</sub>-to-NO converter shall allow for measuring at least 95 per cent of the total NO<sub>2</sub> at the maximum expected concentration of NO<sub>2</sub>.

8.1.11.5.4. Procedure

The following procedure shall be used to verify the performance of a NO<sub>2</sub>-to-NO converter:

- (a) For the instrument setup the analyser and NO<sub>2</sub>-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<sub>2</sub>-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<sub>2</sub>-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<sub>x</sub> concentration expected during testing. The NO<sub>2</sub> 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  $x_{\text{NOref}}$ . 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<sub>2</sub> supply shall be turned on and the O<sub>2</sub> flow rate adjusted so that the NO indicated by the analyser is about 10 percent less than  $x_{\text{NOref}}$ . 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  $x_{\text{NO+O2mix}}$ ;
  - (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  $x_{\text{NOref}}$ , 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  $x_{\text{NOmeas}}$ ;
  - (v) The NO<sub>x</sub> analyser shall be switched to NO<sub>x</sub> mode and total NO<sub>x</sub> measured. The concentration of NO<sub>x</sub> shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as  $x_{\text{NOxmeas}}$ ;

- (vi) The ozonator shall be switched off but gas flow through the system shall be maintained. The NO<sub>x</sub> analyser will indicate the NO<sub>x</sub> in the NO + O<sub>2</sub> mixture. The concentration of NO<sub>x</sub> shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as  $x_{\text{NO}_x+\text{O}_2\text{mix}}$ ;
- (vii) O<sub>2</sub> supply shall be turned off. The NO<sub>x</sub> analyser will indicate the NO<sub>x</sub> in the original NO-in-N<sub>2</sub> mixture. The concentration of NO<sub>x</sub> shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as  $x_{\text{NO}_x\text{ref}}$ . This value shall be no more than 5 per cent above the  $x_{\text{NO}_x\text{ref}}$  value;
- (d) Performance evaluation. The efficiency of the NO<sub>x</sub> converter shall be calculated by substituting the concentrations obtained into the following equation:

$$\text{Efficiency}[\%] = \left( 1 + \frac{x_{\text{NO}_x\text{meas}} - x_{\text{NO}_x+\text{O}_2\text{mix}}}{x_{\text{NO}_x+\text{O}_2\text{mix}} - x_{\text{NO}_x\text{meas}}} \right) \cdot 100 \quad (8-7)$$

- (e) If the result is less than 95 per cent, the NO<sub>2</sub>-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 paragraph 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 paragraph 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 paragraph 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  $\pm 10 \mu\text{g}$  or  $\pm 10$  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 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 paragraph 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 paragraph 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 paragraph, all PM mass determinations made since the last successful reference media (e.g. filter) mass validation shall be invalidated. Reference PM filters may be 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-paragraph (j) of this paragraph, 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 paragraph 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-paragraph (i) of this paragraph, at least one reference mass difference that meets the criteria in this paragraph 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<sup>3</sup> 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<sup>3</sup> 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<sup>3</sup> shall be used.

8.1.12.2.3. Air density

Because a PM balance environment shall be tightly controlled to an ambient temperature of  $(22 \pm 1)$  °C and a dew point of  $(9.5 \pm 1)$  °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:

$$m_{\text{cor}} = m_{\text{uncor}} \cdot \left( \frac{1 - \frac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \frac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right) \quad (8-8)$$

where:

- $m_{\text{cor}}$  = PM sample filter mass corrected for buoyancy
- $m_{\text{uncor}}$  = PM sample filter mass uncorrected for buoyancy
- $\rho_{\text{air}}$  = density of air in balance environment
- $\rho_{\text{weight}}$  = density of calibration weight used to span balance
- $\rho_{\text{media}}$  = density of PM sample filter

$$\rho_{\text{air}} = \frac{p_{\text{abs}} \cdot M_{\text{mix}}}{R \cdot T_{\text{amb}}} \quad (8-9)$$

where:

- $p_{\text{abs}}$  = absolute pressure in balance environment
- $M_{\text{mix}}$  = molar mass of air in balance environment
- $R$  = molar gas constant
- $T_{\text{amb}}$  = 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 4B, Appendix A.2, paragraph 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  $\pm 2.5$  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  $\pm 2.5$  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  $\pm 4$  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  $\pm 2.5$  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  $\pm 2$  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<sub>2</sub>) 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 paragraph 8.1.8.6. and the related Figure 3.1. 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  $\leq 0.3$  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  $\leq 1$  s and the combined delay time  $\leq 10$  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  $\pm 2$  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 paragraph 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  $\pm 1$  per cent, the data can be either accepted without any correction or accepted after correction. If the drift is greater than  $\pm 1$  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 2 of Annexes 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  $\pm 4$  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 paragraph 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 paragraph 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 paragraph 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 paragraph 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 paragraph 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 paragraph 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<sup>3</sup>. The following steps are an example of substitution weighing:

- (a) Electrically grounded tweezers or a grounding strap shall be used, as described in paragraph 9.3.4.6.;
- (b) A static neutralizer shall be used as described in paragraph 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 paragraph 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 paragraphs 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 paragraph 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 paragraph 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 paragraph 9.3.4.5.
- 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 paragraph 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 paragraph 9.3.4.3.:
- (a) If it is expected that a filter's total surface concentration of PM will be greater than  $0.353 \mu\text{g}/\text{mm}^2$ , assuming a  $400 \mu\text{g}$  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  $0.353 \mu\text{g}/\text{mm}^2$ , 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 paragraph 8.2.3. shall be repeated (paragraphs 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 Annexes 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 paragraph 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 paragraphs 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 Annexes 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 paragraph 3.1. 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

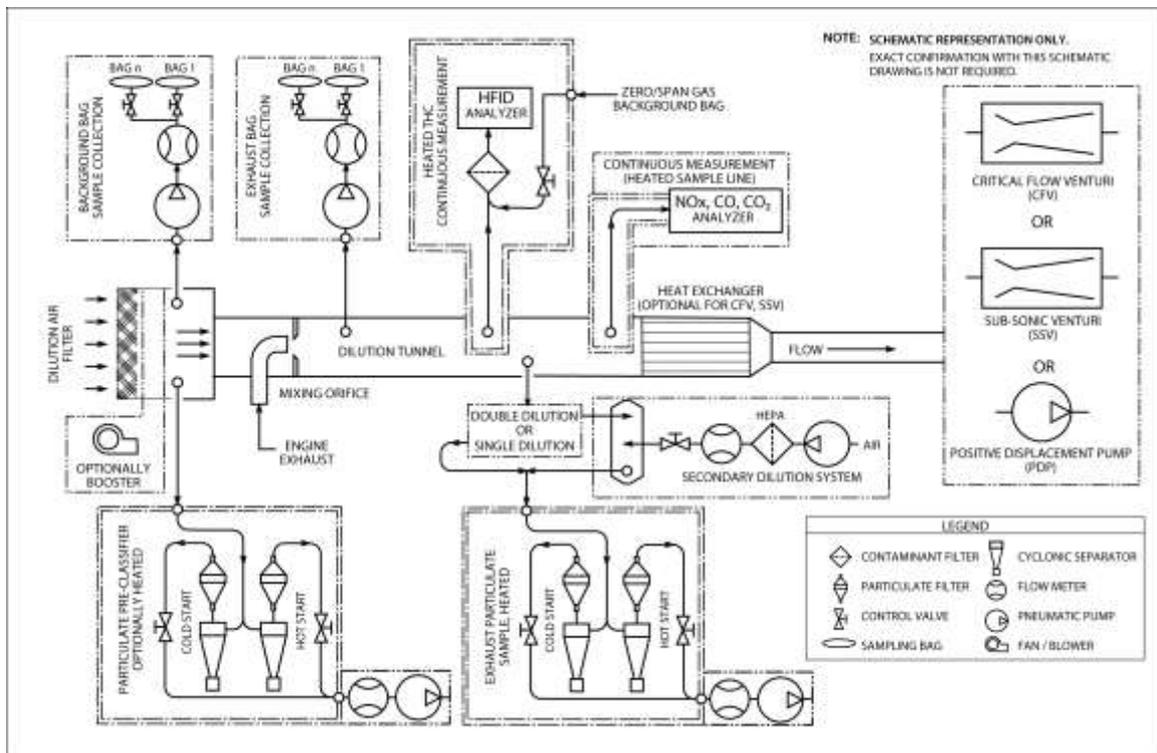
Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flow-meter within the limits. For non constant flow the flow shall be measured directly to allow for proportional 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  $\pm 1.2$  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 paragraph 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 4000 for the diluted exhaust stream, where  $Re$  is based on the inside diameter of the dilution tunnel.  $Re$  is defined in Annexes 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  $\pm 2$  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 paragraph 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

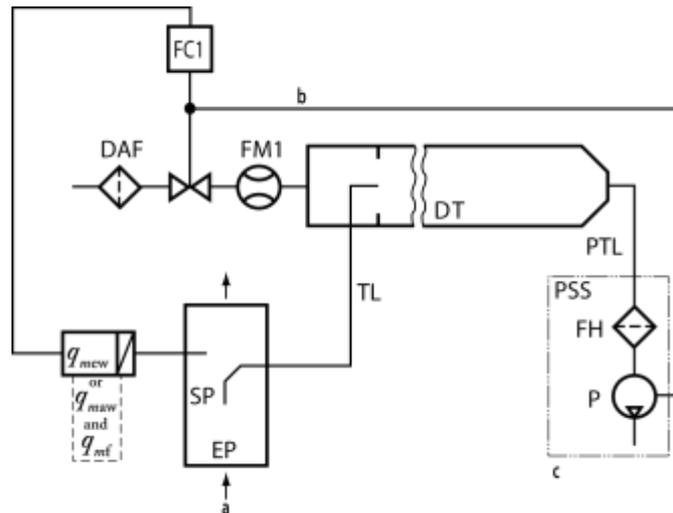
A schematic of a PFD system is shown in Figure 9.2. It is a general schematic showing principles of sample extraction, dilution and PM sampling. It is not meant to indicate that all the components described in the figure are necessary for other possible sampling systems that satisfy the intent of sample 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 paragraphs 8.1.8.6. (periodic calibration) and 8.2.1.2. (validation) for varying dilution PFD, and paragraph 8.1.4.5. as well as Table 8.2 (linearity verification) and paragraph 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:

$q_{\text{mew}}$  = Exhaust gas mass gas flow rate on wet basis

$q_{\text{maw}}$  = Intake air mass flow rate on wet basis

$q_{\text{mf}}$  = Fuel mass flow rate

#### 9.2.3.2. Dilution

The temperature of the diluents (ambient air, synthetic air, or nitrogen as quoted in paragraph 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 paragraph 9.3.3.4.3. For this it is essential that the dilution ratio be determined such that the accuracy requirements of paragraph 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 paragraph 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 its 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 paragraph 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 paragraph 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  $\text{NO}_x$  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 °C 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<sub>x</sub> transfer lines upstream of either an NO<sub>2</sub>-to-NO converter that meets the specifications of paragraph 8.1.11.5. or a chiller that meets the specifications of paragraph 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  $(191 \pm 11)$  °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  $(191 \pm 11)$  °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 paragraph. The moisture content of 0.8 volume per cent H<sub>2</sub>O 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  $\leq 5$  g water/kg dry air (or about 0.8 volume per cent H<sub>2</sub>O), 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 paragraph 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 paragraph 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<sub>2</sub>-to-NO converter or in a sampling system without an NO<sub>2</sub>-to-NO converter is used, the chiller shall meet the NO<sub>2</sub> loss-performance check specified in paragraph 8.1.11.4. The dew point,  $T_{\text{dew}}$ , and absolute pressure,  $p_{\text{total}}$ , downstream of a thermal chiller shall be monitored. The amount of water shall be calculated as specified in Annexes A.7-A.8 by using continuously recorded values of  $T_{\text{dew}}$  and  $p_{\text{total}}$  or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal  $p_{\text{total}}$  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,  $T_{\text{dew}}$  based on the known chiller efficiency and continuous monitoring of chiller temperature,  $T_{\text{chiller}}$  may be calculated. If values of  $T_{\text{chiller}}$  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 Annexes A.7-A.8. If it is valid to assume that  $T_{\text{chiller}}$  is equal to  $T_{\text{dew}}$ ,  $T_{\text{chiller}}$  may be used in lieu of  $T_{\text{dew}}$  according to Annexes A.7-A.8. If it is valid to assume a constant temperature offset between  $T_{\text{chiller}}$  and  $T_{\text{dew}}$ , 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 paragraph 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<sub>x</sub> sample pump upstream of either an NO<sub>2</sub>-to-NO converter that meets paragraph 8.1.11.5. or a chiller that meets paragraph 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  $(191 \pm 11)$  °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 <sub>2</sub> , O <sub>2</sub> , CH <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> , C <sub>3</sub> H <sub>8</sub> , NO, NO <sub>2</sub> <sup>1</sup>	polyvinyl fluoride (PVF) <sup>2</sup> for example Tedlar <sup>TM</sup> , polyvinylidene fluoride <sup>2</sup> for example Kynar <sup>TM</sup> , polytetrafluoroethylene <sup>3</sup> for example Teflon <sup>TM</sup> , or stainless steel <sup>3</sup>
THC, NMHC	polytetrafluoroethylene <sup>4</sup> or stainless steel <sup>4</sup>

<sup>1</sup> As long as aqueous condensation in storage container is prevented.

<sup>2</sup> Up to 40 °C.

<sup>3</sup> Up to 202 °C.

<sup>4</sup> At (191 ± 11) °C.

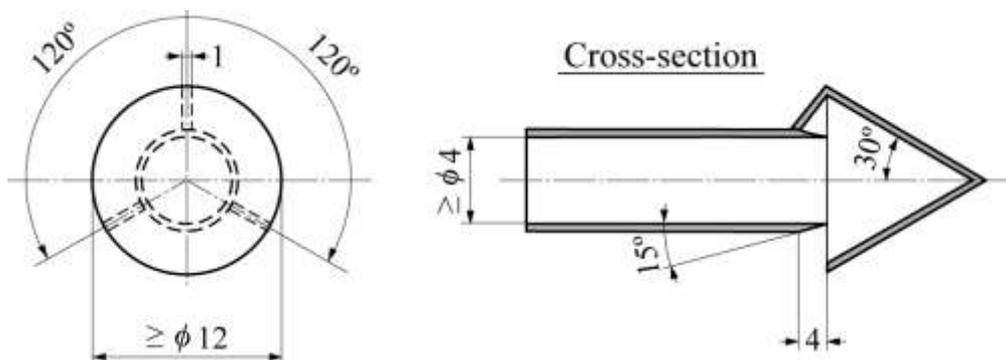
9.3.3. PM sampling

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 paragraph 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 paragraphs 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 paragraph 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 subparagraph (a) of paragraph 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 paragraph 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  $22\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$  during all filter conditioning and weighing. The humidity shall be maintained to a dew point of  $9.5\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$  and a relative humidity of 45 per cent  $\pm 8$  per cent. If the stabilization and weighing environments are separate, the stabilization environment shall be maintained at a tolerance of  $22\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ .

9.3.4.4. Verification of ambient conditions

When using measurement instruments that meet the specifications in paragraph 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 paragraph 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  $\pm 100\text{ Pa}$  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 paragraph 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 paragraph 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 paragraph 5.1.3. Where more than one instrument for a particular measurement is specified, one of them will be identified by the Type Approval Authority 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 paragraph, with prior approval of the Type Approval Authority. Results from all measurements shall be recorded and the raw data shall be retained, as described in paragraph 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**

<i>Applicable test protocol section</i>	<i>Measured values</i>	<i>Minimum command and control frequency</i>	<i>Minimum recording frequency</i>
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 paragraph 8.1., including the requirements of the linearity check of paragraphs 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 paragraph 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**

<i>Measurement instrument</i>	<i>Measured quantity symbol</i>	<i>Complete system rise time</i>	<i>Recording update frequency</i>	<i>Accuracy<sup>a</sup></i>	<i>Repeatability<sup>a</sup></i>
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 flow-meter (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 flow-meters		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	2.5 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 <sub>PM</sub>	N/A	N/A	See 9.4.11.	0.5 µg
Inertial PM balance	m <sub>PM</sub>	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.

<sup>a</sup> 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 paragraph. 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 paragraph 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 paragraph 9.4.4.1. Overall systems for measuring speed and torque shall meet the calibration and verifications in paragraphs 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 paragraph 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 paragraph 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 paragraph 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 paragraph 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 paragraph 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<sub>x</sub> shall not be sampled downstream of the cooling unless the cooler meets the performance verification in paragraph 8.1.11.4.;
- (d) If cooling causes aqueous condensation before the flow reaches a flow-meter,  $T_{\text{dew}}$  and pressure  $p_{\text{total}}$  shall be measured at the flow-meter inlet. These values shall be used in emission calculations according to Annexes 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 paragraphs 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<sub>x</sub> shall not be sampled downstream of the cooling unless the cooler meets the performance verification in paragraph 8.1.11.4.;
- (d) If cooling causes aqueous condensation before the flow reaches a flow-meter, dew point,  $T_{\text{dew}}$  and pressure  $p_{\text{total}}$  shall be measured at the flow-meter inlet. These values shall be used in emission calculations according Annexes 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 paragraph 8.1.8.6.1. and the calibration of differential flow measurement is given in paragraph 8.1.8.6.2.

Overall system for the sample flow-meter shall meet the calibration in paragraph 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 paragraph 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 paragraph 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<sub>2</sub> measurements

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO<sub>2</sub> concentrations in raw or diluted exhaust for either batch or continuous sampling.

