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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 11:
Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions

Moteurs alternatifs à combustion interne — Mesurage des émissions de gaz d'échappement —

Partie 11: Mesurage au banc d'essai des émissions de gaz et de particules des gaz d'échappement de moteurs d'engins mobiles non routiers en régime transitoire

Reference number
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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-11 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust gas emission measurement*:

- *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*
- *Part 2: Measurement of gaseous and particulate exhaust emissions at site*
- *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*
- *Part 4: Test cycles for different engine applications*
- *Part 5: Test fuels*
- *Part 6: Report of measuring results and tests*
- *Part 7: Engine family determination*
- *Part 8: Engine group determination*
- *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions*

Introduction

Today's measurement systems depend on the type of test cycle, steady state or transient, and the type of pollutant to be measured. On a steady state cycle, the mass of gaseous emissions can be calculated either from the concentration in the raw exhaust gas and the exhaust flow of the engine, which can easily be determined, or from the concentration in the diluted exhaust gas and the CVS (Constant Volume Sampling) flow of a full flow dilution system. Both equivalent systems are described in ISO 8178-1. For PM, full flow dilution or partial flow dilution systems, in which only a portion of the exhaust gas is diluted, can be used.

On a transient cycle as covered by this International Standard, real-time exhaust flow determination is more difficult. Therefore, the CVS principle has been used for many years due to the fact that exhaust mass flow measurement is not required with this system. The total exhaust gas is diluted, the total flow as the sum of dilution air and exhaust gas flow is kept virtually constant and the emissions (gaseous and PM) are measured in the diluted exhaust gas. The space and cost requirements of such a system are considerably higher than for the partial flow dilution systems used on steady state cycles. On the other hand, raw exhaust measurement and partial flow systems can only be applied to transients if sophisticated control systems and calculation algorithms are used.

For most nonroad applications and heavy-duty engines, the CVS system is large and costly. Therefore, ISO 16183 has been developed by ISO/TC 22/SC 5, which defines raw gaseous emissions measurement and partial flow dilution for heavy-duty engines under transient test conditions. Since many nonroad engines are similar to heavy-duty engines in engine size, displacement and power, it is believed that the contents of ISO 16183 can also be applied to nonroad engines.

For the purpose of this International Standard, both full flow dilution and partial flow dilution/raw exhaust methods are considered equivalent and are therefore covered herein.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 11:
Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions

1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emission from reciprocating internal combustion (RIC) engines under transient conditions on a test bed, necessary for determining one value for each exhaust gas pollutant.

The specific transient test cycle covered by this part of ISO 8178 is applicable to compression-ignition engines for mobile use with a power output between 37 kW and 560 kW, excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used in off-road vehicles and diesel powered off-road industrial equipment as described in 8.3.1.3 of ISO 8178-4. This includes e.g. engines for construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, off-highway trucks, hydraulic excavators, agricultural equipment, self propelled agricultural vehicles (including tractors), forestry equipment, fork lift trucks, road maintenance equipment and mobile cranes.

Many of the procedures described below are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8178-1, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

ISO 8178-5, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5725-2:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 14396:2002, *Reciprocating internal combustion engines — Determination and method for the measurement of engine power — Additional requirements for exhaust emission tests in accordance with ISO 8178*

ISO 15550, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*

ISO 16183:2002, *Heavy duty engines — Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions*

SAE J 1937:1995, *Engine testing with low-temperature charge air-cooler systems in a dynamometer test cell*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
particulate matter
any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature of greater than 315 K (42 °C) and less than or equal to 325 K (52 °C), as measured at a point immediately upstream of the filter

NOTE This is primarily carbon, condensed hydrocarbons, and sulfates with associated water.

3.2
gaseous pollutants
carbon monoxide, hydrocarbons and/or non-methane hydrocarbons, oxides of nitrogen (expressed in nitrogen dioxide (NO_2) equivalent), formaldehyde, and methanol

3.3
partial flow dilution method
process of separating a part of the raw exhaust from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter

3.4
full flow dilution method
process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis

NOTE It is common in many full flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter.