- The NDIR-based system shall meet the calibration and verifications in paragraph 8.1.8.1.
- 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<sub>1</sub>. Methane and non-methane hydrocarbon values shall be determined as described in paragraph 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<sub>4</sub> shall meet all of the verifications for hydrocarbon measurement in paragraph 8.1.10.
- 9.4.7.1.3. FID fuel and burner air
- FID fuel and burner air shall meet the specifications of paragraph 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<sub>4</sub>, shall be quantified either with a non-methane cutter and a FID analyser as described in paragraph 9.4.7.2., or with a gas chromatograph as described in paragraph 9.4.7.3. For a FID analyser used to determine NMHC, its response factor to CH<sub>4</sub>,  $RF_{CH_4}$ , shall be determined as described in paragraph 8.1.10.1. NMHC-related calculations are described in Annexes 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 Annexes 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<sub>4</sub> with a FID analyser. A non-methane cutter oxidizes all non-methane hydrocarbons to CO<sub>2</sub> and H<sub>2</sub>O. 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 paragraph 8.1.10.3. and the results shall be used to calculate NMHC emission in 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 paragraph 8.1.10.3.
- 9.4.7.2.4. Optimization
- A non-methane cutter may be optimised to maximize the penetration of CH<sub>4</sub> and the oxidation of all other hydrocarbons. A sample may be humidified and a sample may be diluted with purified air or oxygen (O<sub>2</sub>) 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<sub>4</sub> concentrations of diluted exhaust for batch sampling. While also a non-methane cutter may be used to measure CH<sub>4</sub>, as described in paragraph 9.4.7.2. a reference procedure based on a gas chromatograph shall be used for comparison with any proposed alternate measurement procedure under paragraph 5.1.3.
- 9.4.8. NO<sub>x</sub> measurements
- Two measurement instruments are specified for NO<sub>x</sub> measurement and either instrument may be used provided it meets the criteria specified in paragraph 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 paragraph 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<sub>2</sub>-to-NO converter is used to measure NO<sub>x</sub> 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 paragraph 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<sub>2</sub>-to-NO converter
- An internal or external NO<sub>2</sub>-to-NO converter that meets the verification in paragraph 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<sub>2</sub>-to-NO converter that meets the verification in paragraph 8.1.11.5.;
  - (b) A CLD connected downstream of any dryer or thermal chiller that meets the verification in paragraph 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<sub>x</sub> 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 paragraph 8.1.11.3.
- 9.4.8.2.3. NO<sub>2</sub>-to-NO converter  
If the NDUV analyser measures only NO, an internal or external NO<sub>2</sub>-to-NO converter that meets the verification in paragraph 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<sub>2</sub>-to-NO converter that meets the verification in paragraph 8.1.11.5;
  - (b) An NDUV shall be connected downstream of any dryer or thermal chiller that meets the verification in paragraph 8.1.11.4.
- 9.4.9. O<sub>2</sub> measurements  
A paramagnetic detection (PMD) or magneto pneumatic detection (MPD) analyser shall be used to measure O<sub>2</sub> concentration in raw or diluted exhaust for batch or continuous sampling.
- 9.4.10. Air-to-fuel ratio measurements  
A Zirconia (ZrO<sub>2</sub>) analyser may be used to measure air-to-fuel ratio in raw exhaust for continuous sampling. O<sub>2</sub> measurements with intake air or fuel flow measurements may be used to calculate exhaust flow rate according to Annexes 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 paragraph 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  $\mu\text{mol/mol}$  is expected, then it would be allowed to use a zero gas with CO contamination less than or equal to 2.000  $\mu\text{mol/mol}$ ;
    - (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 [ $\mu\text{mol/mol}$  = ppm (3.2.)]**

<i>Constituent</i>	<i>Purified Synthetic Air<sup>a</sup></i>	<i>Purified N<sub>2</sub><sup>a</sup></i>
THC (C <sub>1</sub> equivalent)	$\leq 0.05 \mu\text{mol/mol}$	$\leq 0.05 \mu\text{mol/mol}$
CO	$\leq 1 \mu\text{mol/mol}$	$\leq 1 \mu\text{mol/mol}$
CO <sub>2</sub>	$\leq 10 \mu\text{mol/mol}$	$\leq 10 \mu\text{mol/mol}$
O <sub>2</sub>	0.205 to 0.215 mol/mol	$\leq 2 \mu\text{mol/mol}$
NO <sub>x</sub>	$\leq 0.02 \mu\text{mol/mol}$	$\leq 0.02 \mu\text{mol/mol}$

<sup>a</sup> 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 [ $\mu\text{mol/mol} = \text{ppm}$  (3.2.)]**

<i>Constituent</i>	<i>Purified Synthetic Air<sup>a</sup></i>	<i>Purified N<sub>2</sub><sup>a</sup></i>
THC (C <sub>1</sub> equivalent)	$\leq 1 \mu\text{mol/mol}$	$\leq 1 \mu\text{mol/mol}$
CO	$\leq 1 \mu\text{mol/mol}$	$\leq 1 \mu\text{mol/mol}$
CO <sub>2</sub>	$\leq 400 \mu\text{mol/mol}$	$\leq 400 \mu\text{mol/mol}$
O <sub>2</sub>	0.18 to 0.21 mol/mol	-
NO <sub>x</sub>	$\leq 0.1 \mu\text{mol/mol}$	$\leq 0.1 \mu\text{mol/mol}$

<sup>a</sup> 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<sub>2</sub> concentration of (0.39 to 0.41) mol/mol, balance He. The mixture shall not contain more than 0.05  $\mu\text{mol/mol}$  THC;
  - (ii) FID burner air shall be used that meets the specifications of purified air in paragraph (a) of this paragraph;
  - (iii) FID zero gas. Flame-ionization detectors shall be zeroed with purified gas that meets the specifications in paragraph (a) of this paragraph, except that the purified gas O<sub>2</sub> concentration may be any value;
  - (iv) FID propane span gas. The THC FID shall be spanned and calibrated with span concentrations of propane, C<sub>3</sub>H<sub>8</sub>. It shall be calibrated on a carbon number basis of one (C<sub>1</sub>);
  - (v) FID methane span gas. If a CH<sub>4</sub> 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<sub>4</sub>. It shall be calibrated on a carbon number basis of one (C<sub>1</sub>);
- (c) The following gas mixtures shall be used, with gases traceable within  $\pm 1.0$  per cent of the international and/or national recognized standards true value or of other gas standards that are approved:
- (i) CH<sub>4</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable);
  - (ii) C<sub>2</sub>H<sub>6</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable);
  - (iii) C<sub>3</sub>H<sub>8</sub>, balance purified synthetic air and/or N<sub>2</sub> (as applicable);
  - (iv) CO, balance purified N<sub>2</sub>;
  - (v) CO<sub>2</sub>, balance purified N<sub>2</sub>;
  - (vi) NO, balance purified N<sub>2</sub>;

- (vii) NO<sub>2</sub>, balance purified synthetic air;
  - (viii) O<sub>2</sub>, balance purified N<sub>2</sub>;
  - (ix) C<sub>3</sub>H<sub>8</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>;
  - (x) C<sub>3</sub>H<sub>8</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, NO, balance purified N<sub>2</sub>.
- (d) Gases for species other than those listed in sub-paragraph (c) of this paragraph 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 paragraph 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<sub>2</sub> or purified synthetic air. If the gas dividers meet the specifications in paragraph 9.4.5.6., and the gases being blended meet the requirements of sub-paragraphs (a) and (c) of this paragraph, the resulting blends are considered to meet the requirements of this paragraph 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-paragraph (b) of this paragraph.
- (b) Calibration gases may be relabelled and used after their expiration date if it is approved in advance by Type Approval Authority.

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 4B - Appendix A.1**

**(Reserved)**

## Annex 4B - Appendix A.2

### Statistics

#### A.2.1. Arithmetic mean

The arithmetic mean,  $\bar{y}$ , shall be calculated as follows:

$$\bar{y} = \frac{\sum_{i=1}^N y_i}{N} \quad (\text{A.2-1})$$

#### A.2.2. Standard deviation

The standard deviation for a non-biased (*e.g.*,  $N-1$ ) sample,  $\sigma$ , shall be calculated as follows:

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^N (y_i - \bar{y})^2}{(N-1)}} \quad (\text{A.2-2})$$

#### A.2.3. Root mean square

The root mean square,  $rms_y$ , shall be calculated as follows:

$$rms_y = \sqrt{\frac{1}{N} \sum_{i=1}^N y_i^2} \quad (\text{A.2-3})$$

#### 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,  $\nu$ , shall be calculated as follows:

$$t = \frac{|\bar{y}_{\text{ref}} - \bar{y}|}{\sqrt{\frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N}}} \quad (\text{A.2-4})$$

$$\nu = \frac{\left( \frac{\sigma_{\text{ref}}^2}{N_{\text{ref}}} + \frac{\sigma_y^2}{N} \right)^2}{\frac{(\sigma_{\text{ref}}^2 / N_{\text{ref}})^2}{N_{\text{ref}} - 1} + \frac{(\sigma_y^2 / N)^2}{N - 1}} \quad (\text{A.2-5})$$

- (b) For a paired  $t$ -test, the  $t$  statistic and its number of degrees of freedom,  $\nu$ , shall be calculated as follows, noting that the  $\varepsilon_i$  are the errors (*e.g.*, differences) between each pair of  $y_{refi}$  and  $y_i$ :

$$t = \frac{|\bar{\varepsilon}| \cdot \sqrt{N}}{\sigma_{\varepsilon}} \quad \nu = N - 1 \quad (\text{A.2-6})$$

- (c) Table A.2.1 of this paragraph 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,  $\nu$**

$\nu$	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

v	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:

$$F_y = \frac{\sigma_y^2}{\sigma_{\text{ref}}^2} \quad (\text{A.2-7})$$

- (a) For a 90 per cent confidence  $F$ -test, Table 2 of this paragraph is used to compare  $F$  to the  $F_{\text{crit}90}$  values tabulated versus  $(N-1)$  and  $(N_{\text{ref}}-1)$ . If  $F$  is less than  $F_{\text{crit}90}$ , then  $F$  passes the  $F$ -test at 90 per cent confidence;
- (b) For a 95 per cent confidence  $F$ -test, Table 3 of this paragraph is used to compare  $F$  to the  $F_{\text{crit}95}$  values tabulated versus  $(N-1)$  and  $(N_{\text{ref}}-1)$ . If  $F$  is less than  $F_{\text{crit}95}$ , 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**

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+	
$N_{ref}-1$																				
1	39.86	49.50	53.59	55.83	57.24	58.20	58.90	59.43	59.85	60.19	60.70	61.22	61.74	62.00	62.26	62.52	62.79	63.06	63.32	
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.381	9.392	9.408	9.425	9.441	9.450	9.458	9.466	9.475	9.483	9.491	
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.240	5.230	5.216	5.200	5.184	5.176	5.168	5.160	5.151	5.143	5.134	
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.936	3.920	3.896	3.870	3.844	3.831	3.817	3.804	3.790	3.775	3.761	
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.316	3.297	3.268	3.238	3.207	3.191	3.174	3.157	3.140	3.123	3.105	
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.958	2.937	2.905	2.871	2.836	2.818	2.800	2.781	2.762	2.742	2.722	
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.725	2.703	2.668	2.632	2.595	2.575	2.555	2.535	2.514	2.493	2.471	
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.561	2.538	2.502	2.464	2.425	2.404	2.383	2.361	2.339	2.316	2.293	
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.440	2.416	2.379	2.340	2.298	2.277	2.255	2.232	2.208	2.184	2.159	
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.347	2.323	2.284	2.244	2.201	2.178	2.155	2.132	2.107	2.082	2.055	
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.274	2.248	2.209	2.167	2.123	2.100	2.076	2.052	2.026	2.000	1.972	
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.214	2.188	2.147	2.105	2.060	2.036	2.011	1.986	1.960	1.932	1.904	
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.164	2.138	2.097	2.053	2.007	1.983	1.958	1.931	1.904	1.876	1.846	
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.122	2.095	2.054	2.010	1.962	1.938	1.912	1.885	1.857	1.828	1.797	
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.086	2.059	2.017	1.972	1.924	1.899	1.873	1.845	1.817	1.787	1.755	
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.055	2.028	1.985	1.940	1.891	1.866	1.839	1.811	1.782	1.751	1.718	
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.028	2.001	1.958	1.912	1.862	1.836	1.809	1.781	1.751	1.719	1.686	
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	2.005	1.977	1.933	1.887	1.837	1.810	1.783	1.754	1.723	1.691	1.657	
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.984	1.956	1.912	1.865	1.814	1.787	1.759	1.730	1.699	1.666	1.631	
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.965	1.937	1.892	1.845	1.794	1.767	1.738	1.708	1.677	1.643	1.607	
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.948	1.920	1.875	1.827	1.776	1.748	1.719	1.689	1.657	1.623	1.586	
20	2.949	2.561	2.351	2.219	2.128	2.061	2.008	1.967	1.933	1.904	1.859	1.811	1.759	1.731	1.702	1.671	1.639	1.604	1.567	
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.919	1.890	1.845	1.796	1.744	1.716	1.686	1.655	1.622	1.587	1.549	
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.906	1.877	1.832	1.783	1.730	1.702	1.672	1.641	1.607	1.571	1.533	
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.895	1.866	1.820	1.771	1.718	1.689	1.659	1.627	1.593	1.557	1.518	
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.884	1.855	1.809	1.760	1.706	1.677	1.647	1.615	1.581	1.544	1.504	
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.874	1.845	1.799	1.749	1.695	1.666	1.636	1.603	1.569	1.531	1.491	
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.865	1.836	1.790	1.740	1.685	1.656	1.625	1.593	1.558	1.520	1.478	
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.857	1.827	1.781	1.731	1.676	1.647	1.616	1.583	1.547	1.509	1.467	
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.849	1.819	1.773	1.722	1.667	1.638	1.606	1.573	1.538	1.499	1.456	
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.793	1.763	1.715	1.662	1.605	1.574	1.541	1.506	1.467	1.425	1.377	
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.738	1.707	1.657	1.603	1.543	1.511	1.476	1.437	1.395	1.348	1.291	
120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.684	1.652	1.601	1.545	1.482	1.447	1.409	1.368	1.320	1.265	1.193	
1000+	2.706	2.303	2.084	1.945	1.847	1.774	1.717	1.670	1.632	1.599	1.546	1.487	1.421	1.383	1.342	1.295	1.240	1.169	1.000	

Table A.2.3  
**Critical  $F$  values,  $F_{crit95}$ , versus  $N-1$  and  $N_{ref}-1$  at 95 per cent confidence**

$N-1$	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	1000+
$N_{ref}-1$																			
1	161.4	199.5	215.7	224.5	230.1	233.9	236.7	238.8	240.5	241.8	243.9	245.9	248.0	249.0	250.1	251.1	252.2	253.2	254.3
2	18.51	19.00	19.16	19.24	19.29	19.33	19.35	19.37	19.38	19.39	19.41	19.42	19.44	19.45	19.46	19.47	19.47	19.48	19.49
3	10.12	9.552	9.277	9.117	9.014	8.941	8.887	8.845	8.812	8.786	8.745	8.703	8.660	8.639	8.617	8.594	8.572	8.549	8.526
4	7.709	6.944	6.591	6.388	6.256	6.163	6.094	6.041	5.999	5.964	5.912	5.858	5.803	5.774	5.746	5.717	5.688	5.658	5.628
5	6.608	5.786	5.410	5.192	5.050	4.950	4.876	4.818	4.773	4.735	4.678	4.619	4.558	4.527	4.496	4.464	4.431	4.399	4.365
6	5.987	5.143	4.757	4.534	4.387	4.284	4.207	4.147	4.099	4.060	4.000	3.938	3.874	3.842	3.808	3.774	3.740	3.705	3.669
7	5.591	4.737	4.347	4.120	3.972	3.866	3.787	3.726	3.677	3.637	3.575	3.511	3.445	3.411	3.376	3.340	3.304	3.267	3.230
8	5.318	4.459	4.066	3.838	3.688	3.581	3.501	3.438	3.388	3.347	3.284	3.218	3.150	3.115	3.079	3.043	3.005	2.967	2.928
9	5.117	4.257	3.863	3.633	3.482	3.374	3.293	3.230	3.179	3.137	3.073	3.006	2.937	2.901	2.864	2.826	2.787	2.748	2.707
10	4.965	4.103	3.708	3.478	3.326	3.217	3.136	3.072	3.020	2.978	2.913	2.845	2.774	2.737	2.700	2.661	2.621	2.580	2.538
11	4.844	3.982	3.587	3.357	3.204	3.095	3.012	2.948	2.896	2.854	2.788	2.719	2.646	2.609	2.571	2.531	2.490	2.448	2.405
12	4.747	3.885	3.490	3.259	3.106	2.996	2.913	2.849	2.796	2.753	2.687	2.617	2.544	2.506	2.466	2.426	2.384	2.341	2.296
13	4.667	3.806	3.411	3.179	3.025	2.915	2.832	2.767	2.714	2.671	2.604	2.533	2.459	2.420	2.380	2.339	2.297	2.252	2.206
14	4.600	3.739	3.344	3.112	2.958	2.848	2.764	2.699	2.646	2.602	2.534	2.463	2.388	2.349	2.308	2.266	2.223	2.178	2.131
15	4.543	3.682	3.287	3.056	2.901	2.791	2.707	2.641	2.588	2.544	2.475	2.403	2.328	2.288	2.247	2.204	2.160	2.114	2.066
16	4.494	3.634	3.239	3.007	2.852	2.741	2.657	2.591	2.538	2.494	2.425	2.352	2.276	2.235	2.194	2.151	2.106	2.059	2.010
17	4.451	3.592	3.197	2.965	2.810	2.699	2.614	2.548	2.494	2.450	2.381	2.308	2.230	2.190	2.148	2.104	2.058	2.011	1.960
18	4.414	3.555	3.160	2.928	2.773	2.661	2.577	2.510	2.456	2.412	2.342	2.269	2.191	2.150	2.107	2.063	2.017	1.968	1.917
19	4.381	3.522	3.127	2.895	2.740	2.628	2.544	2.477	2.423	2.378	2.308	2.234	2.156	2.114	2.071	2.026	1.980	1.930	1.878
20	4.351	3.493	3.098	2.866	2.711	2.599	2.514	2.447	2.393	2.348	2.278	2.203	2.124	2.083	2.039	1.994	1.946	1.896	1.843
21	4.325	3.467	3.073	2.840	2.685	2.573	2.488	2.421	2.366	2.321	2.250	2.176	2.096	2.054	2.010	1.965	1.917	1.866	1.812
22	4.301	3.443	3.049	2.817	2.661	2.549	2.464	2.397	2.342	2.297	2.226	2.151	2.071	2.028	1.984	1.938	1.889	1.838	1.783
23	4.279	3.422	3.028	2.796	2.640	2.528	2.442	2.375	2.320	2.275	2.204	2.128	2.048	2.005	1.961	1.914	1.865	1.813	1.757
24	4.260	3.403	3.009	2.776	2.621	2.508	2.423	2.355	2.300	2.255	2.183	2.108	2.027	1.984	1.939	1.892	1.842	1.790	1.733
25	4.242	3.385	2.991	2.759	2.603	2.490	2.405	2.337	2.282	2.237	2.165	2.089	2.008	1.964	1.919	1.872	1.822	1.768	1.711
26	4.225	3.369	2.975	2.743	2.587	2.474	2.388	2.321	2.266	2.220	2.148	2.072	1.990	1.946	1.901	1.853	1.803	1.749	1.691
27	4.210	3.354	2.960	2.728	2.572	2.459	2.373	2.305	2.250	2.204	2.132	2.056	1.974	1.930	1.884	1.836	1.785	1.731	1.672
28	4.196	3.340	2.947	2.714	2.558	2.445	2.359	2.291	2.236	2.190	2.118	2.041	1.959	1.915	1.869	1.820	1.769	1.714	1.654
29	4.183	3.328	2.934	2.701	2.545	2.432	2.346	2.278	2.223	2.177	2.105	2.028	1.945	1.901	1.854	1.806	1.754	1.698	1.638
30	4.171	3.316	2.922	2.690	2.534	2.421	2.334	2.266	2.211	2.165	2.092	2.015	1.932	1.887	1.841	1.792	1.740	1.684	1.622
40	4.085	3.232	2.839	2.606	2.450	2.336	2.249	2.180	2.124	2.077	2.004	1.925	1.839	1.793	1.744	1.693	1.637	1.577	1.509
60	4.001	3.150	2.758	2.525	2.368	2.254	2.167	2.097	2.040	1.993	1.917	1.836	1.748	1.700	1.649	1.594	1.534	1.467	1.389
120	3.920	3.072	2.680	2.447	2.290	2.175	2.087	2.016	1.959	1.911	1.834	1.751	1.659	1.608	1.554	1.495	1.429	1.352	1.254
1000+	3.842	2.996	2.605	2.372	2.214	2.099	2.010	1.938	1.880	1.831	1.752	1.666	1.571	1.517	1.459	1.394	1.318	1.221	1.000

A.2.6. Slope

The least-squares regression slope,  $a_{1y}$ , shall be calculated as follows:

$$a_{1y} = \frac{\sum_{i=1}^N (y_i - \bar{y}) \cdot (y_{refi} - \bar{y}_{ref})}{\sum_{i=1}^N (y_{refi} - \bar{y}_{ref})^2} \quad (\text{A.2-8})$$

A.2.7. Intercept

The least-squares regression intercept,  $a_{0y}$ , shall be calculated as follows:

$$a_{0y} = \bar{y} - (a_{1y} \cdot \bar{y}_{ref}) \quad (\text{A.2-9})$$

A.2.8. Standard estimate of error

The standard estimate of error,  $SEE$ , shall be calculated as follows:

$$SEE_y = \sqrt{\frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{refi})]^2}{N - 2}} \quad (\text{A.2-10})$$

A.2.9. Coefficient of determination

The coefficient of determination,  $r^2$ , shall be calculated as follows:

$$r_y^2 = 1 - \frac{\sum_{i=1}^N [y_i - a_{0y} - (a_{1y} \cdot y_{refi})]^2}{\sum_{i=1}^N [y_i - \bar{y}]^2} \quad (\text{A.2-11})$$

## Annex 4B - 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:

$$a_g = 9.7803267715 \left[ 1 + 5.2790414 \times 10^{-3} \sin^2 \theta + 2.32718 \times 10^{-5} \sin^4 \theta + 1.262 \times 10^{-7} \sin^6 \theta + 7 \times 10^{-10} \sin^8 \theta \right] \quad (\text{A.3-1})$$

where:

$\theta$  = Degrees north or south latitude

## Annex 4B - 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<sub>2</sub>. This is the basis for a system verification check based on CO<sub>2</sub> measurements.

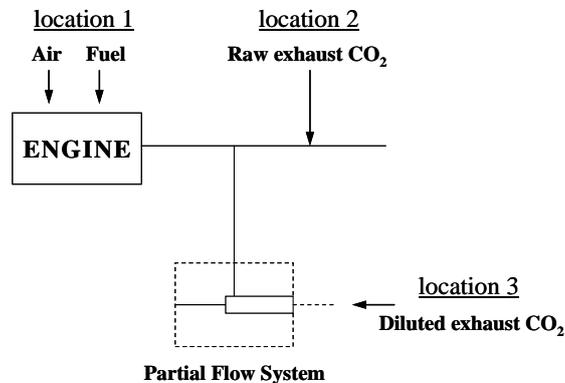
The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO<sub>2</sub> concentrations and gas flow rates at those points.

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 paragraphs.

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 CH<sub>α</sub>O<sub>ε</sub> is given by:

$$q_{mCf} = \frac{12.011}{12.011 + \alpha + 15.9994 \cdot \varepsilon} \cdot q_{mf} \quad (\text{A.4-1})$$

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  $q_{mCe}$  [kg/s] shall be determined from the raw CO<sub>2</sub> concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left( \frac{c_{CO_2,r} - c_{CO_2,a}}{100} \right) \cdot q_{mew} \cdot \frac{12.011}{M_e} \quad (A.4-2)$$

where:

$c_{CO_2,r}$  = wet CO<sub>2</sub> concentration in the raw exhaust gas [per cent]

$c_{CO_2,a}$  = wet CO<sub>2</sub> 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<sub>2</sub> is measured on a dry basis it shall be converted to a wet basis according to paragraph A.7.3.2. or A.8.2.2.

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  $q_{mCp}$  [kg/s] (with equivalent meaning equivalent to a full flow system where the total flow is diluted) shall be determined from the dilute CO<sub>2</sub> 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  $q_{mdew}/q_{mp}$ .

$$q_{mCp} = \left( \frac{c_{CO_2,d} - c_{CO_2,a}}{100} \right) \cdot q_{mew} \cdot \frac{12.011}{M_e} \cdot \frac{q_{mdew}}{q_{mp}} \quad (A.4-3)$$

where:

$c_{CO_2,d}$  = wet CO<sub>2</sub> concentration in the dilute exhaust gas at the outlet of the dilution tunnel [per cent]

$c_{CO_2,a}$  = wet CO<sub>2</sub> 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<sub>2</sub> is measured on a dry basis, it shall be converted to wet basis according to paragraph A.7.3.2. or A.8.2.2.

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 paragraph A.8.2.4.2.)

Alternatively, the following exhaust gas molar masses may be used:

$M_e$  (diesel) = 28.9 g/mol

## **Annex 4B - Appendix A.5**

**(Reserved)**

## **Annex 4B - Appendix A.6**

**(Reserved)**

## Annex 4B - Appendix A.7

### Molar based emission calculations

A.7.0. Symbol conversion

A.7.0.1. General symbols

<i>Appendix A.7<sup>1</sup></i>	<i>Appendix A.8</i>	<i>Unit</i>	<i>Quantity</i>
$A$		$m^2$	Area
$A_t$		$m^2$	Venturi throat cross-sectional area
$a_0$	$b, D_0$	t.b.d. <sup>7</sup>	y intercept of the regression line, PDP calibration intercept
$a_1$	$m$	t.b.d. <sup>7</sup>	Slope of the regression line
$\beta$	$r_D$	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 <sup>2</sup>
$e$	$e$	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)
$\gamma$		-	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
$\mu$	$\mu$	kg/(m·s)	Dynamic viscosity

<i>Appendix A.7<sup>1</sup></i>	<i>Appendix A.8</i>	<i>Unit</i>	<i>Quantity</i>
$M$	$M$	g/mol	Molar mass <sup>3</sup>
$M_{\text{gas}}^4$	$M_{\text{gas}}$	g/mol	Molar mass of gaseous components
$m$	$m$	kg	Mass
$\dot{m}$	$q_m$	kg/s	Mass rate
$\nu$		m <sup>2</sup> /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
$p_{\text{abs}}$	$p_p$	kPa	Absolute pressure
$p_{\text{H}_2\text{O}}$	$p_r$	kPa	Water vapour pressure
$PF$	$1 - E$	per cent	Penetration fraction (E = conversion efficiency)
$\dot{V}$	$q_v$	m <sup>3</sup> /s	Volume flow rate
$\rho$	$\rho$	kg/m <sup>3</sup>	Mass density
$r$		-	Ratio of pressures
$R_a$		µm	Average surface roughness
$Re^{\#}$	$Re$	-	Reynolds number
$RH\%$	$RH$	per cent	Relative humidity
$\sigma$	$\sigma$	-	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
$\Delta t$	$\Delta t$	s	Time interval
$V$	$V$	m <sup>3</sup>	Volume
$\dot{V}$	$q_v$	m <sup>3</sup> /s	Volume rate
$W$	$W$	kWh	Work

<i>Appendix A.7<sup>1</sup></i>	<i>Appendix A.8</i>	<i>Unit</i>	<i>Quantity</i>
$W_{act}$	$W_{act}$	kWh	Actual cycle work of the test cycle
$WF$	$WF$	-	Weighing factor
$w$	$w$	g/g	Mass fraction
$X^5$	$c$	mol/mol, per cent vol	Amount of substance mole fraction <sup>6</sup> / concentration (also in $\mu\text{mol/mol} = \text{ppm}$ )
$\bar{x}$		mol/mol	Flow-weighted mean concentration
$y$		-	Generic variable
$\bar{y}$		-	Arithmetic mean
$Z$		-	Compressibility factor

<sup>1</sup> See subscripts; e.g.:  $\dot{m}_{air}$  for mass rate of dry air or  $\dot{m}_{fuel}$  for fuel mass rate.

<sup>2</sup> 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.

<sup>3</sup> See paragraph A.7.1.1. of this section for the values to use for molar masses. In the cases of  $\text{NO}_x$  and HC, the Regulations specify effective molar masses based on assumed speciation rather than actual speciation.

<sup>4</sup> See symbols and abbreviations for the chemical components.

<sup>5</sup> See specific symbols in the table of chemical balance.

<sup>6</sup> The mole fractions for THC and NMHC are expressed on a C1 equivalent basis.

<sup>7</sup> t.b.d.= to be defined.

#### A.7.0.2. Subscripts

<i>Appendix A.7</i>	<i>Appendix A.8<sup>1</sup></i>	<i>Quantity</i>
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

<i>Appendix A.7</i>	<i>Appendix A.8<sup>1</sup></i>	<i>Quantity</i>
dry		Dry quantity
exh		Raw exhaust
exp		Expected quantity
eq		Equivalent quantity
fuel		Fuel
	<i>i</i>	Instantaneous measurement (e.g.: 1 Hz)
<i>i</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

<i>Appendix A.7</i>	<i>Appendix A.8<sup>1</sup></i>	<i>Quantity</i>
vac		Vacuum quantity
weight		Calibration weight
wet		Wet quantity
zero		Zero quantity

<sup>1</sup> 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)

<i>Appendix A.7</i>	<i>Appendix A.8</i>	<i>Quantity</i>
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH <sub>4</sub>	CH <sub>4</sub>	Methane
C <sub>2</sub> H <sub>6</sub>	C <sub>2</sub> H <sub>6</sub>	Ethane
C <sub>3</sub> H <sub>8</sub>	C <sub>3</sub> H <sub>8</sub>	Propane
CO	CO	Carbon monoxide
CO <sub>2</sub>	CO <sub>2</sub>	Carbon dioxide
DOP	DOP	Di-octylphthalate
H		Atomic hydrogen
H <sub>2</sub>		Molecular hydrogen
HC	HC	Hydrocarbon
H <sub>2</sub> O	H <sub>2</sub> O	Water
He		Helium
N		Atomic nitrogen
N <sub>2</sub>		Molecular nitrogen
NMHC	NMHC	Non-methane hydrocarbon
NO <sub>x</sub>	NO <sub>x</sub>	Oxides of nitrogen
NO	NO	Nitric oxide
NO <sub>2</sub>	NO <sub>2</sub>	Nitrogen dioxide

Appendix A.7	Appendix A.8	Quantity
O		Atomic oxygen
PM	PM	Particulate matter
S		Sulphur

#### A.7.0.4. Symbols and abbreviations for the fuel composition

Appendix A.7 <sup>1</sup>	Appendix A.8 <sup>2</sup>	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]
$\alpha$	$\alpha$	Atomic hydrogen-to-carbon ratio (H/C)
$\beta$	$\varepsilon$	Atomic oxygen-to-carbon ratio (O/C) <sup>3</sup>
$\gamma$	$\gamma$	Atomic sulphur-to-carbon ratio (S/C)
$\delta$	$\delta$	Atomic nitrogen-to-carbon ratio (N/C)

<sup>1</sup> Referred to a fuel with chemical formula  $CH_\alpha O_\beta S_\gamma N_\delta$

<sup>2</sup> Referred to a fuel with chemical formula  $CH_\alpha O_\varepsilon N_\delta S_\gamma$

<sup>3</sup> Attention should be paid to the different meaning of symbol  $\beta$  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  $\varepsilon$  of Appendix A.8.

<sup>4</sup> 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

$x_{\text{dil/exh}}$	=	Amount of dilution gas or excess air per mole of exhaust
$x_{\text{H}_2\text{Oexh}}$	=	Amount of water in exhaust per mole of exhaust
$x_{\text{Ccombdry}}$	=	Amount of carbon from fuel in the exhaust per mole of dry exhaust
$x_{\text{H}_2\text{Oexhdry}}$	=	Amount of water in exhaust per dry mole of dry exhaust
$x_{\text{prod/intdry}}$	=	Amount of dry stoichiometric products per dry mole of intake air
$x_{\text{dil/exhdry}}$	=	Amount of dilution gas and/or excess air per mole of dry exhaust
$x_{\text{int/exhdry}}$	=	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust

$x_{\text{raw/exhdry}}$	=	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust
$x_{\text{O2intdry}}$	=	Amount of intake air O <sub>2</sub> per mole of dry intake air
$x_{\text{CO2intdry}}$	=	Amount of intake air CO <sub>2</sub> per mole of dry intake air
$x_{\text{H2Ointdry}}$	=	Amount of intake air H <sub>2</sub> O per mole of dry intake air
$x_{\text{CO2int}}$	=	Amount of intake air CO <sub>2</sub> per mole of intake air
$x_{\text{CO2dil}}$	=	Amount of dilution gas CO <sub>2</sub> per mole of dilution gas
$x_{\text{CO2dildry}}$	=	Amount of dilution gas CO <sub>2</sub> per mole of dry dilution gas
$x_{\text{H2Odildry}}$	=	Amount of dilution gas H <sub>2</sub> O per mole of dry dilution gas
$x_{\text{H2Odil}}$	=	Amount of dilution gas H <sub>2</sub> O per mole of dilution gas
$x_{\text{[emission]meas}}$	=	Amount of measured emission in the sample at the respective gas analyser
$x_{\text{[emission]dry}}$	=	Amount of emission per dry mole of dry sample
$x_{\text{H2O[emission]meas}}$	=	Amount of water in sample at emission-detection location
$x_{\text{H2Oint}}$	=	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 annex uses the following values for dry air composition:

$$x_{\text{O2airdry}} = 0.209445 \text{ mol/mol}$$

$$x_{\text{CO2airdry}} = 0.000375 \text{ mol/mol}$$

This annex uses the following molar masses or effective molar masses of chemical species:

$M_{\text{air}}$	=	28.96559 g/mol (dry air)
$M_{\text{Ar}}$	=	39.948 g/mol (argon)
$M_{\text{C}}$	=	12.0107 g/mol (carbon)
$M_{\text{CO}}$	=	28.0101 g/mol (carbon monoxide)
$M_{\text{CO2}}$	=	44.0095 g/mol (carbon dioxide)
$M_{\text{H}}$	=	1.00794 g/mol (atomic hydrogen)
$M_{\text{H2}}$	=	2.01588 g/mol (molecular hydrogen)
$M_{\text{H2O}}$	=	18.01528 g/mol (water)
$M_{\text{He}}$	=	4.002602 g/mol (helium)
$M_{\text{N}}$	=	14.0067 g/mol (atomic nitrogen)
$M_{\text{N2}}$	=	28.0134 g/mol (molecular nitrogen)
$M_{\text{NMHC}}$	=	13.875389 g/mol (non-methane hydrocarbon <sup>(a)</sup> )
$M_{\text{NOx}}$	=	46.0055 g/mol (oxides of nitrogen <sup>(b)</sup> )

$M_{\text{O}}$	=	15.9994 g/mol (atomic oxygen)
$M_{\text{O}_2}$	=	31.9988 g/mol (molecular oxygen)
$M_{\text{C}_3\text{H}_8}$	=	44.09562 g/mol (propane)
$M_{\text{S}}$	=	32.065 g/mol (sulphur)
$M_{\text{THC}}$	=	13.875389 g/mol (total hydrocarbon <sup>(a)</sup> )

- (a) The effective molar masses of THC and NMHC are defined by an atomic hydrogen-to-carbon ratio,  $\alpha$ , of 1.85;
- (b) The effective molar mass of  $\text{NO}_x$  is defined by the molar mass of nitrogen dioxide,  $\text{NO}_2$ .

This annex uses the following molar gas constant  $R$  for ideal gases:

$$R = 8.314472 \text{ J}/(\text{mol} \cdot \text{K})$$

This annex uses the following ratios of specific heats  $\gamma$   $[\text{J}/(\text{kg} \cdot \text{K})]/[\text{J}/(\text{kg} \cdot \text{K})]$  for dilution air and diluted exhaust:

$$\gamma_{\text{air}} = 1.399 \text{ (ratio of specific heats for intake air or dilution air)}$$

$$\gamma_{\text{dil}} = 1.399 \text{ (ratio of specific heats for diluted exhaust)}$$

$$\gamma_{\text{dil}} = 1.385 \text{ (ratio of specific heats for raw exhaust)}$$

#### 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  $p_{\text{H}_2\text{O}}$  [kPa] for a given saturation temperature condition,  $T_{\text{sat}}$  [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:

$$\begin{aligned} \log_{10}(p_{\text{H}_2\text{O}}) = & 10.79574 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right) - 5.02800 \cdot \log_{10}\left(\frac{T_{\text{sat}}}{273.16}\right) + \\ & + 1.50475 \cdot 10^{-4} \cdot \left(1 - 10^{-8.2969 \cdot \left(\frac{T_{\text{sat}}}{273.16} - 1\right)}\right) + 0.42873 \cdot 10^{-3} \cdot \left(10^{4.76955 \cdot \left(1 - \frac{273.16}{T_{\text{sat}}}\right)} - 1\right) - 0.2138602 \end{aligned} \quad (\text{A.7-1})$$

where:

$p_{\text{H}_2\text{O}}$  = vapour pressure of water at saturation temperature condition [kPa]

$T_{\text{sat}}$  = saturation temperature of water at measured condition [K]

- (b) For humidity measurements made over ice at ambient temperatures from (-100 to 0) °C:

$$\log_{10}(p_{\text{sat}}) = -9.096853 \cdot \left( \frac{273.16}{T_{\text{sat}}} - 1 \right) - 3.566506 \cdot \log_{10} \left( \frac{273.16}{T_{\text{sat}}} \right) + 0.876812 \cdot \left( 1 - \frac{T_{\text{sat}}}{273.16} \right) - 0.2138602 \quad (\text{A.7-2})$$

where:

$$T_{\text{sat}} = \text{saturation temperature of water at measured condition [K]}$$

#### A.7.1.2.2. Dew point

If humidity is measured as a dew point, the amount of water in an ideal gas  $x_{\text{H}_2\text{O}}$  [mol/mol] shall be obtained as follows:

$$x_{\text{H}_2\text{O}} = \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad (\text{A.7-3})$$

where:

$$x_{\text{H}_2\text{O}} = \text{amount of water in an ideal gas [mol/mol]}$$

$$p_{\text{H}_2\text{O}} = \text{vapour pressure of water at the measured dew point, } T_{\text{sat}}=T_{\text{dew}} \text{ [kPa]}$$

$$p_{\text{abs}} = \text{wet static absolute pressure at the location of dew point measurement [kPa]}$$

#### A.7.1.2.3. Relative humidity

If humidity is measured as a relative humidity  $RH\%$ , the amount of water of an ideal gas  $x_{\text{H}_2\text{O}}$  [mol/mol] is calculated as follows:

$$x_{\text{H}_2\text{O}} = \frac{RH\%}{100} \cdot \frac{p_{\text{H}_2\text{O}}}{p_{\text{abs}}} \quad (\text{A.7-4})$$

where:

$$RH\% = \text{relative humidity [per cent]}$$

$$p_{\text{H}_2\text{O}} = \text{water vapour pressure at 100 per cent relative humidity at the location of relative humidity measurement, } T_{\text{sat}}=T_{\text{amb}} \text{ [kPa]}$$

$$p_{\text{abs}} = \text{wet static absolute pressure at the location of relative humidity measurement [kPa]}$$

#### A.7.1.3. Fuel properties

The general chemical formula of fuel is  $\text{CH}_\alpha\text{O}_\beta\text{S}_\gamma\text{N}_\delta$  with  $\alpha$  atomic hydrogen-to-carbon ratio (H/C),  $\beta$  atomic oxygen-to-carbon ratio (O/C),  $\gamma$  atomic sulphur-to-carbon ratio (S/C) and  $\delta$  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  $\text{CH}_\alpha\text{O}_\beta$  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,  $\alpha$ , atomic oxygen-to-carbon ratio,  $\beta$ , and carbon mass fraction of fuel,  $w_C$  for diesel fuels**

<i>Fuel</i>	<i>Atomic hydrogen and oxygen-to-carbon ratios</i> $CH_\alpha O_\beta$	<i>Carbon mass concentration, <math>w_C</math></i> [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<sub>4</sub> initial contamination corrections

- (a) If THC emissions are required to be determined,  $x_{\text{THC}[\text{THC-FID}]}$  shall be calculated by using the initial THC contamination concentration  $x_{\text{THC}[\text{THC-FID}]\text{init}}$  from paragraph 7.3.1.2. as follows:

$$x_{\text{THC}[\text{THC-FID}]\text{cor}} = x_{\text{THC}[\text{THC-FID}]\text{uncorr}} - x_{\text{THC}[\text{THC-FID}]\text{init}} \quad (\text{A.7-5})$$

where:

$x_{\text{THC}[\text{THC-FID}]\text{cor}}$  = THC concentration corrected for contamination [mol/mol]

$x_{\text{THC}[\text{THC-FID}]\text{uncorr}}$  = THC uncorrected concentration [mol/mol]

$x_{\text{THC}[\text{THC-FID}]\text{init}}$  = initial THC contamination concentration [mol/mol]

- (b) For the NMHC determination described in paragraph A.7.1.4.2.,  $x_{\text{THC}[\text{THC-FID}]}$  shall be corrected for initial HC contamination using equation (A.7-5). The initial contamination of the CH<sub>4</sub> sample train may be corrected using equation (A.7-5), substituting in CH<sub>4</sub> concentrations for THC.

A.7.1.4.2. NMHC determination

To determine NMHC concentration,  $x_{\text{NMHC}}$ , one of the following shall be used:

- (a) If CH<sub>4</sub> 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,  $x_{\text{NMHC}}$  shall be calculated using the non-methane cutter's penetration fractions (*PF*) of CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> from paragraph 8.1.10.3., and using the HC contamination and dry-to-wet corrected THC concentration  $x_{\text{THC}[\text{THC-FID}]\text{cor}}$  as determined in subparagraph (a) of paragraph of A.7.1.4.1.:

- (i) The following equation for penetration fractions determined using an NMC configuration as outlined in paragraph 8.1.10.3.4.1. shall be used:

$$x_{\text{NMHC}} = \frac{x_{\text{THC[THC-FID]cor}} - x_{\text{THC[NMC-FID]}} \cdot RF_{\text{CH4[THC-FID]}}}{1 - RFPF_{\text{C2H6[NMC-FID]}} \cdot RF_{\text{CH4[THC-FID]}}} \quad (\text{A.7-6})$$

where:

- $x_{\text{NMHC}}$  = concentration of NMHC
- $x_{\text{THC[THC-FID]cor}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC
- $x_{\text{THC[NMC-FID]}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC
- $RF_{\text{CH4[THC-FID]}}$  = response factor of THC FID to CH<sub>4</sub>, according to paragraph 8.1.10.1.4.
- $RFPF_{\text{C2H6[NMC-FID]}}$  = non-methane cutter combined ethane response factor and penetration fraction, according to paragraph 8.1.10.3.4.1.

- (ii) For penetration fractions determined using an NMC configuration as outlined in paragraph 8.1.10.3.4.2., the following equation shall be used:

$$x_{\text{NMHC}} = \frac{x_{\text{THC[THC-FID]cor}} \cdot PF_{\text{CH4[NMC-FID]}} - x_{\text{THC[NMC-FID]}}}{PF_{\text{CH4[NMC-FID]}} - PF_{\text{C2H6[NMC-FID]}}} \quad (\text{A.7-7})$$

where:

- $x_{\text{NMHC}}$  = concentration of NMHC
- $x_{\text{THC[THC-FID]cor}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC
- $PF_{\text{CH4[NMC-FID]}}$  = non-methane cutter CH<sub>4</sub> penetration fraction, according to paragraph 8.1.10.3.4.2.
- $x_{\text{THC[NMC-FID]}}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC
- $PF_{\text{C2H6[NMC-FID]}}$  = non-methane cutter ethane penetration fraction, according to paragraph 8.1.10.3.4.2.

- (iii) For penetration fractions determined using an NMC configuration as outlined in paragraph 8.1.10.3.4.3., the following equation shall be used:

$$x_{\text{NMHC}} = \frac{x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} \cdot PF_{\text{CH}_4[\text{NMC-FID}]} - x_{\text{THC}[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}}{PF_{\text{CH}_4[\text{NMC-FID}]} - RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]} \cdot RF_{\text{CH}_4[\text{THC-FID}]}} \quad (\text{A.7-8})$$

where:

- $x_{\text{NMHC}}$  = concentration of NMHC
- $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID during sampling while bypassing the NMC
- $PF_{\text{CH}_4[\text{NMC-FID}]}$  = non-methane cutter  $\text{CH}_4$  penetration fraction, according to paragraph 8.1.10.3.4.3.
- $x_{\text{THC}[\text{NMC-FID}]}$  = concentration of THC, HC contamination (optional) and dry-to-wet corrected, as measured by the NMC FID during sampling through the NMC
- $RFPF_{\text{C}_2\text{H}_6[\text{NMC-FID}]}$  = non-methane cutter  $\text{CH}_4$  combined ethane response factor and penetration fraction, according to paragraph 8.1.10.3.4.3.
- $RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC FID to  $\text{CH}_4$ , according to paragraph 8.1.10.1.4.

- (c) For a gas chromatograph,  $x_{\text{NMHC}}$  shall be calculated using the THC analyser's response factor ( $RF$ ) for  $\text{CH}_4$ , from paragraph 8.1.10.1.4., and the HC contamination and dry-to-wet corrected initial THC concentration  $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  as determined in paragraph (a) above as follows:

$$x_{\text{NMHC}} = x_{\text{THC}[\text{THC-FID}]_{\text{cor}}} - RF_{\text{CH}_4[\text{THC-FID}]} \cdot x_{\text{CH}_4} \quad (\text{A.7-9})$$

where:

- $x_{\text{NMHC}}$  = concentration of NMHC
- $x_{\text{THC}[\text{THC-FID}]_{\text{cor}}}$  = concentration of THC, HC contamination and dry-to-wet corrected, as measured by the THC FID
- $x_{\text{CH}_4}$  = concentration of  $\text{CH}_4$ , HC contamination (optional) and dry-to-wet corrected, as measured by the gas chromatograph FID
- $RF_{\text{CH}_4[\text{THC-FID}]}$  = response factor of THC-FID to  $\text{CH}_4$

#### 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 paragraphs 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,  $x_{\text{H}_2\text{Oexh}}$ , 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,  $x_{\text{dil/exh}}$ , 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,  $x_{\text{H}_2\text{Oexh}}$ , fraction of dilution air in diluted exhaust (or excess air in the raw exhaust),  $x_{\text{dil/exh}}$ , and the amount of products on a C1 basis per dry mole of dry measured flow,  $x_{\text{Ccombdry}}$ . 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  $\pm 0.0025$  mol/mol of their respective mean values over the test interval. For each emission concentration,  $x$ , and amount of water  $x_{\text{H}_2\text{Oexh}}$ , it shall be determined their completely dry concentrations,  $x_{\text{dry}}$  and  $x_{\text{H}_2\text{Oexhdry}}$ . It shall also be used fuel's atomic hydrogen-to-carbon ratio,  $\alpha$ , oxygen-to-carbon ratio,  $\beta$  and carbon mass fraction of fuel,  $w_{\text{C}}$ . For the test fuel,  $\alpha$  and  $\beta$  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,  $x_{\text{CO}_2\text{meas}}$ ,  $x_{\text{NOmeas}}$ , and  $x_{\text{H}_2\text{Oint}}$ , shall be converted to dry concentrations by dividing them by one minus the amount of water present during their respective measurements; for example:  $x_{\text{H}_2\text{OxCO}_2\text{meas}}$ ,  $x_{\text{H}_2\text{OxNOmeas}}$ , and  $x_{\text{H}_2\text{Oint}}$ . If the amount of water present during a "wet" measurement is the same as the unknown amount of water in the exhaust flow,  $x_{\text{H}_2\text{Oexh}}$ , it has to be iteratively solved for that value in the system of equations. If only total  $\text{NO}_x$  are measured and not NO and  $\text{NO}_2$  separately, good engineering judgement shall be used to estimate a split in the total  $\text{NO}_x$  concentration between NO and  $\text{NO}_2$  for the chemical balances. The molar concentration of  $\text{NO}_x$ ,  $x_{\text{NOx}}$ , may be assumed to be 75 per cent NO and 25 per cent  $\text{NO}_2$ . For  $\text{NO}_2$  storage aftertreatment systems,  $x_{\text{NOx}}$  may be assumed to be 25 per cent NO and 75 per cent  $\text{NO}_2$ . For calculating the mass of  $\text{NO}_x$  emissions, the molar mass of  $\text{NO}_2$  for the effective molar mass of all  $\text{NO}_x$  species, regardless of the actual  $\text{NO}_2$  fraction of  $\text{NO}_x$ , shall be used;
- (b) Equations (A.7-10 to A.7-26) in paragraph (d) of this paragraph A.7.2.3. have to be entered into a computer program to iteratively solve for  $x_{\text{H}_2\text{Oexh}}$ ,  $x_{\text{Ccombdry}}$  and  $x_{\text{dil/exh}}$ . Good engineering judgment shall be used to guess initial values for  $x_{\text{H}_2\text{Oexh}}$ ,  $x_{\text{Ccombdry}}$ , and  $x_{\text{dil/exh}}$ . 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  $x_{\text{Ccombdry}}$  as the sum of the measured  $\text{CO}_2$ , CO, and THC values is recommended. Guessing an initial  $x_{\text{dil}}$  between 0.75 and 0.95 ( $0.75 < x_{\text{dil}} < 0.95$ ), 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  $\pm 1$  per cent of their respective most recently calculated values;
- (c) The following symbols and subscripts are used in the equation system of sub-paragraph (c) of this paragraph where  $x$  unit is mol/mol:

<i>Symbol</i>	<i>Description</i>
$x_{\text{dil/exh}}$	Amount of dilution gas or excess air per mole of exhaust
$x_{\text{H}_2\text{Oexh}}$	Amount of $\text{H}_2\text{O}$ in exhaust per mole of exhaust
$x_{\text{Ccombdry}}$	Amount of carbon from fuel in the exhaust per mole of dry exhaust
$x_{\text{H}_2\text{Oexhdry}}$	Amount of water in exhaust per dry mole of dry exhaust
$x_{\text{prod/intdry}}$	Amount of dry stoichiometric products per dry mole of intake air
$x_{\text{dil/exhdry}}$	Amount of dilution gas and/or excess air per mole of dry exhaust
$x_{\text{int/exhdry}}$	Amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust
$x_{\text{raw/exhdry}}$	Amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust
$x_{\text{O}_2\text{intdry}}$	Amount of intake air $\text{O}_2$ per mole of dry intake air; $x_{\text{O}_2\text{intdry}} = 0.209445$ mol/mol may be assumed

Symbol	Description
$x_{\text{CO}_2\text{intdry}}$	Amount of intake air CO <sub>2</sub> per mole of dry intake air. $x_{\text{CO}_2\text{intdry}} = 375 \mu\text{mol/mol}$ may be used, but measuring the actual concentration in the intake air is recommended
$x_{\text{H}_2\text{Ointdry}}$	Amount of the intake air H <sub>2</sub> O per mole of dry intake air
$x_{\text{CO}_2\text{int}}$	Amount of intake air CO <sub>2</sub> per mole of intake air
$x_{\text{CO}_2\text{dil}}$	Amount of dilution gas CO <sub>2</sub> per mole of dilution gas
$x_{\text{CO}_2\text{dildry}}$	Amount of dilution gas CO <sub>2</sub> per mole of dry dilution gas. If air is used as diluent, $x_{\text{CO}_2\text{dildry}} = 375 \mu\text{mol/mol}$ may be used, but measuring the actual concentration in the intake air is recommended
$x_{\text{H}_2\text{Odildry}}$	Amount of dilution gas H <sub>2</sub> O per mole of dry dilution gas
$x_{\text{H}_2\text{Odil}}$	Amount of dilution gas H <sub>2</sub> O per mole of dilution gas
$x_{[\text{emission}]\text{meas}}$	Amount of measured emission in the sample at the respective gas analyser
$x_{[\text{emission}]\text{dry}}$	Amount of emission per dry mole of dry sample
$x_{\text{H}_2\text{O}[\text{emission}]\text{meas}}$	Amount of water in sample at emission-detection location. These values shall be measured or estimated according to paragraph 9.3.2.3.1.
$x_{\text{H}_2\text{Oint}}$	Amount of water in the intake air, based on a humidity measurement of intake air
$\alpha$	Atomic hydrogen-to-carbon ratio of the mixture of fuel(s) ( $\text{CH}_\alpha\text{O}_\beta$ ) being combusted, weighted by molar consumption
$\beta$	Atomic oxygen-to-carbon ratio of the mixture of fuel(s) ( $\text{CH}_\alpha\text{O}_\beta$ ) being combusted, weighted by molar consumption

- (d) The following equations shall be used to iteratively solve for  $x_{\text{dil/exh}}$ ,  $x_{\text{H}_2\text{Oexh}}$  and  $x_{\text{Ccombdry}}$ :

$$x_{\text{dil/exh}} = 1 - \frac{x_{\text{raw/exhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}} \quad (\text{A.7-10})$$

$$x_{\text{H}_2\text{Oexh}} = \frac{x_{\text{H}_2\text{Oexhdry}}}{1 + x_{\text{H}_2\text{Oexhdry}}} \quad (\text{A.7-11})$$

$$x_{\text{Ccombdry}} = x_{\text{CO}_2\text{dry}} + x_{\text{COdry}} + x_{\text{THCdry}} - x_{\text{CO}_2\text{dil}} \cdot x_{\text{dil/exhdry}} - x_{\text{CO}_2\text{int}} \cdot x_{\text{int/exhdry}} \quad (\text{A.7-12})$$

$$x_{\text{H}_2\text{Oexhdry}} = \frac{\alpha}{2} (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + x_{\text{H}_2\text{Odil}} \cdot x_{\text{dil/exhdry}} + x_{\text{H}_2\text{Oint}} \cdot x_{\text{int/exhdry}} \quad (\text{A.7-13})$$

$$x_{\text{dil/exhdry}} = \frac{x_{\text{dil/exh}}}{1 - x_{\text{H}_2\text{Oexh}}} \quad (\text{A.7-14})$$

$$x_{\text{int/exhdry}} = \frac{1}{2 \cdot x_{\text{O}_2\text{int}}} \left[ \left( \frac{\alpha}{2} - \beta + 2 \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) - (x_{\text{COdry}} - x_{\text{NOdry}} - 2x_{\text{NO}_2\text{dry}}) \right] \quad (\text{A.7-15})$$

$$x_{\text{raw/exhdry}} = \frac{1}{2} \left[ \left( \frac{\alpha}{2} + \beta \right) (x_{\text{Ccombdry}} - x_{\text{THCdry}}) + (2x_{\text{THCdry}} + x_{\text{COdry}} - x_{\text{NO}_2\text{dry}}) \right] + x_{\text{int/exhdry}} \quad (\text{A.7-16})$$

$$x_{\text{O}_2\text{int}} = \frac{0.209820 - x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}} \quad (\text{A.7-17})$$

$$x_{\text{CO}_2\text{int}} = \frac{x_{\text{CO}_2\text{intdry}}}{1 + x_{\text{H}_2\text{Ointdry}}} \quad (\text{A.7-18})$$

$$x_{\text{H}_2\text{Ointdry}} = \frac{x_{\text{H}_2\text{Oint}}}{1 - x_{\text{H}_2\text{Oint}}} \quad (\text{A.7-19})$$

$$x_{\text{CO}_2\text{dil}} = \frac{x_{\text{CO}_2\text{dildry}}}{1 + x_{\text{H}_2\text{Odildry}}} \quad (\text{A.7-20})$$

$$x_{\text{H}_2\text{Odildry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}} \quad (\text{A.7-21})$$

$$x_{\text{COdry}} = \frac{x_{\text{COmeas}}}{1 - x_{\text{H}_2\text{OCOmeas}}} \quad (\text{A.7-22})$$

$$x_{\text{CO}_2\text{dry}} = \frac{x_{\text{CO}_2\text{meas}}}{1 - x_{\text{H}_2\text{OCO}_2\text{meas}}} \quad (\text{A.7-23})$$

$$x_{\text{NOdry}} = \frac{x_{\text{NOmeas}}}{1 - x_{\text{H}_2\text{ONomeas}}} \quad (\text{A.7-24})$$

$$x_{\text{NO}_2\text{dry}} = \frac{x_{\text{NO}_2\text{meas}}}{1 - x_{\text{H}_2\text{ONO}_2\text{meas}}} \quad (\text{A.7-25})$$

$$x_{\text{THCdry}} = \frac{x_{\text{THCmeas}}}{1 - x_{\text{H}_2\text{O}^+\text{THCmeas}}} \quad (\text{A.7-26})$$

At the end of the chemical balance, the molar flow rate  $\dot{n}_{\text{exh}}$  is calculated as specified in paragraphs A.7.3.3. and A.7.4.3.

A.7.2.4. NO<sub>x</sub> correction for humidity

All the NO<sub>x</sub> concentrations, including dilution air background concentrations, shall be corrected for intake-air humidity using the following equation:

$$x_{\text{NOxcor}} = x_{\text{NOxuncor}} \cdot (9.953 \cdot x_{\text{H}_2\text{O}} + 0.832) \quad (\text{A.7-27})$$

where:

$x_{\text{NOxuncor}}$  = uncorrected NO<sub>x</sub> molar concentration in the exhaust gas [μmol/mol]

$x_{\text{H}_2\text{O}}$  = 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  $m_{\text{gas}}$  [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:

$$m_{\text{gas}} = M_{\text{gas}} \cdot \int \dot{n}_{\text{exh}} \cdot x_{\text{gas}} \cdot dt \quad (\text{A.7-28})$$

where:

$M_{\text{gas}}$  = molar mass of the generic gaseous emission [g/mol]

$\dot{n}_{\text{exh}}$  = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gas}}$  = 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:

$$m_{\text{gas}} = M_{\text{gas}} \cdot \int \dot{n}_{\text{exh}} \cdot x_{\text{gas}} \cdot dt \Rightarrow m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \sum_{i=1}^N \dot{n}_{\text{exhi}} \cdot x_{\text{gasi}} \quad (\text{A.7-29})$$

where:

$M_{\text{gas}}$  = generic emission molar mass [g/mol]

$\dot{n}_{\text{exhi}}$  = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gasi}}$  = 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  $m_{\text{gas}}$  [g/test] shall be calculated by means of the following equation:

$$m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \sum_{i=1}^N \dot{n}_{\text{exhi}} \cdot x_{\text{gasi}} \quad (\text{A.7-30})$$

where:

$M_{\text{gas}}$  = generic emission molar mass [g/mol]

$\dot{n}_{\text{exhi}}$  = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$x_{\text{gasi}}$  = 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  $m_{\text{gas}}$  [g/test] shall be calculated by means of the following equation:

$$m_{\text{gas}} = M_{\text{gas}} \cdot \dot{n}_{\text{exh}} \cdot \bar{x}_{\text{gas}} \cdot \Delta t \quad (\text{A.7-31})$$

where:

$M_{\text{gas}}$  = generic emission molar mass [g/mol]

$\dot{n}_{\text{exh}}$  = exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{\text{gas}}$  = mean gaseous emission molar fraction on a wet basis [mol/mol]

$\Delta t$  = 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:

$$m_{\text{gas}} = \frac{1}{f} \cdot M_{\text{gas}} \cdot \bar{x}_{\text{gas}} \cdot \sum_{i=1}^N \dot{n}_{\text{exhi}} \quad (\text{A.7-32})$$

where:

$M_{\text{gas}}$  = generic emission molar mass [g/mol]

$\dot{n}_{\text{exhi}}$  = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{\text{gas}}$  = 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 paragraph are obtained from the results of the chemical balance calculated in paragraph A.7.2. The following relation exists between gas molar concentrations in the measured flow  $x_{\text{gasdry}}$  and  $x_{\text{gas}}$  [mol/mol] expressed on a dry and wet basis respectively:

$$x_{\text{gasdry}} = \frac{x_{\text{gas}}}{1 - x_{\text{H}_2\text{O}}} \quad (\text{A.7-33})$$

$$x_{\text{gas}} = \frac{x_{\text{gasdry}}}{1 + x_{\text{H}_2\text{Odry}}} \quad (\text{A.7-34})$$

where:

$x_{\text{H}_2\text{O}}$  = molar fraction of water in the measured flow on a wet basis [mol/mol]

$x_{\text{H}_2\text{Odry}}$  = 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:

$$x = x_{\text{[emission]meas}} \left[ \frac{(1 - x_{\text{H}_2\text{Oexh}})}{1 - x_{\text{H}_2\text{O[emission]meas}}} \right] \quad (\text{A.7-35})$$

where:

$x_{\text{[emission]meas}}$  = molar fraction of emission in the measured flow at measurement location [mol/mol]

$x_{\text{H}_2\text{O[emission]meas}}$  = amount of water in the measured flow at the concentration measurement [mol/mol]

$x_{\text{H}_2\text{Oexh}}$  = 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 paragraph 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,  $\dot{n}_{\text{exh}}$ , based on the measured intake air molar flow rate,  $\dot{n}_{\text{int}}$ , or the measured fuel mass flow rate,  $\dot{m}_{\text{fuel}}$ , and the values calculated using the chemical balance in paragraph A.7.2.3. It shall be solved for the chemical balance in paragraph A.7.2.3. at the same frequency that  $\dot{n}_{\text{int}}$  or  $\dot{m}_{\text{fuel}}$  is updated and recorded.

(a) Crankcase flow rate. The raw exhaust flow can be calculated based on  $\dot{n}_{\text{int}}$  or  $\dot{m}_{\text{fuel}}$  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 paragraph 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  $\dot{n}_{\text{int}}$ , exhaust gas molar flow rate  $\dot{n}_{\text{exh}}$  [mol/s] shall be calculated as follows:

$$\dot{n}_{\text{exh}} = \frac{\dot{n}_{\text{int}}}{\left[ 1 + \frac{(x_{\text{int/exhdry}} - x_{\text{raw/exhdry}})}{(1 + x_{\text{H2Oexhdry}})} \right]} \quad (\text{A.7-36})$$

where:

- $\dot{n}_{\text{exh}}$  = raw exhaust molar flow rate from which emissions are measured [mol/s]
- $\dot{n}_{\text{int}}$  = intake air molar flow rate including humidity in intake air [mol/s]
- $x_{\text{int/exhdry}}$  = amount of intake air required to produce actual combustion products per mole of dry (raw or diluted) exhaust [mol/mol]
- $x_{\text{raw/exhdry}}$  = amount of undiluted exhaust, without excess air, per mole of dry (raw or diluted) exhaust [mol/mol]
- $x_{\text{H2Oexhdry}}$  = 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  $\dot{m}_{\text{fuel}}$ ,  $\dot{n}_{\text{exh}}$  [mol/s] shall be calculated as follows:

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_{\text{C}} \cdot (1 + x_{\text{H2Oexhdry}})}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \quad (\text{A.7-37})$$

where:

- $\dot{n}_{\text{exh}}$  = raw exhaust molar flow rate from which emissions are measured
- $\dot{m}_{\text{fuel}}$  = fuel flow rate including humidity in intake air [g/s]
- $w_{\text{C}}$  = carbon mass fraction for the given fuel [g/g]
- $x_{\text{H2Oexhdry}}$  = amount of H<sub>2</sub>O 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]

$x_{gasi}$  = 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

$$m_{gas} = M_{gas} \cdot \dot{n}_{exh} \cdot \bar{x}_{gas} \cdot \Delta t \quad (\text{see A.7-31})$$

where:

$M_{gas}$  = generic emission molar mass [g/mol]

$\dot{n}_{exh}$  = exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{gas}$  = mean gaseous emission molar fraction on a wet basis [mol/mol]

$\Delta t$  = time duration of test interval

(b) Batch sampling, regardless varying flow or constant rate is the following equation shall be used:

$$m_{gas} = \frac{1}{f} \cdot M_{gas} \cdot \bar{x}_{gas} \cdot \sum_{i=1}^N \dot{n}_{exhi} \quad (\text{see A.7-32})$$

where:

$M_{gas}$  = generic emission molar mass [g/mol]

$\dot{n}_{exhi}$  = instantaneous exhaust gas molar flow rate on a wet basis [mol/s]

$\bar{x}_{\text{gas}}$  = 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  $\dot{n}_{\text{airdil}}$  [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,  $\bar{x}_{\text{dil/exh}}$ ;

(ii) The total flow of dilution air  $n_{\text{airdil}}$  [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  $n_{\text{airdil}}$  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  $m_{\text{bknd}}$  [g] by multiplying it by emission molar mass,  $M_{\text{gas}}$  [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,  $n_{\text{airdil}}$ . 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 paragraph A.7.2. In this case, the total mass of background shall be calculated, using the total flow of diluted exhaust,  $n_{\text{dexh}}$ . Then this result shall be multiplied by the flow-weighted mean fraction of dilution air in diluted exhaust,  $\bar{x}_{\text{dil/exh}}$ .

Considering the two cases (v) and (vi), the following equations shall be used:

$$m_{\text{bknd}} = M_{\text{gas}} \cdot x_{\text{gasdil}} \cdot n_{\text{airdil}} \quad \text{or} \quad m_{\text{bknd}} = M_{\text{gas}} \cdot \bar{x}_{\text{dil/exh}} \cdot \bar{x}_{\text{bknd}} \cdot n_{\text{dexh}} \quad (\text{A.7-38})$$

$$m_{\text{gascor}} = m_{\text{gas}} - m_{\text{bknd}} \quad (\text{A.7-39})$$

where:

$m_{\text{gas}}$	=	total mass of the gaseous emission [g]
$m_{\text{bkgnd}}$	=	total background masses [g]
$m_{\text{gascor}}$	=	mass of gas corrected for background emissions [g]
$M_{\text{gas}}$	=	molecular mass of generic gaseous emission [g/mol]
$x_{\text{gasdil}}$	=	gaseous emission concentration in dilution air [mol/mol]
$n_{\text{airdil}}$	=	dilution air molar flow [mol]
$\bar{x}_{\text{dil/exh}}$	=	flow-weighted mean fraction of dilution air in diluted exhaust [mol/mol]
$\bar{x}_{\text{bkgnd}}$	=	gas fraction of background [mol/mol]
$n_{\text{dexh}}$	=	total flow of diluted exhaust [mol]

#### A.7.4.2. Dry-to wet concentration conversion

The same relations for raw gases (paragraph 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  $x_{\text{H}_2\text{Odil}}^{\text{dry}}$  [mol/mol]:

$$x_{\text{H}_2\text{Odil}}^{\text{dry}} = \frac{x_{\text{H}_2\text{Odil}}}{1 - x_{\text{H}_2\text{Odil}}} \quad (\text{see A.7-21})$$

where:

$x_{\text{H}_2\text{Odil}}$  = 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  $\dot{n}_{\text{exh}}$  [mol/s] can be calculated based on fuel mass flow rate  $\dot{m}_{\text{fuel}}$ :

$$\dot{n}_{\text{exh}} = \frac{\dot{m}_{\text{fuel}} \cdot w_{\text{C}} \cdot (1 + x_{\text{H}_2\text{Oexhdry}})}{M_{\text{C}} \cdot x_{\text{Ccombdry}}} \quad (\text{see A.7-37})$$

where:

$\dot{n}_{\text{exh}}$	=	raw exhaust molar flow rate from which emissions are measured
$\dot{m}_{\text{fuel}}$	=	fuel flow rate including humidity in intake air [g/s]
$w_{\text{C}}$	=	carbon mass fraction for the given fuel [g/g]
$x_{\text{H}_2\text{Oexhdry}}$	=	amount of H <sub>2</sub> O per dry mole of measured flow [mol/mol]
$M_{\text{C}}$	=	molecular mass of carbon 12.0107 g/mol
$x_{\text{Ccombdry}}$	=	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 1 to this annex, shall be used to calculate molar flow rate  $\dot{n}$  [mol/s] as follows:

$$\dot{n} = f_{n,PDP} \cdot \frac{p_{in} \cdot V_{rev}}{R \cdot T_{in}} \quad (A.7-40)$$

where:

$$V_{rev} = \frac{a_1}{f_{n,PDP}} \cdot \sqrt{\frac{p_{out} - p_{in}}{p_{in}}} + a_0 \quad (A.7-41)$$

where:

- $a_1$  = calibration coefficient [m<sup>3</sup>/s]  
 $a_0$  = calibration coefficient [m<sup>3</sup>/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<sup>3</sup>/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 Appendix 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:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{in}}{\sqrt{Z \cdot M_{mix} \cdot R \cdot T_{in}}} \quad (A.7-42)$$

where:

- $p_{in}$  = inlet pressure [Pa]  
 $A_t$  = Venturi throat cross-sectional area [m<sup>2</sup>]  
 $R$  = 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 1 to 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 <sup>2</sup> ]
$R$	=	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  $\bar{M}_{PM}$  (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]:

$$m_{PM} = \bar{M}_{PM} \cdot \sum_{i=1}^N (\dot{n}_i \cdot \Delta t_i) \quad (\text{A.7-44})$$

where:

$\dot{n}_i$	=	instantaneous exhaust molar flow rate [mol/s]
$\bar{M}_{PM}$	=	mean PM concentration [g/mol]
$\Delta t_i$	=	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]

$\Delta t$  = time duration of test interval [s]

For sampling with a constant dilution ratio (DR),  $m_{PM}$  [g] shall be calculated using the following equation:

$$m_{PM} = m_{PMdil} \cdot DR \quad (A.7-46)$$

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  $x_{dil/exh}$ :

$$DR = \frac{1}{1 - x_{dil/exh}} \quad (A.7-47)$$

#### A.7.4.4.2. Background correction

The same approach as that of paragraph A.7.4.1. shall be applied to correct the mass of PM for the background. Multiplying  $\bar{M}_{PMbknd}$  by the total flow of dilution air, the total background mass of PM ( $m_{PMbknd}$  [g]) is obtained. Subtraction of total background mass from total mass gives background corrected mass of particulates  $m_{PMcor}$  [g]:

$$m_{PMcor} = m_{PMuncor} - \bar{M}_{PMbknd} \cdot n_{airdil} \quad (A.7-48)$$

where:

$m_{PMuncor}$  = uncorrected PM mass [g]

$\bar{M}_{PMbknd}$  = 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 paragraphs 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:

$$W_{act} = \sum_{i=1}^N P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \cdot \frac{2 \cdot \pi}{60} \sum_{i=1}^N (n_i \cdot T_i) \quad (A.7-49)$$

where:

$P_i$	=	instantaneous engine power [kW]
$n_i$	=	instantaneous engine speed [ $\text{min}^{-1}$ ]
$T_i$	=	instantaneous engine torque [N·m]
$W_{\text{act}}$	=	actual cycle work [kWh]
$f$	=	data sampling rate [Hz]
$N$	=	number of measurements [-]

The specific emissions  $e_{\text{gas}}$  [g/kWh] shall be calculated in the following ways depending on the type of test cycle.

$$e_{\text{gas}} = \frac{m_{\text{gas}}}{W_{\text{act}}} \quad (\text{A.7-50})$$

where:

$m_{\text{gas}}$	=	total mass of emission [g/test]
$W_{\text{act}}$	=	cycle work [kWh]

In case of the transient cycle, the final test result  $e_{\text{gas}}$  [g/kWh] shall be a weighted average from cold start test and hot start test by using:

$$e_{\text{gas}} = \frac{(0.1 \cdot m_{\text{cold}}) + (0.9 \cdot m_{\text{hot}})}{(0.1 \cdot W_{\text{actcold}}) + (0.9 \cdot W_{\text{acthot}}} \quad (\text{A.7-51})$$

In case of an infrequent (periodic) exhaust regeneration (paragraph 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  $e_{\text{gas}}$  [g/kWh] are calculated as follows:

$$e_{\text{gas}} = \frac{\sum_{i=1}^{N_{\text{mode}}} (\dot{m}_{\text{gas},i} \cdot WF_i)}{\sum_{i=1}^{N_{\text{mode}}} (P_i \cdot WF_i)} \quad (\text{A.7-52})$$

where:

$\dot{m}_{\text{gas},i}$	=	mean emission mass flow rate for the mode $i$ [g/h]
$P_i$	=	engine power for the mode $i$ [kW] with $P_i = P_{\text{max}i} + P_{\text{aux}i}$ (see paragraphs 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  $e_{\text{gas}}$  [g/kWh] and  $m_{\text{gas}}$  [g/test] are substituted by  $e_{\text{PM}}$  [g/kWh] and  $m_{\text{PM}}$  [g/test] respectively:

$$e_{\text{PM}} = \frac{m_{\text{PM}}}{W_{\text{act}}} \quad (\text{A.7-53})$$

where:

$m_{\text{PM}}$  = total mass of particulates emission, calculated according to paragraph A.8.3.4. [g/test]

$W_{\text{act}}$  = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in paragraph A.7.5.1.

A.7.5.2.2. Steady state discrete-mode cycle

The particulate specific emission  $e_{\text{PM}}$  [g/kWh] shall be calculated in the following way:

A.7.5.2.2.1. For the single-filter method

$$e_{\text{PM}} = \frac{\dot{m}_{\text{PM}}}{\sum_{i=1}^N (P_i \cdot WF_i)} \quad (\text{A.7-54})$$

where:

$P_i$  = engine power for the mode  $i$  [kW] with  $P_i = P_{\text{maxi}} + P_{\text{auxi}}$  (see paragraphs 6.3. and 7.7.1.2.)

$WF_i$  = weighing factor for the mode  $i$  [-]

$\dot{m}_{\text{PM}}$  = particulate mass flow rate [g/h]

A.7.5.2.2.2. For the multiple-filter method

$$e_{\text{PM}} = \frac{\sum_{i=1}^N (\dot{m}_{\text{PM}i} \cdot WF_i)}{\sum_{i=1}^N (P_i \cdot WF_i)} \quad (\text{A.7-55})$$

where:

$P_i$  = engine power for the mode  $i$  [kW] with  $P_i = P_{\text{maxi}} + P_{\text{auxi}}$  (see paragraphs 6.3. and 7.7.1.2.)

$WF_i$  = weighing factor for the mode  $i$  [-]

$\dot{m}_{\text{PM}i}$  = particulate mass flow rate at mode  $i$  [g/h]

For the single-filter method, the effective weighing factor,  $WF_{\text{eff}i}$ , for each mode shall be calculated in the following way:

$$WF_{\text{eff}i} = \frac{m_{\text{smpldex}hi} \cdot \overline{\dot{m}_{\text{eqdexhwet}}}}{m_{\text{smpldex}} \cdot \dot{m}_{\text{eqdexhwet}i}} \quad (\text{A.7-56})$$

where:

$m_{\text{smpldex}hi}$  = mass of the diluted exhaust sample passed through the particulate sampling filters at mode  $i$  [kg]

$m_{\text{smpldex}}$  = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

$\dot{m}_{\text{eqdexhwet}i}$  = equivalent diluted exhaust gas mass flow rate at mode  $i$  [kg/s]

$\overline{\dot{m}_{\text{eqdexhwet}}}$  = average equivalent diluted exhaust gas mass flow rate [kg/s]

The value of the effective weighing factors shall be within  $\pm 0.005$  (absolute value) of the weighing factors listed in Annex 5.

## Annex 4B - Appendix A.7.1

### Diluted exhaust flow (CVS) calibration

This Appendix 1 describes the calculations for calibrating various flow-meters. Paragraph A.7.6.1. of this Appendix 1 first 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,  $\dot{n}_{\text{ref}}$ , as a reference quantity. If he adopted reference meter outputs a flow rate in a different quantity, such as standard volume rate,  $\dot{V}_{\text{stdref}}$ , actual volume rate,  $\dot{V}_{\text{actref}}$ , or mass rate,  $\dot{m}_{\text{ref}}$ , 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:

$$\dot{n}_{\text{ref}} = \frac{\dot{V}_{\text{stdref}} \cdot p_{\text{std}}}{T_{\text{std}} \cdot R} = \frac{\dot{V}_{\text{actref}} \cdot p_{\text{act}}}{T_{\text{act}} \cdot R} = \frac{\dot{m}_{\text{ref}}}{M_{\text{mix}}} \quad (\text{A.7-57})$$

where:

$\dot{n}_{\text{ref}}$	=	reference molar flow rate [mol/s]
$\dot{V}_{\text{stdref}}$	=	reference volume flow rate, corrected to a standard pressure and a standard temperature [m <sup>3</sup> /s]
$\dot{V}_{\text{actref}}$	=	reference volume flow rate, at the actual pressure and temperature [m <sup>3</sup> /s]
$\dot{m}_{\text{ref}}$	=	reference mass flow [g/s]
$p_{\text{std}}$	=	standard pressure [Pa]
$p_{\text{act}}$	=	actual pressure of the gas [Pa]
$T_{\text{std}}$	=	standard temperature [K]
$T_{\text{act}}$	=	actual temperature of the gas [K]
$R$	=	molar gas constant [J/(mol·K)]
$M_{\text{mix}}$	=	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 paragraph 8.1.8.4., as follows:

- (a) PDP volume pumped per revolution,  $V_{rev}$  ( $m^3/rev$ ):

$$V_{rev} = \frac{\bar{n}_{ref} \cdot R \cdot \bar{T}_{in}}{\bar{p}_{in} \cdot \bar{f}_{nPDP}} \quad (A.7-58)$$

where:

$\bar{n}_{ref}$  = mean value of reference molar flow rate [mol/s]

R = molar gas constant [J/(mol · K)]

$\bar{T}_{in}$  = mean inlet temperature [K]

$\bar{p}_{in}$  = mean inlet pressure [Pa]

$\bar{f}_{nPDP}$  = mean rotational speed [rev/s]

- (b) PDP slip correction factor,  $K_s$  [s/rev]:

$$K_s = \frac{1}{\bar{f}_{nPDP}} \cdot \sqrt{\frac{\bar{p}_{out} - \bar{p}_{in}}{\bar{p}_{out}}} \quad (A.7-59)$$

where:

$\bar{n}_{ref}$  = mean reference molar flow rate [mol/s]

$\bar{T}_{in}$  = mean inlet temperature [K]

$\bar{p}_{in}$  = mean inlet pressure [Pa]

$\bar{p}_{out}$  = mean outlet pressure [Pa]

$\bar{f}_{nPDP}$  = mean PDP revolution speed [rev/s]

R = molar gas constant [J/(mol · 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 4B Appendix A.2;

- (d) The procedure in sub-paragraphs (a) through (c) of this paragraph shall be repeated for every speed that PDP is operated;

- (e) The following table illustrates these calculations for different values of  $\bar{f}_{nPDP}$ :

Table A.7.2  
**Example of PDP calibration data**

$\bar{f}_{n\text{PDP}}$ [rev/min]	$\bar{f}_{n\text{PDP}}$ [rev/s]	$a_1$ [m <sup>3</sup> /min]	$a_1$ [m <sup>3</sup> /s]	$a_0$ [m <sup>3</sup> /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 paragraph 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.,  $r_{\text{SSV}}$  versus  $r_{\text{CFV}}$ ). These governing equations assume one-dimensional isentropic inviscid compressible flow of an ideal gas. In paragraph 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,  $\gamma$ , 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  $\gamma$  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:

$$\dot{n} = C_d \cdot C_f \cdot \frac{A_t \cdot p_{\text{in}}}{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}} \quad (\text{A.7-60})$$

where:

- $C_d$  = Discharge coefficient, as determined in paragraph A.7.6.3.(a) [-]  
 $C_f$  = Flow coefficient, as determined in paragraph A.7.6.3.(b) [-]  
 $A_t$  = Venturi throat cross-sectional area [m<sup>2</sup>]  
 $p_{\text{in}}$  = Venturi inlet absolute static pressure [Pa]  
 $Z$  = Compressibility factor [-]

$M_{\text{mix}}$  = Molar mass of gas mixture [kg/mol]

$R$  = Molar gas constant [J/(mol·K)]

$T_{\text{in}}$  = Venturi inlet absolute temperature [K]

(a) Using the data collected in paragraph 8.1.8.4.,  $C_d$  is calculated using the following equation:

$$C_d = \dot{n}_{\text{ref}} \cdot \frac{\sqrt{Z \cdot M_{\text{mix}} \cdot R \cdot T_{\text{in}}}}{C_f \cdot A_t \cdot p_{\text{in}}} \quad (\text{A.7-61})$$

where:

$\dot{n}_{\text{ref}}$  = 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,  $C_{f\text{CFV}}$  is derived from the following table based on values for  $\beta$  (ratio of venturi throat to inlet diameters) and  $\gamma$  (ratio of specific heats of the gas mixture), using linear interpolation to find intermediate values:

Table A.7.3  
 **$C_{f\text{CFV}}$  versus  $\beta$  and  $\gamma$  for CFV flow-meters**

$\beta$	$C_{f\text{CFV}}$	
	$\gamma_{\text{exh}}=1.385$	$\gamma_{\text{dexh}}=\gamma_{\text{air}}=1.399$
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

$\beta$	$\gamma_{\text{exh}}=1.385$	$C_{\text{ICFV}}$ $\gamma_{\text{dexh}}=\gamma_{\text{air}}=1.399$
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  $C_f$ :

$$C_f = \left[ \frac{2 \cdot \gamma \cdot \left( r^{\frac{\gamma-1}{\gamma}} - 1 \right)}{(\gamma-1) \cdot \left( \beta^4 - r^{\frac{-2}{\gamma}} \right)} \right]^{\frac{1}{2}} \quad (\text{A.7-62})$$

where:

- $\gamma$  = 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-paragraph (c)(3) of this section
- $\beta$  = 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:

$$r_{SSV} = 1 - \frac{\Delta p_{SSV}}{p_{in}} \quad (A.7-63)$$

where:

$\Delta p_{SSV}$  = differential static pressure; venturi inlet minus venturi throat [Pa]

(ii) For CFV systems only,  $r_{CFV}$  shall be calculated iteratively using the following equation:

$$r_{CFV}^{\frac{1-\gamma}{\gamma}} + \left( \frac{\gamma-1}{2} \right) \cdot \beta^4 \cdot r_{CFV}^{\frac{2}{\gamma}} = \frac{\gamma+1}{2} \quad (A.7-64)$$

(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  $\gamma = 1.385$  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  $\gamma = 1.399$  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,  $x_{H_2O}$ , determined as described in paragraph A.7.1.2., as follows:

$$M_{mix} = M_{air} \cdot (1 - x_{H_2O}) + M_{H_2O} \cdot (x_{H_2O}) \quad (A.7-65)$$

where:

$M_{air}$  = 28.96559 g/mol

$M_{H_2O}$  = 18.01528 g/mol

$x_{H_2O}$  = 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  $\pm 1$  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  $M_{\text{mix}}$  may be assumed**

<i>If calibration <math>T_{\text{dew}}</math> (°C) is...</i>	<i>the following constant <math>M_{\text{mix}}</math> (g/mol) is assumed</i>	<i>for the following ranges of <math>T_{\text{dew}}</math> (°C) during emission tests<sup>a</sup></i>
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

<sup>a</sup> 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,  $\mu$ , is needed to compute  $Re^{\#}$ , a specific viscosity model may be used to determine  $\mu$  for calibration gas (usually air), using good engineering judgment. Alternatively, the Sutherland three-coefficient viscosity model may be used to approximate  $\mu$ :

$$Re^{\#} = \frac{4 \cdot M_{\text{mix}} \cdot \dot{n}_{\text{ref}}}{\pi \cdot d_t \cdot \mu} \quad (\text{A.7-66})$$

where:

$d_t$  = diameter of the SSV throat [m]

$M_{\text{mix}}$  = mixture molar mass [kg/mol]

$\dot{n}_{\text{ref}}$  = reference molar flow rate [mol/s]

and, using the Sutherland three-coefficient viscosity model:

$$\mu = \mu_0 \left( \frac{T_{\text{in}}}{T_0} \right)^{\frac{3}{2}} \cdot \left( \frac{T_0 + S}{T_{\text{in}} + S} \right) \quad (\text{A.7-67})$$

where:

- $\mu$  = Dynamic viscosity of calibration gas [kg/(m·s)]  
 $\mu_0$  = 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**

<i>Gas<sup>a</sup></i>	$\mu_0$ <i>kg/(m·s)</i>	$T_0$ <i>K</i>	$S$ <i>K</i>	<i>Temp range within ±2 per cent error</i> <i>K</i>	<i>Pressure limit</i> <i>kPa</i>
Air	1.716 x 10 <sup>-5</sup>	273	111	170 to 1900	≤ 1800
CO <sub>2</sub>	1.370 x 10 <sup>-5</sup>	273	222	190 to 1700	≤ 3600
H <sub>2</sub> O	1.12 x 10 <sup>-5</sup>	350	1,064	360 to 1500	≤ 10000
O <sub>2</sub>	1.919 x 10 <sup>-5</sup>	273	139	190 to 2000	≤ 2500
N <sub>2</sub>	1.663 x 10 <sup>-5</sup>	273	107	100 to 1500	≤ 1600

<sup>a</sup> 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 4B, Appendix A.2;
- (iv) If the equation meets the criteria of  $SEE < 0.5\% \cdot \dot{m}_{ref\ max}$  (or  $\dot{m}_{ref\ max}$ ) 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 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:

- (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;

$$r = 1 - (\Delta p / p_{in}) \quad (A.7-69)$$

- (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 mean  $C_d$  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 subparagraph (e) (4) through (8) of this section shall be repeated.

## Annex 4B - Appendix A.7.2

### Drift correction

#### A.7.7.1. Scope and frequency

The calculations in this Appendix 2 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 2. 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 paragraph 8.2.2.2.

#### A.7.7.2. Correction principles

The calculations in this Appendix 2 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 paragraph A.7.5. of Annex 4B, 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 paragraph 8.2.2.2.

#### 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,  $\bar{x}$ ;
- (b) Correction for drift shall be done using the following equation:

$$x_{\text{idriftcor}} = x_{\text{refzero}} + \left( x_{\text{refspan}} - x_{\text{refzero}} \right) \frac{2x_i - (x_{\text{prezero}} + x_{\text{postzero}})}{\left( x_{\text{prespan}} + x_{\text{postspan}} \right) - \left( x_{\text{prezero}} + x_{\text{postzero}} \right)} \quad (\text{A.7-70})$$

where:

- $x_{\text{idriftcor}}$  = concentration corrected for drift [ $\mu\text{mol/mol}$ ]
- $x_{\text{refzero}}$  = reference concentration of the zero gas, which is usually zero unless known to be otherwise [ $\mu\text{mol/mol}$ ]
- $x_{\text{refspan}}$  = reference concentration of the span gas [ $\mu\text{mol/mol}$ ]

- 
- |                       |   |   |
|-----------------------|---|---|
| $x_{\text{prespan}}$  | = | pre-test interval gas analyser response to the span gas concentration [ $\mu\text{mol/mol}$ ]       |
| $x_{\text{postspan}}$ | = | post-test interval gas analyser response to the span gas concentration [ $\mu\text{mol/mol}$ ]      |
| $x_i$ or $\bar{x}$    | = | concentration recorded, i.e. measured, during test, before drift correction [ $\mu\text{mol/mol}$ ] |
| $x_{\text{prezero}}$  | = | pre-test interval gas analyser response to the zero gas concentration [ $\mu\text{mol/mol}$ ]       |
| $x_{\text{postzero}}$ | = | post-test interval gas analyser response to the zero gas concentration [ $\mu\text{mol/mol}$ ]      |
- (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,  $x_{\text{prespan}}$ , is not recorded,  $x_{\text{prespan}}$  shall be set equal to the reference concentration of the span gas:  $x_{\text{prespan}} = x_{\text{refspan}}$ ;
- (f) If any pre-test interval analyser response to the zero gas concentration,  $x_{\text{prezero}}$ , is not recorded,  $x_{\text{prezero}}$  shall be set equal to the reference concentration of the zero gas:  $x_{\text{prezero}} = x_{\text{refzero}}$ ;
- (g) Usually the reference concentration of the zero gas,  $x_{\text{refzero}}$ , is zero:  $x_{\text{refzero}} = 0 \mu\text{mol/mol}$ . However, in some cases it might be known that  $x_{\text{refzero}}$  has a non-zero concentration. For example, if a  $\text{CO}_2$  analyser is zeroed using ambient air, the default ambient air concentration of  $\text{CO}_2$ , which is  $375 \mu\text{mol/mol}$ , may be used. In this case,  $x_{\text{refzero}} = 375 \mu\text{mol/mol}$ . When an analyser is zeroed using a non-zero  $x_{\text{refzero}}$ , the analyser shall be set to output the actual  $x_{\text{refzero}}$  concentration. For example, if  $x_{\text{refzero}} = 375 \mu\text{mol/mol}$ , the analyser shall be set to output a value of  $375 \mu\text{mol/mol}$  when the zero gas is flowing to the analyser.

## Annex 4B - 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. <sup>3</sup>	y intercept of the regression line
$m$	$a_1$	t.b.d. <sup>3</sup>	Slope of the regression line
$A/F_{st}$		-	Stoichiometric air to fuel ratio
$C_d$	$C_d$	-	Discharge coefficient
$c$	$x$	ppm, % vol	Concentration ( $\mu\text{mol}/\text{mol} = \text{ppm}$ )
$c_d$	<sup>1</sup>	ppm, % vol	Concentration on dry basis
$c_w$	<sup>1</sup>	ppm, % vol	Concentration on wet basis
$c_b$	<sup>1</sup>	ppm, % vol	Background concentration
$D$	$x_{dil}$	-	Dilution factor <sup>2</sup>
$D_0$		$\text{m}^3/\text{rev}$	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
$K_V$		$\left[ \left( \sqrt{K} \cdot \text{m}^4 \cdot \text{s} \right) / \text{kg} \right]$	CFV calibration function
$k_f$		$\text{m}^3/\text{kg fuel}$	Fuel specific factor
$k_h$		-	Humidity correction factor for NO <sub>x</sub> , diesel engines

<i>Appendix A.8</i>	<i>Appendix A.7</i>	<i>Unit</i>	<i>Quantity</i>
$k_{Dr}$	$k_{Dr}$	-	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
$\mu$	$\mu$	kg/(m·s)	Dynamic viscosity
$M$	$M$	g/mol	Molar mass <sup>3</sup>
$M_a$	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

Appendix A.8	Appendix A.7	Unit	Quantity
$m_{ssd}$		kg	Mass of secondary dilution air
$n$	$f_n$	$\text{min}^{-1}$	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
$p_r$	$p_{H_2O}$	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
$q_v$	$\dot{V}$	$\text{m}^3/\text{s}$	Volume flow rate
$q_{vcvs}$	1	$\text{m}^3/\text{s}$	CVS volume rate

Appendix A.8	Appendix A.7	Unit	Quantity
$q_{Vs}$	<sup>1</sup>	dm <sup>3</sup> /min	System flow rate of exhaust analyser system
$q_{Vt}$	<sup>1</sup>	cm <sup>3</sup> /min	Tracer gas flow rate
$\rho$	$\rho$	kg/m <sup>3</sup>	Mass density
$\rho_e$		kg/m <sup>3</sup>	Exhaust gas density
$r_d$	$DR$	-	Dilution ratio <sup>2</sup>
$RH$		per cent	Relative humidity
$r_D$	$\beta$	m/m	Ratio of diameters (CVS systems)
$r_p$		-	Pressure ratio of SSV
$Re$	$Re^\#$	-	Reynolds number
$\sigma$	$\sigma$	-	Standard deviation
$T$	$T$	°C	Temperature
$T_a$		K	Absolute temperature
$t$	$t$	s	Time
$\Delta t$	$\Delta t$	s	Time interval
$u$		-	Ratio between densities of gas component and exhaust gas
$V$	$V$	m <sup>3</sup>	Volume
$q_v$	$\dot{V}$	m <sup>3</sup> /s	Volume rate
$V_0$		m <sup>3</sup> /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
$\bar{y}$	$\bar{y}$		Arithmetic mean

<sup>1</sup> See subscripts; e.g.:  $\dot{m}_{air}$  for mass rate of dry air,  $\dot{m}_{fuel}$  for fuel mass rate, etc.

<sup>2</sup> 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  $DR$ .

<sup>3</sup> t.b.d. = to be defined

A.8.0.2. Subscripts

<i>Appendix A.8<sup>1</sup></i>	<i>Appendix A.7</i>	<i>Quantity</i>
act	act	Actual quantity
<i>i</i>		Instantaneous measurement (e.g.: 1 Hz)
	<i>i</i>	An individual of a series

<sup>1</sup> 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)

<i>Appendix A.8</i>	<i>Appendix A.7</i>	<i>Quantity</i>
Ar	Ar	Argon
C1	C1	Carbon 1 equivalent hydrocarbon
CH <sub>4</sub>	CH <sub>4</sub>	Methane
C <sub>2</sub> H <sub>6</sub>	C <sub>2</sub> H <sub>6</sub>	Ethane
C <sub>3</sub> H <sub>8</sub>	C <sub>3</sub> H <sub>8</sub>	Propane
CO	CO	Carbon monoxide
CO <sub>2</sub>	CO <sub>2</sub>	Carbon dioxide
DOP	DOP	Di-octylphthalate
HC	HC	Hydrocarbon
H <sub>2</sub> O	H <sub>2</sub> O	Water
NMHC	NMHC	Non-methane hydrocarbon
NO <sub>x</sub>	NO <sub>x</sub>	Oxides of nitrogen
NO	NO	Nitric oxide
NO <sub>2</sub>	NO <sub>2</sub>	Nitrogen dioxide
PM	PM	Particulate matter
S	S	Sulphur

A.8.0.4. Symbols and abbreviations for the fuel composition

Appendix A.8 <sup>1</sup>	Appendix A.7 <sup>2</sup>	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]
$\alpha$	$\alpha$	Atomic hydrogen-to-carbon ratio (H/C)
$\varepsilon$	$\beta$	Atomic oxygen-to-carbon ratio (O/C) <sup>3</sup>
$\gamma$	$\gamma$	Atomic sulphur-to-carbon ratio (S/C)
$\delta$	$\delta$	Atomic nitrogen-to-carbon ratio (N/C)

<sup>1</sup> Referred to a fuel with chemical formula  $CH_\alpha O_\varepsilon N_\delta S_\gamma$

<sup>2</sup> Referred to a fuel with chemical formula  $CH_\alpha O_\beta S_\gamma N_\delta$

<sup>3</sup> Attention should be paid to the different meaning of symbol  $\beta$  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  $\varepsilon$  of Appendix A.8.

<sup>4</sup> 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  $CH_4$  ( $c_{CH_4}$  [-]) shall be calculated as follows for sub-paragraph (a):

$$c_{NMHC} = \frac{c_{HC(w/oNMC)} \cdot (1 - E_{CH_4}) - c_{HC(w/NMC)}}{E_{C_2H_6} - E_{CH_4}} \quad (A.8-1a)$$

$$c_{CH_4} = \frac{c_{HC(w/NMC)} - c_{HC(w/oNMC)} \cdot (1 - E_{C_2H_6})}{RF_{CH_4[THC-FID]} \cdot (E_{C_2H_6} - E_{CH_4})} \quad (A.8-2a)$$

The concentration of NMHC and CH<sub>4</sub> shall be calculated as follows for sub-paragraph (b):

$$c_{\text{NMHC}} = \frac{c_{\text{HC(w/oNMC)}} \cdot (1 - E_{\text{CH}_4}) - c_{\text{HC(w/NMC)}} \cdot RF_{\text{CH}_4[\text{THC-FID}]} \cdot (1 - E_{\text{CH}_4})}{E_{\text{C}_2\text{H}_6} - E_{\text{CH}_4}} \quad (\text{A.8-1b})$$

$$c_{\text{CH}_4} = \frac{c_{\text{HC(w/NMC)}} \cdot RF_{\text{CH}_4[\text{THC-FID}]} \cdot (1 - E_{\text{CH}_4}) - c_{\text{HC(w/oNMC)}} \cdot (1 - E_{\text{C}_2\text{H}_6})}{RF_{\text{CH}_4[\text{THC-FID}]} \cdot (E_{\text{C}_2\text{H}_6} - E_{\text{CH}_4})} \quad (\text{A.8-2b})$$

where:

$c_{\text{HC(w/NMC)}}$  = HC concentration with sample gas flowing through the NMC [ppm]

$c_{\text{HC(w/oNMC)}}$  = HC concentration with sample gas bypassing the NMC [ppm]

$RF_{\text{CH}_4[\text{THC-FID}]}$  = methane response factor as determined in paragraph 8.1.10.1.4. [-]

$E_{\text{CH}_4}$  = methane efficiency, as determined in paragraph 8.1.10.3. [-]

$E_{\text{C}_2\text{H}_6}$  = ethane efficiency, as determined in paragraph 8.1.10.3. [-]

If  $RF_{\text{CH}_4[\text{THC-FID}]} < 1.05$ , 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  $q_{\text{mgas},i}$  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:

$$q_{\text{mgas},i} = k_h \cdot k \cdot u_{\text{gas}} \cdot q_{\text{mew},i} \cdot c_{\text{gas},i} \cdot 3600 \quad (\text{A.8-3})$$

$q_{\text{mgas},i}$  = emission rate in mode  $i$  of the steady state test [g/h]

$k$  = 1 for  $c_{\text{gasr},w,i}$  in [ppm] and  $k = 10,000$  for  $c_{\text{gasr},w,i}$  in [per cent vol]

$k_h$  = NO<sub>x</sub> correction factor [-], only to be applied for the NO<sub>x</sub> emission calculation (see paragraph A.8.2.2.)

$u_{\text{gas}}$  = 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)

$q_{\text{mew},i}$  = exhaust gas mass flow rate in mode  $i$  on a wet basis [kg/s]

$c_{\text{gas},i}$  = 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  $m_{\text{gas}}$  [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:

$$m_{\text{gas}} = \frac{1}{f} \cdot k_h \cdot k \cdot u_{\text{gas}} \cdot \sum_{i=1}^N (q_{\text{mew},i} \cdot c_{\text{gas},i}) \quad (\text{A.8-4})$$

where:

- $f$  = data sampling rate [Hz]
- $k_h$  = NO<sub>x</sub> correction factor [-], only to be applied for the NO<sub>x</sub> emission calculation
- $k$  = 1 for  $c_{\text{gasr},w,i}$  in [ppm] and  $k = 10,000$  for  $c_{\text{gasr},w,i}$  in [per cent vol]
- $u_{\text{gas}}$  = component specific factor [-] (see paragraph A.8.2.4.)
- $N$  = number of measurements [-]
- $q_{\text{mew},i}$  = instantaneous exhaust gas mass flow rate on a wet basis [kg/s]
- $c_{\text{gas},i}$  = instantaneous emission concentration in the raw exhaust gas, on a wet basis [ppm] or [per cent vol]

The following paragraphs show how the needed quantities ( $c_{\text{gas},i}$ ,  $u_{\text{gas}}$  and  $q_{\text{mew},i}$ ) 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:

$$k_{w,a} = \frac{\left( 1 - \frac{1.2442 \cdot H_a + 111.19 \cdot w_H \cdot \frac{q_{\text{mf},i}}{q_{\text{mad},i}}}{773.4 + 1.2442 \cdot H_a + \frac{q_{\text{mf},i}}{q_{\text{mad},i}} \cdot k_f \cdot 1000} \right)}{\left( 1 - \frac{p_r}{p_b} \right)} \quad (\text{A.8-6})$$

where:

- $H_a$  = intake air humidity [g H<sub>2</sub>O/kg dry air]
- $q_{\text{mf},i}$  = instantaneous fuel flow rate [kg/s]
- $q_{\text{mad},i}$  = 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 [ $\text{m}^3/\text{kg}$  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:

$$k_{w,a} = \frac{\frac{1}{1 + \alpha \cdot 0.005 \cdot (c_{\text{CO}_2} + c_{\text{CO}})} - k_{w1}}{1 - \frac{p_r}{p_b}} \quad (\text{A.8-9})$$

where:

- $c_{\text{CO}_2}$  = concentration of  $\text{CO}_2$  in the raw exhaust gas, on a dry basis [per cent vol]  
 $c_{\text{CO}}$  = 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))  
 $\alpha$  = 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<sub>x</sub> correction for humidity and temperature

As the NO<sub>x</sub> emission depends on ambient air conditions, the NO<sub>x</sub> 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<sub>2</sub>O/kg dry air.

$$k_h = \frac{15.698 \cdot H_a}{1000} + 0.832 \quad (\text{A.8-11})$$

where:

$H_a$  = humidity of the intake air [g H<sub>2</sub>O/kg dry air]

A.8.2.4. Component specific factor  $u$

A.8.2.4.1. Tabulated values

Applying some simplifications (assumption on the  $\lambda$  value and on intake air conditions as shown in the following table) to the equations of paragraph A.8.2.4.2. figures for  $u_{\text{gas}}$ , can be calculated (see paragraph A.8.2.1.). The  $u_{\text{gas}}$  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 <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>
$\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]		2.053	1.250	0.621	1.9636	1.4277	0.716
Fuel	$\rho_c$ [kg/m <sup>3</sup> ]	Coefficient $u_{\text{gas}}$ at $\lambda = 2$ , 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,  $u_{\text{gas},i}$  can be calculated by the density ratio of the component and the exhaust or alternatively by the corresponding ratio of molar masses:

$$u_{\text{gas},i} = M_{\text{gas}} / (M_{e,i} \cdot 1000) \quad (\text{A.8-12})$$

or

$$u_{\text{gas},i} = \rho_{\text{gas}} / (\rho_{e,i} \cdot 1000) \quad (\text{A.8-13})$$

where:

$M_{\text{gas}}$  = molar mass of the gas component [g/mol]

$M_{e,i}$  = instantaneous molar mass of the wet raw exhaust gas [g/mol]

$\rho_{\text{gas}}$  = density of the gas component [kg/m<sup>3</sup>]

$\rho_{e,i}$  = instantaneous density of the wet raw exhaust gas [kg/m<sup>3</sup>]

The molar mass of the exhaust,  $M_{e,i}$  shall be derived for a general fuel composition  $\text{CH}_\alpha\text{O}_\varepsilon\text{N}_\delta\text{S}_\gamma$  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]
- $\alpha$  = molar hydrogen-to-carbon ratio [-]
- $\delta$  = molar nitrogen-to-carbon ratio [-]
- $\varepsilon$  = molar oxygen-to-carbon ratio [-]
- $\gamma$  = atomic sulphur-to-carbon ratio [-]
- $H_a$  = intake air humidity [g H<sub>2</sub>O/kg dry air]
- $M_a$  = dry intake air molecular mass = 28.965 g/mol

The instantaneous raw exhaust density  $\rho_{e,i}$  [kg/m<sup>3</sup>] shall be derived as follows:

$$\rho_{e,i} = \frac{1000 + H_a + 1000 \cdot (q_{mf,i} / q_{mad,i})}{773.4 + 1.2434 \cdot H_a + k_f \cdot 1000 \cdot (q_{mf,i} / q_{mad,i})} \quad (\text{A.8-15})$$

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<sub>2</sub>O/kg dry air]
- $k_f$  = combustion additional volume [m<sup>3</sup>/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:

$$q_{mew,i} = \frac{q_{vt} \cdot \rho_e}{10^{-6} \cdot (c_{mix,i} - c_b)} \quad (A.8-17)$$

where:

- $q_{vt}$  = tracer gas flow rate [m<sup>3</sup>/s]
- $c_{mix,i}$  = instantaneous concentration of the tracer gas after mixing [ppm]
- $\rho_e$  = density of the raw exhaust gas [kg/m<sup>3</sup>]
- $c_b$  = 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:

$$q_{mew,i} = q_{maw,i} \cdot \left( 1 + \frac{1}{A/F_{st} \cdot \lambda_i} \right) \quad (A.8-18)$$

with:

$$A/F_{st} = \frac{138.0 \cdot \left( 1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12.011 + 1.00794 \cdot \alpha + 15.9994 \cdot \varepsilon + 14.0067 \cdot \delta + 32.065 \cdot \gamma} \quad (A.8-19)$$

$$\lambda_i = \frac{\left( 100 - \frac{c_{COd} \cdot 10^{-4}}{2} - c_{HCw} \cdot 10^{-4} \right) + \left( \frac{\alpha}{4} \cdot \frac{1 - \frac{2 \cdot c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{COd} \cdot 10^{-4}}{3.5 \cdot c_{CO2d}}} \right) \cdot (c_{CO2d} + c_{COd} \cdot 10^{-4})}{4.764 \cdot \left( 1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \cdot (c_{CO2d} + c_{COd} \cdot 10^{-4} + c_{HCw} \cdot 10^{-4})} \quad (A.8-20)$$

where:

- $q_{maw,i}$  = wet intake air mass flow rate [kg/s]
- $A/F_{st}$  = stoichiometric air-to-fuel ratio [-]
- $\lambda_i$  = instantaneous excess air ratio [-]
- $c_{COd}$  = concentration of CO in the raw exhaust gas on a dry basis [ppm]

$c_{\text{CO}_2\text{d}}$	=	concentration of CO <sub>2</sub> in the raw exhaust gas on a dry basis [per cent]
$c_{\text{HCw}}$	=	concentration of HC in the raw exhaust gas on a wet basis [ppm C1]
$\alpha$	=	molar hydrogen-to-carbon ratio [-]
$\delta$	=	molar nitrogen-to-carbon ratio [-]
$\varepsilon$	=	molar oxygen-to-carbon ratio [-]
$\gamma$	=	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  $q_{\text{mew},i}$  [kg/s]:

$$q_{\text{mew},i} = q_{\text{mf},i} \cdot \left[ \frac{1.4 \cdot w_{\text{C}}^2}{(1.0828 \cdot w_{\text{C}} + k_{\text{fd}} \cdot f_{\text{c}}) f_{\text{c}}} \left( 1 + \frac{H_{\text{a}}}{1000} \right) + 1 \right] \quad (\text{A.8-21})$$

with the carbon factor  $f_{\text{c}}$  [-] given by:

$$f_{\text{c}} = 0.5441 \cdot (c_{\text{CO}_2\text{d}} - c_{\text{CO}_2\text{d,a}}) + \frac{c_{\text{COd}}}{18522} + \frac{c_{\text{HCw}}}{17355} \quad (\text{A.8-22})$$

where:

$q_{\text{mf},i}$	=	instantaneous fuel mass flow rate [kg/s]
$w_{\text{C}}$	=	carbon content of fuel [per cent mass]
$H_{\text{a}}$	=	intake air humidity [g H <sub>2</sub> O/kg dry air]
$k_{\text{fd}}$	=	combustion additional volume on a dry basis [m <sup>3</sup> /kg fuel]
$c_{\text{CO}_2\text{d}}$	=	dry CO <sub>2</sub> concentration in the raw exhaust [per cent]
$c_{\text{CO}_2\text{d,a}}$	=	dry CO <sub>2</sub> concentration in the ambient air [per cent]
$c_{\text{COd}}$	=	dry CO concentration in the raw exhaust [ppm]
$c_{\text{HCw}}$	=	wet HC concentration in the raw exhaust [ppm]

and factor  $k_{\text{fd}}$  [m<sup>3</sup>/kg fuel] that is calculated on a dry basis by subtracting the water formed by combustion from  $k_{\text{f}}$ :

$$k_{\text{fd}} = k_{\text{f}} - 0.11118 \cdot w_{\text{H}} \quad (\text{A.8-23})$$

where:

$k_{\text{f}}$	=	fuel specific factor of equation (A.8-7) [m <sup>3</sup> /kg fuel]
$w_{\text{H}}$	=	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  $m_{\text{gas}}$  [g/test] shall be determined from the following equation:

$$m_{\text{gas}} = k_h \cdot k \cdot u_{\text{gas}} \cdot c_{\text{gas}} \cdot m_{\text{ed}} \quad (\text{A.8-24})$$

where:

$u_{\text{gas}}$  = ratio between density of exhaust component and density of air, as given in Table A.8.2 or calculated with equation (A.8-35) [-]

$c_{\text{gas}}$  = mean background corrected concentration of the component on a wet basis [ppm] or [per cent vol] respectively

$k_h$  = NO<sub>x</sub> correction factor [-], only to be applied for the NO<sub>x</sub> emission calculation

$k$  = 1 for  $c_{\text{gasr,w,i}}$  in [ppm],  $k = 10,000$  for  $c_{\text{gasr,w,i}}$  in [per cent vol]

$m_{\text{ed}}$  = total diluted exhaust gas mass over the cycle [kg/test]

For systems with flow compensation (without heat exchanger), the mass of the pollutants  $m_{\text{gas}}$  [g/test] shall be determined by calculation of the instantaneous mass emissions, by integration and by background correction according to the following equation:

$$m_{\text{gas}} = k_h \cdot k \cdot \left\{ \sum_{i=1}^N \left[ \left( m_{\text{ed},i} \cdot c_e \cdot u_{\text{gas}} \right) \right] - \left[ \left( m_{\text{ed}} \cdot c_d \cdot \left( 1 - \frac{1}{D} \right) \cdot u_{\text{gas}} \right) \right] \right\} \quad (\text{A.8-25})$$

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]

$m_{\text{ed},i}$  = mass of the diluted exhaust gas during time interval  $i$  [kg]

$m_{\text{ed}}$  = total mass of diluted exhaust gas over the cycle [kg]

$u_{\text{gas}}$  = tabulated value from Table A.8.2 [-]

$D$  = dilution factor (see equation (A.8-29) of paragraph A.8.3.2.2.) [-]

$k_h$  = NO<sub>x</sub> correction factor [-], only to be applied for the NO<sub>x</sub> emission calculation

$k$  = 1 for  $c$  in [ppm],  $k = 10,000$  for  $c$  in [per cent vol]

The concentrations  $c_{\text{gas}}$ ,  $c_e$  and  $c_d$  can be either values measured in a batch sample (bag, but not allowed for  $\text{NO}_x$  and HC) or be averaged by integration from continuous measurements. Also  $m_{\text{ed},i}$  has to be averaged by integration over the test cycle.

The following equations show how the needed quantities ( $c_e$ ,  $u_{\text{gas}}$  and  $m_{\text{ed}}$ ) shall be calculated.

A.8.3.2. Dry-to wet concentration conversion

All concentrations in paragraph 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:

$$k_{w,e} = \left[ \left( 1 - \frac{\alpha \cdot c_{\text{CO}_2w}}{200} \right) - k_{w2} \right] \cdot 1.008 \quad (\text{A.8-26})$$

or

$$k_{w,e} = \left( \frac{(1 - k_{w2})}{1 + \frac{\alpha \cdot c_{\text{CO}_2d}}{200}} \right) \cdot 1.008 \quad (\text{A.8-27})$$

where:

- $k_{w,e}$  = dry-to-wet conversion factor for the diluted exhaust gas [-]
- $\alpha$  = molar hydrogen to carbon ratio of the fuel [-]
- $c_{\text{CO}_2w}$  = concentration of  $\text{CO}_2$  in the diluted exhaust gas on a wet basis [per cent vol]
- $c_{\text{CO}_2d}$  = concentration of  $\text{CO}_2$  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  $\text{H}_2\text{O}$ /kg dry air]
- $H_d$  = dilution air humidity [g  $\text{H}_2\text{O}$ /kg dry air]
- $D$  = dilution factor (see equation (A.8-29) of paragraph 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:

$$D = \frac{F_S}{c_{CO_2,e} + (c_{HC,e} + c_{CO,e}) \cdot 10^{-4}} \quad (\text{A.8-29})$$

where:

- $F_S$  = stoichiometric factor [-]  
 $c_{CO_2,e}$  = 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:

- $\alpha$  = 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

$$k_{w,d} = (1 - k_{w3}) \cdot 1.008 \quad (\text{A.8-32})$$

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:

$$c_{\text{gas}} = c_{\text{gas,e}} - c_{\text{d}} \cdot \left(1 - \frac{1}{D}\right) \quad (\text{A.8-34})$$

where:

$c_{\text{gas}}$  = net concentration of the gaseous pollutant [ppm] or [per cent vol]

$c_{\text{gas,e}}$  = emission concentration in the diluted exhaust gas, on a wet basis [ppm] or [per cent vol]

$c_{\text{d}}$  = emission concentration in the dilution air, on a wet basis [ppm] or [per cent vol]

$D$  = dilution factor (see equation (A.8-29) of paragraph A.8.3.2.2.) [-]

A.8.3.3. Component specific factor  $u$

The component specific factor  $u_{\text{gas}}$  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.

$$u = \frac{M_{\text{gas}}}{M_{\text{d,w}} \cdot 1000} = \frac{M_{\text{gas}}}{\left[ M_{\text{da,w}} \cdot \left(1 - \frac{1}{D}\right) + M_{\text{r,w}} \cdot \left(\frac{1}{D}\right) \right] \cdot 1000} \quad (\text{A.8-35})$$

where:

$M_{\text{gas}}$  = molar mass of the gas component [g/mol]

$M_{\text{d,w}}$  = molar mass of diluted exhaust gas [g/mol]

$M_{\text{da,w}}$  = molar mass of dilution air [g/mol]

$M_{\text{r,w}}$  = molar mass of raw exhaust gas [g/mol]

$D$  = dilution factor (see equation (A.8-29) of paragraph 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 <sub>x</sub>	CO	HC	CO <sub>2</sub>	O <sub>2</sub>	CH <sub>4</sub>
$\rho_{\text{gas}}$ [kg/m <sup>3</sup> ]		2.053	1.250	0.621	1.9636	1.4277	0.716
Fuel	$\rho_{\text{e}}$ [kg/m <sup>3</sup> ]	Coefficient $u_{\text{gas}}$ at $\lambda = 2$ , 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  $\pm 6$  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 [m<sup>3</sup>/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/m<sup>3</sup> = 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 [m<sup>3</sup>/rev]

$p_p$  = absolute pressure at pump inlet [kPa]

$n_{p,i}$  = total revolutions of pump per time interval  $i$  [rev/ $\Delta t$ ]

$\bar{T}$  = average temperature of the diluted exhaust gas at pump inlet [K]

1.293 kg/m<sup>3</sup> = 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  $\pm 11$  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  $\left[ (\sqrt{K} \cdot m^4 \cdot s) / kg \right]$   
 $p_p$  = absolute pressure at venturi inlet [kPa]  
 $T$  = absolute temperature at venturi inlet [K]  
 $1.293 \text{ kg/m}^3$  = 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:

- $\Delta t_i$  = time interval of the test [s]  
 $K_V$  = calibration coefficient of the critical flow venturi for standard conditions  $\left[ (\sqrt{K} \cdot m^4 \cdot s) / kg \right]$   
 $p_p$  = absolute pressure at venturi inlet [kPa]  
 $T$  = absolute temperature at venturi inlet [K]  
 $1.293 \text{ kg/m}^3$  = 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  $\pm 11\text{K}$  over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \cdot q_{vSSV} \cdot \Delta t \quad (\text{A.8-40})$$

where:

- $1.293 \text{ kg/m}^3$  = air density at 273.15 K and 101.325 kPa  
 $\Delta t$  = cycle time [s]  
 $q_{vSSV}$  = air flow rate at standard conditions (101.325 kPa, 273.15 K) [ $\text{m}^3/\text{s}$ ]

with

$$q_{vSSV} = \frac{A_0}{60} d_v^2 C_d p_p \sqrt{\left[ \frac{1}{T_{in}} (r_p^{1.4286} - r_p^{1.7143}) \cdot \left( \frac{1}{1 - r_D^4 r_p^{1.4286}} \right) \right]} \quad (\text{A.8-41})$$

where:

$$A_0 = \text{collection of constants and units conversions} = 0.0056940 \left[ \frac{\text{m}^3 \cdot \text{K}^{\frac{1}{2}} \cdot 1}{\text{min} \cdot \text{kPa} \cdot \text{mm}^2} \right]$$

$$d_V = \text{diameter of the SSV throat [mm]}$$

$$C_d = \text{discharge coefficient of the SSV [-]}$$

$$p_p = \text{absolute pressure at venturi inlet [kPa]}$$

$$T_{in} = \text{temperature at the venturi inlet [K]}$$

$$r_p = \text{ratio of the SSV throat to inlet absolute static pressure,} \left( 1 - \frac{\Delta p}{p_a} \right) [-]$$

$$r_D = \text{ratio of the SSV throat diameter to the inlet pipe inner diameter} \frac{d}{D} [-]$$

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:

$$1.293 \text{ kg/m}^3 = \text{air density at 273.15 K and 101.325 kPa}$$

$$\Delta t_i = \text{time interval [s]}$$

$$q_{VSSV} = \text{volumetric flow rate of the SSV [m}^3/\text{s]}$$

#### 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 paragraph 8.1.12.2.5.

##### A.8.3.5.1.1. Partial flow dilution system

The calculation for double dilution system is shown in paragraph 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:

$$m_f = \text{particulate mass sampled over the cycle [mg]}$$

$$r_s = \text{average sample ratio over the test cycle [-]}$$

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 paragraph 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 paragraph 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 paragraph 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 paragraphs 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:

$$W_{act} = \sum_{i=1}^N P_i \cdot \Delta t_i = \frac{1}{f} \cdot \frac{1}{3600} \cdot \frac{1}{10^3} \frac{2 \cdot \pi}{60} \sum_{i=1}^N (n_i \cdot T_i) \quad (\text{A.8-60})$$

where:

$P_i$	=	instantaneous engine power [kW]
$n_i$	=	instantaneous engine speed [ $\text{min}^{-1}$ ]
$T_i$	=	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 (paragraph 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.8.4.1.2. Steady-state discrete-mode cycle

The specific emissions  $e_{\text{gas}}$  [g/kWh] are calculated as follows:

$$e_{\text{gas}} = \frac{\sum_{i=1}^{N_{\text{mode}}} (q_{m\text{gas},i} \cdot WF_i)}{\sum_{i=1}^{N_{\text{mode}}} (P_i \cdot WF_i)} \quad (\text{A.8-63})$$

where:

$q_{m\text{gas},i}$  = mean emission mass flow rate for the mode  $i$  [g/h]

$P_i$  = engine power for the mode  $i$  [kW] with  $P_i = P_{\text{max}i} + P_{\text{aux}i}$  (see paragraphs 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  $e_{\text{gas}}$  [g/kWh] and  $m_{\text{gas}}$  [g/test] are substituted by  $e_{\text{PM}}$  [g/kWh] and  $m_{\text{PM}}$  [g/test] respectively:

$$e_{\text{PM}} = \frac{m_{\text{PM}}}{W_{\text{act}}} \quad (\text{A.8-64})$$

where:

$m_{\text{PM}}$  = total mass of particulates emission, calculated according to paragraph A.8.3.5. [g/test]

$W_{\text{act}}$  = cycle work [kWh]

The emissions on the transient composite cycle (i.e. cold phase and hot phase) shall be calculated as shown in paragraph A.8.4.1.

A.8.4.2.2. Steady state discrete-mode cycle

The particulate specific emission  $e_{\text{PM}}$  [g/kWh] shall be calculated in the following way:

(a) For the single-filter method

$$e_{\text{PM}} = \frac{q_{m\text{PM}}}{\sum_{i=1}^N (P_i \cdot WF_i)} \quad (\text{A.8-65})$$

where:

$P_i$  = engine power for the mode  $i$  [kW] with  
 $P_i = P_{\max i} + P_{\text{aux}i}$  (see paragraphs 6.3. and 7.7.1.2.)

$WF_i$  = weighing factor for the mode  $i$  [-]

$q_{\text{mPM}}$  = particulate mass flow rate [g/h]

(b) For the multiple-filter method

$$e_{\text{PM}} = \frac{\sum_{i=1}^N (q_{\text{mPM}i} \cdot WF_i)}{\sum_{i=1}^N (P_i \cdot WF_i)} \quad (\text{A.8-66})$$

where:

$P_i$  = engine power for the mode  $i$  [kW] with  
 $P_i = P_{\max i} + P_{\text{aux}i}$  (see paragraphs 6.3. and 7.7.1.2.)

$WF_i$  = weighing factor for the mode  $i$  [-]

$q_{\text{mPM}i}$  = 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:

$$WF_{ei} = \frac{m_{\text{sepi}} \cdot \overline{q_{\text{medf}}}}{m_{\text{sep}} \cdot q_{\text{medfi}}} \quad (\text{A.8-67})$$

where:

$m_{\text{sepi}}$  = mass of the diluted exhaust sample passed through the particulate sampling filters at mode  $i$  [kg]

$\overline{q_{\text{medf}}}$  = average equivalent diluted exhaust gas mass flow rate [kg/s]

$q_{\text{medfi}}$  = equivalent diluted exhaust gas mass flow rate at mode  $i$  [kg/s]

$m_{\text{sep}}$  = mass of the diluted exhaust sample passed through the particulate sampling filters [kg]

The value of the effective weighing factors shall be within  $\pm 0.005$  (absolute value) of the weighing factors listed in Annex 5.

## Annex 4B - 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<sup>3</sup>/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 ( $q_{\text{CVS}}$ ) at each restriction setting (minimum 6 settings) shall be calculated in standard m<sup>3</sup>/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<sup>3</sup>/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{\text{CVS}}}{n} \cdot \frac{T}{273.15} \cdot \frac{101.325}{p_p} \quad (\text{A.8-68})$$

where:

$q_{\text{CVS}}$  = airflow rate at standard conditions (101.325 kPa, 273.15 K) [m<sup>3</sup>/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:

$$X_0 = \frac{1}{n} \cdot \sqrt{\frac{\Delta p_p}{p_p}} \quad (\text{A.8-69})$$

where:

- $\Delta p_p$  = 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  $D_0$  [ $\text{m}^3/\text{rev}$ ] and  $m$  [ $\text{m}^3/\text{s}$ ], 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  $\pm 0.5$  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  $\text{m}^3/\text{s}$  from the flow-meter data using the manufacturer's prescribed method. The calibration coefficient  $K_V$  [ $(\sqrt{K} \cdot \text{m}^4 \cdot \text{s})/\text{kg}$ ] 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) [ $\text{m}^3/\text{s}$ ]  
 $T$  = 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  $\pm 0.3$  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:

$$C_d = \frac{q_{VSSV}}{\frac{A_0}{60} \cdot d_v^2 \cdot p_p \cdot \sqrt{\left[ \frac{1}{T_{in,V}} (r_p^{1.4286} - r_p^{1.7143}) \left( \frac{1}{1 - r_D^4 \cdot r_p^{1.4286}} \right) \right]}} \quad (A.8-72)$$

where:

$$A_0 = \text{collection of constants and units conversions} = 0.0056940 \left[ \frac{m^3 \cdot K^{\frac{1}{2}} \cdot 1}{min \cdot kPa \cdot mm^2} \right]$$

$$q_{VSSV} = \text{air flow rate at standard conditions (101.325 kPa, 273.15 K) [m}^3\text{/s]}$$

$$T_{in,V} = \text{temperature at the venturi inlet [K]}$$

$$d_v = \text{diameter of the SSV throat [mm]}$$

$$r_p = \text{ratio of the SSV throat to inlet absolute static pressure} = 1 - \Delta p / p_p \text{ [-]}$$

$$r_D = \text{ratio of the SSV throat diameter, } d_v, \text{ to the inlet pipe inner diameter D [-]}$$

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:

$$Re = A_1 \cdot 60 \cdot \frac{q_{VSSV}}{d_v \cdot \mu} \quad (A.8-73)$$

with

$$\mu = \frac{b \times T^{1.5}}{S + T} \quad (A.8-74)$$

where:

$$A_1 = \text{collection of constants and units conversions} = 27.43831 \left[ \frac{\text{kg}}{\text{m}^3} \cdot \frac{\text{min}}{\text{s}} \cdot \frac{\text{mm}}{\text{m}} \right]$$

$$q_{vSSV} = \text{air flow rate at standard conditions (101.325 kPa, 273.15 K)} \\ [\text{m}^3/\text{s}]$$

$$d_v = \text{diameter of the SSV throat [mm]}$$

$$\mu = \text{absolute or dynamic viscosity of the gas [kg/(m}\cdot\text{s)]}$$

$$b = 1.458 \times 10^6 \text{ (empirical constant) [kg/(m}\cdot\text{s}\cdot\text{K}^{0.5})]$$

$$S = 110.4 \text{ (empirical constant) [K]}$$

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  $\pm 0.5$  per cent of the measured  $C_d$  for each calibration point.

## Annex 4B - 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 4B.

$$c_{\text{idriftcor}} = c_{\text{refzero}} + (c_{\text{refspan}} - c_{\text{refzero}}) \frac{2c_i - (c_{\text{prezero}} + c_{\text{postzero}})}{(c_{\text{prespan}} + c_{\text{postspan}}) - (c_{\text{prezero}} + c_{\text{postzero}})} \quad (\text{A.8-75})$$

where:

- $c_{\text{idriftcor}}$  = concentration corrected for drift [ppm]
- $c_{\text{refzero}}$  = reference concentration of the zero gas, which is usually zero unless known to be otherwise [ppm]
- $c_{\text{refspan}}$  = reference concentration of the span gas [ppm]
- $c_{\text{prespan}}$  = pre-test interval gas analyser response to the span gas concentration [ppm]
- $c_{\text{postspan}}$  = post-test interval gas analyser response to the span gas concentration [ppm]
- $c_i$  or  $\bar{c}$  = concentration recorded, i.e. measured, during test, before drift correction [ppm]
- $c_{\text{prezero}}$  = pre-test interval gas analyser response to the zero gas concentration [ppm]
- $c_{\text{postzero}}$  = post-test interval gas analyser response to the zero gas concentration [ppm]

## Annex 5

### Test cycles

1. Test cycles
  - 1.1. Steady-state discrete-mode testing
    - (a) For variable-speed engines, the following 8-mode cycle<sup>1</sup> shall be followed in dynamometer operation on the test engine:

<i>Mode Number</i>	<i>Engine Speed</i>	<i>Torque [per cent]</i>	<i>Weighing Factor</i>
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

- (b) For constant-speed engines, the following 5-mode cycle<sup>2</sup> shall be followed in dynamometer operation on the test engine:

<i>Mode Number</i>	<i>Engine Speed</i>	<i>Torque [per cent]</i>	<i>Weighing Factor</i>
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<sup>3</sup> 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.

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<sup>1</sup> Identical to C1 cycle as described in paragraph 8.3. of ISO 8178-4 : 2008.

<sup>2</sup> Identical to D2 cycle as described in paragraph 8.4. of ISO 8178-4 : 2008.

<sup>3</sup> For a better illustration of the prime power definition, see figure 2 of ISO 8528-1:1993(E).

1.2. Steady-state ramped-modal testing

- (a) For variable-speed engines, the following 9-mode duty cycle applies in case of ramped-modal testing:

<i>RMC mode</i>	<i>Time in mode [s]</i>	<i>Engine speed<sup>a,c</sup></i>	<i>Torque (per cent)<sup>b,c</sup></i>
1a Steady-state	126	Warm idle	0
1b Transition	20	Linear transition <sup>(2)</sup>	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

<sup>a</sup> Speed terms as per footnote of the steady-state discrete mode test.

<sup>b</sup> The percent torque is relative to the maximum torque at the commanded engine speed.

<sup>c</sup> 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:

<i>RMC mode</i>	<i>Time in mode [s]</i>	<i>Engine speed</i>	<i>Torque (per cent)<sup>a,b</sup></i>
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

<sup>a</sup> The percent torque is relative to maximum test torque.

<sup>b</sup> 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:

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

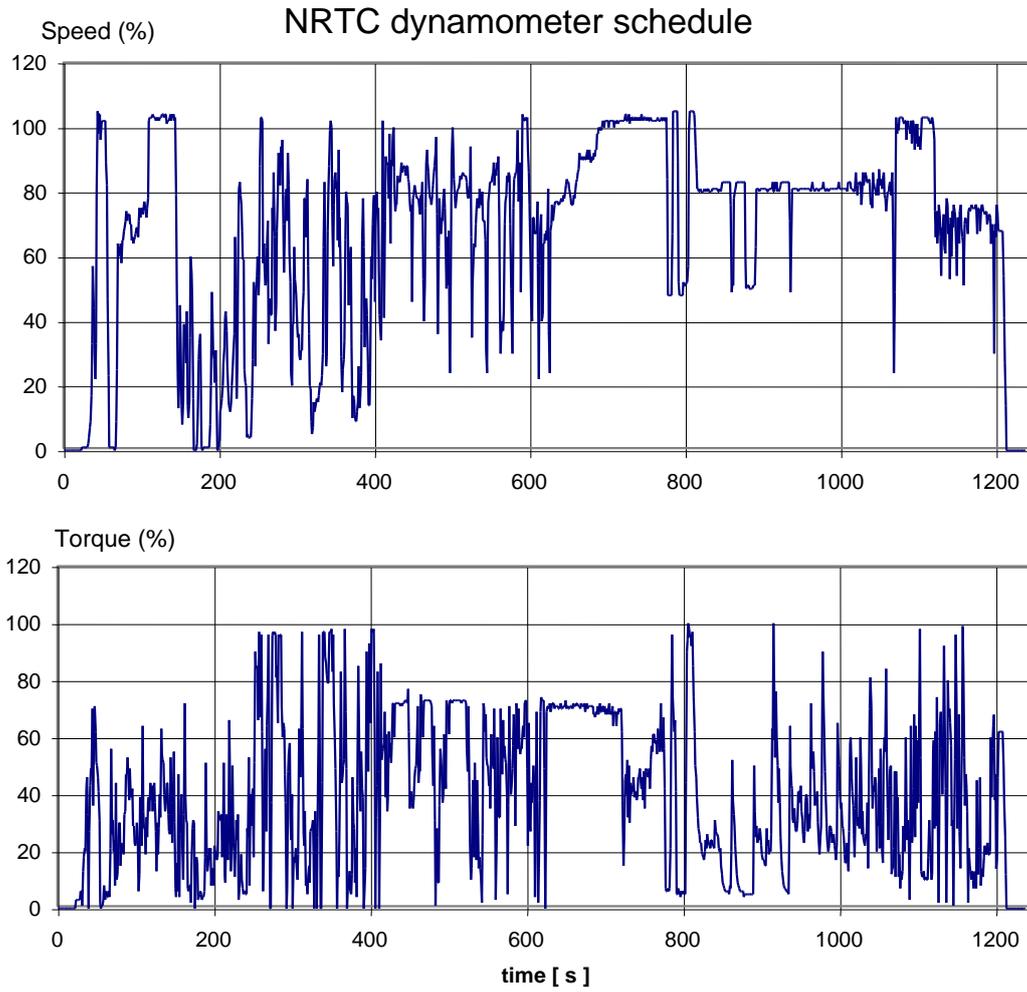
<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
742	103	39	792	52	5	842	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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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

<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>	<i>Time</i>	<i>Norm.</i>	<i>Norm.</i>
<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>	<i>s</i>	<i>Speed</i>	<i>Torque</i>
	<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>		<i>%</i>	<i>%</i>
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 reference fuel prescribed for approval tests and to verify conformity of production

Table 1  
For power bands D to G

	<i>Limits and Units</i> <sup>1,2</sup>	<i>Test Method</i>
Cetane Number <sup>4</sup>	min. 45 <sup>7</sup> max. 50	ISO 5165
Density at 15 °C	min. 835 kg/m <sup>3</sup> max. 845 kg/m <sup>3</sup> <sup>10</sup>	ISO 3675, ASTM D4052
Distillation <sup>3</sup> 95 % point	Maximum 370 °C	ISO 3405
Viscosity at 40 °C	Minimum 2.5 mm <sup>2</sup> /s Maximum 3.5 mm <sup>2</sup> /s	ISO 3104
Sulphur content	Minimum 0.1 % mass <sup>9</sup> Maximum 0.2 % mass <sup>8</sup>	ISO 8754, EN 24260
Flash Point	Minimum 55 °C	ISO 2719
CFPP	Minimum - Maximum +5 °C	EN 116
Copper corrosion	Maximum 1	ISO 2160
Conradson carbon residue (10 per cent DR)	Maximum 0.3 % mass	ISO 10370
Ash content	Maximum 0.01 % mass	ASTM D482 <sup>11</sup>
Water content	Maximum 0.05 % mass	ASTM D95, D1744
Neutralization (strong acid) number	Minimum 0.20 mg KOH/g	
Oxidation stability <sup>5</sup>	Maximum 2.5 mg/100 ml	ASTM D2274
Additives <sup>6</sup>		

<sup>1</sup> If it is required to calculate thermal efficiency of an engine or vehicle, the calorific value of the fuel can be calculated from:

$$\text{Specific energy (calorific value) (net) MJ/kg} = (46.423 - 8.792 d^2 + 3.170 d) \times (1 - (x + y + s)) + 9.420 s - 2.499 x$$

where:

d is the density at 15 °C

x is the proportion by mass of water (%/100)

y is the proportion by mass of ash (%/100)

s is the proportion by mass of sulphur (%/100)

<sup>2</sup> The values quoted in the specification are "true values". In establishment of their limit values the terms of ASTM D3244 "Defining a basis for petroleum produce quality disputes" 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 statistical reasons, the manufacturer of fuel should 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 the question as to whether a fuel meets the requirements of the specifications, the terms of ASTM D3244 should be applied.

<sup>3</sup> The figures quoted show the evaporated quantities (percentage recovered + percentage loss).

<sup>4</sup> The range of cetane is not in accordance with the requirement of a minimum range of 4R. However, in cases of dispute between fuel supplier and fuel user, the terms in ASTM D3244 can be used to resolve such disputes provided replicate measurements, of sufficient number to achieve the necessary precision, are made in preference to single determinations.

<sup>5</sup> Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.

<sup>6</sup> This fuel should be based straight run and cracked hydrocarbon distillate components only; desulphurization is allowed. It shall not contain any metallic additives or cetane improver additives.

<sup>7</sup> Lower values are permitted, in which case the cetane number of the reference fuel used is to be reported.

<sup>8</sup> Higher values are permitted, in which case the sulphur content of the reference fuel used is to be reported.

<sup>9</sup> To be kept under constant review in the light of trends in the markets. For the purpose of the initial approval of an engine on request of the applicant, a 0.05 per cent mass nominal sulphur level (minimum 0.03 per cent mass) is permissible, in which case the measured particulate level shall be corrected upward to the average value that is nominally specified for fuel sulphur content (0.15 per cent mass) per the equation below:

$$PT_{adj} = PT + [SFC \times 0.0917 \times (NSLF - FSF)]$$

where:

$PT_{adj}$  = adjusted PT value (g/kWh)

PT = measured weighted specific emissions value for particulate emission (g/kWh)

SFC = weighted specific fuel consumption (g/kWh) calculated according to the formula as below

NSLF = average of the nominal specification of sulphur content mass fraction (i.e. 0.15 %/100)

FSF = fuel sulphur content mass fraction (%/100)

Equation for the calculation of the weighted specific fuel consumption:

$$SFC = \frac{\sum_{i=1}^n G_{FUEL,i} \times WF_i}{\sum_{i=1}^n P_i \times WF_i} \quad \text{where : } P_i = P_{m,i} + P_{AE,i}$$

For the purpose of conformity of production assessments in accordance with paragraph 7.4.2., the requirements shall be met using reference fuel which complies with the minimum/maximum level of 0.1/0.2 per cent mass.

<sup>10</sup> Higher values are permitted up to 855 kg/m<sup>3</sup>, in which case the density of the reference fuel used is to be reported. For the purpose of conformity of production assessments in accordance with paragraph 7.4.2., the requirements shall be met using reference fuel which complies with the minimum/maximum level of 835/845 kg/m<sup>3</sup>.

<sup>11</sup> To be replaced by EN/ISO 6245 with effect of the date of implementation.

<sup>12</sup> All fuel characteristics and limit values are to be kept under review in light of trends in the markets.

Table 2  
**For power bands H to K**

Parameter	Unit	Limits <sup>1</sup>		Test Method
		minimum	maximum	
Cetane number <sup>2</sup>		52.0	54.0	EN-ISO 5165
Density at 15°C	kg/m <sup>3</sup>	833	837	EN-ISO 3675
Distillation:				
50 per cent point	°C	245	-	EN-ISO 3405
95 per cent point	°C	345	350	EN-ISO 3405
- Final boiling point	°C	-	370	EN-ISO 3405
Flash point	°C	55	-	EN 22719
CFPP	°C	-	-5	EN 116
Viscosity at 40°C	mm <sup>2</sup> /s	2.5	3.5	EN-ISO 3104
Polycyclic aromatic hydrocarbons	per cent m/m	3.0	6.0	IP 391
Sulphur content <sup>3</sup>	mg/kg	-	300	ASTM D 5453
Copper corrosion		-	class 1	EN-ISO 2160
Conradson carbon residue (10 per cent DR)	per cent m/m	-	0.2	EN-ISO 10370
Ash content	per cent m/m	-	0.01	EN-ISO 6245
Water content	per cent m/m	-	0.05	EN-ISO 12937
Neutralization (strong acid) number	mg KOH/g	-	0.02	ASTM D 974
Oxidation stability <sup>4</sup>	mg/ml	-	0.025	EN-ISO 12205

<sup>1</sup> 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 should 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 the questions as to whether a fuel meets the requirements of the specifications, the terms of ISO 4259 should be applied.

<sup>2</sup> The range for the 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.

<sup>3</sup> The actual sulphur content of the fuel used for the test shall be reported.

<sup>4</sup> Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.

Table 3  
For power bands L to P and Q and R

Parameter	Unit	Limits <sup>1</sup>		Test Method
		minimum	maximum	
Cetane number <sup>2</sup>			54.0	EN-ISO 5165
Density at 15 °C	kg/m <sup>3</sup>	833	865	EN-ISO 3675
Distillation:				
50 per cent point	°C	245	-	EN-ISO 3405
95 per cent point	°C	345	350	EN-ISO 3405
- Final boiling point	°C	-	370	EN-ISO 3405
Flash point	°C	55	-	EN 22719
CFPP	°C	-	-5	EN 116
Viscosity at 40 °C	mm <sup>2</sup> /s	2.3	3.3	EN-ISO 3104
Polycyclic aromatic hydrocarbons	per cent m/m	3.0	6.0	IP 391
Sulphur content <sup>3</sup>	mg/kg	-	10	ASTM D 5453
Copper corrosion		-	class 1	EN-ISO 2160
Conradson carbon residue (10 per cent DR)	per cent m/m	-	0.2	EN-ISO 10370
Ash content	per cent m/m	-	0.01	EN-ISO 6245
Water content	per cent m/m	-	0.02	EN-ISO 12937
Neutralization (strong acid) number	mg KOH/g	-	0.02	ASTM D 974
Oxidation stability <sup>4</sup>	mg/ml	-	0.025	EN-ISO 12205
Lubricity (HFRR wear scar diameter at 60 °C)	µm	-	400	CEC F-06-A-96
FAME	prohibited			

<sup>1</sup> 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 should 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 the questions as to whether a fuel meets the requirements of the specifications, the terms of ISO 4259 should be applied.

<sup>2</sup> The range for the 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.

<sup>3</sup> The actual sulphur content of the fuel used for the Type I test shall be reported.

<sup>4</sup> Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice should be sought from the supplier as to storage conditions and life.

## Annex 7

### Installation requirements for equipment and auxiliaries

<i>Number</i>	<i>Equipment and auxiliaries</i>	<i>Fitted for emission test</i>
1	Inlet system Inlet manifold Crankcase emission control system Air flow-meter Air filter Inlet silencer Induction-heating device of inlet manifold	Yes Yes Yes Yes <sup>a</sup> Yes <sup>a</sup> Yes, standard production equipment. If possible to be set in the most favourable condition
2	Exhaust system Exhaust aftertreatment Exhaust manifold Connecting pipes Silencer Tail pipe Exhaust brake Pressure charging device	Yes Yes Yes <sup>b</sup> Yes <sup>b</sup> Yes <sup>b</sup> No <sup>c</sup> Yes
3	Fuel supply pump	Yes <sup>d</sup>
4	Fuel injection equipment Prefilter Filter Pump High-pressure pipe Injector Electronic control unit, sensors, etc. Governor/control system	Yes Yes Yes Yes Yes Yes Yes

<i>Number</i>	<i>Equipment and auxiliaries</i>	<i>Fitted for emission test</i>
	Automatic full-load stop for the control rack depending on atmospheric conditions	Yes
5	Liquid-cooling equipment Radiator Fan Fan cowl Water pump Thermostat	No No No Yes <sup>e</sup> Yes <sup>f</sup>
6	Air cooling Cowl Fan or Blower Temperature-regulating device	No <sup>g</sup> No <sup>g</sup> No
7	Electrical equipment Generator	Yes <sup>h</sup>
8	Pressure charging equipment Compressor driven either directly by the engine and/or by the exhaust gases Charge air cooler Coolant pump or fan (engine-driven) Coolant flow control device	Yes Yes <sup>g,i</sup> No <sup>g</sup> Yes
9	Auxiliary test-bed fan	Yes, if necessary
10	Anti-pollution device	Yes
11	Starting equipment	Yes or test bed equipment <sup>j</sup>
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

<sup>a</sup> 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.

<sup>b</sup> 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.

<sup>c</sup> If an exhaust brake is incorporated in the engine, the throttle valve shall be fixed in the fully open position.

<sup>d</sup> 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).

<sup>e</sup> 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.

<sup>f</sup> The thermostat may be fixed in the fully open position.

<sup>g</sup> 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.

<sup>h</sup> 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.

<sup>i</sup> 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.

<sup>j</sup> The power for electrical or other starting systems shall be provided from the test bed.

## Annex 8

### Durability requirements

This Annex shall apply to CI engines from power bands H upwards only.

1. Verifying the durability of engines for power bands H to P

This section shall apply to CI engines for power bands H to P only.

- 1.1. Manufacturers shall determine a Deterioration Factor (*DF*) value for each regulated pollutant. Such *DFs* shall be used for type approval and production line testing, by either:

- (a) Adding the *DF* to the emission test result, if paragraph 1.2.1. applies, or
- (b) Multiplying the emission test result with the *DF*, if paragraph 1.2.2. applies.

- 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 test 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 characteristic of the engine families that will apply the resulting *DF* values for certification 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 will be performed according to the procedures defined in this Regulation for the test engine after initial run-in but before any service accumulation, and at the completion of the durability. 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 shall not be witnessed by the approval authority.

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 determined 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  $\text{NO}_x + \text{HC}$  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  $\text{NO}_x + \text{HC}$  *DF*, separate HC and  $\text{NO}_x$  *DF*s shall be determined and applied separately when calculating the deteriorated emission levels from an emissions test result before combining the resultant deteriorated  $\text{NO}_x$  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 Type Approval Authority, 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 paragraph 2.

- 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 Type Approval Authority.
- 1.2. *DF* information in approval applications
  - 1.2.1. Additive *DFs* shall be specified for each pollutant in an engine family certification 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 certification application for CI engines using an after-treatment device.
  - 1.2.3. The manufacturer shall furnish to the Type Approval Authority on request with information to support the *DF* values. This would typically include emission test results, service accumulation test schedule, maintenance procedures together with information to support engineering judgements of technological equivalency, if applicable.
- 2. Verifying the durability of engines for power bands Q and R  
(Reserved)  
Until such time as a separate method for verifying the durability of engines for power bands Q and R is introduced into this Regulation, section 1 of this annex shall apply to power bands Q and R.
- 3. Emission durability periods
  - 3.1. Manufacturers shall use the EDP in Table 1 of this paragraph.

Table 1  
**EDP categories for CI engines from power bands from H upwards (hours)**

<i>Category (power band)</i>	<i>Useful life (hours) (PDE)</i>
≤ 37 kW (constant speed engines)	3,000
≤ 37 kW (variable speed engines)	5,000
> 37 kW	8,000