3.5
specific emissions
mass emissions expressed in g/kWh

3.6
steady-state test cycle
test cycle with a sequence of engine test modes in which the engine is given sufficient time to achieve defined speed, torque and stability criteria at each mode

3.7
transient test cycle
test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time

3.8
rated speed

engine speed at which, according to the statement of the engine manufacturer, the rated or prime power is delivered

NOTE For details see ISO 14396.

3.9
low speed

lowest engine speed where 50 % of the rated or prime power is delivered

3.10
high speed

highest engine speed where 70 % of the rated or prime power is delivered

3.11
reference speed

100 per cent speed value to be used for denormalizing the relative speed values of the NRTC test, as set out in 6.4.2

3.12
response time

difference in time between a rapid change of the component to be measured at the reference point and the appropriate change in the response of the measuring system whereby the change of the measured component is at least 60 % FS and takes place in less than 0,1 second

NOTE 1 The system response time (t_{90}) consists of the delay time to the system and of the rise time of the system.

NOTE 2 The response time may vary dependent on where the reference point for the change of the component to be measured is defined, either at the sampling probe or directly at the port entrance of the analyser; in this International Standard, the sampling probe is defined as the reference point.

3.13
delay time

time between the change of the component to be measured at the reference point and a system response of 10 % of the final reading (t_{10})

NOTE 1 For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector.

NOTE 2 For the delay time, the sampling probe is defined as the reference point.

3.14
rise time

time between the 10 % and 90 % response of the final reading ($t_{90} - t_{10}$)

NOTE 1 This is the instrument response after the component to be measured has reached the instrument.

NOTE 2 For the rise time, the sampling probe is defined as the reference point.

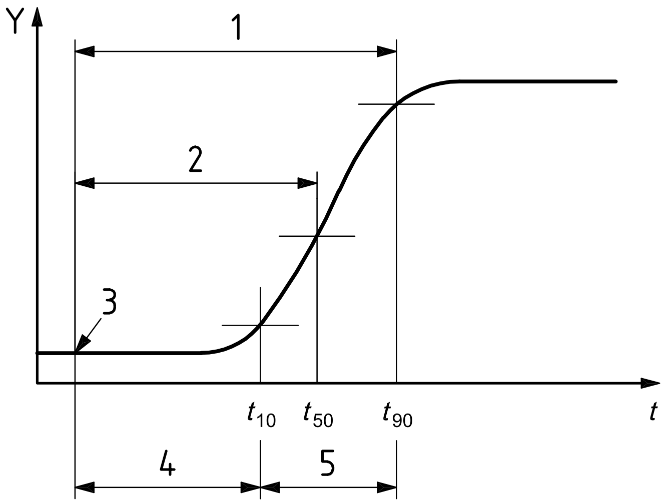
3.15
transformation time

time between the change of the component to be measured at the reference point and a system response of 50 % of the final reading (t_{50})

NOTE 1 For the transformation time, the sampling probe is defined as the reference point.

NOTE 2 The transformation time is used for the signal alignment of different measurement instruments.

NOTE 3 3.12 to 3.15 do not apply to full flow dilution systems covered by Clause 10.



Key

Y response

1 response time
2 transformation time
3 step input
4 delay time
5 rise time

Figure 1 — Definitions of system response

4 Symbols and abbreviated terms

4.1 General symbols

Table 1 — List of general symbols

Symbol	Unit	Term
A/F_{st}	—	Stoichiometric air to fuel ratio
c	ppm / Vol%	Concentration
C_c	—	Slip factor
d_e	m	Exhaust pipe diameter
d_p	m	Sampling probe diameter
d_{PM}	m	Particle diameter
f	Hz	Data sampling rate
f_a	—	Laboratory atmospheric factor
E_{CO2}	%	CO_2 quench of NO_x analyser
E_E	%	Ethane efficiency
E_{H2O}	%	Water quench of NO_x analyser
E_M	%	Methane efficiency
E_{NOx}	%	Efficiency of NO_x converter
η	Pa*s	Dynamic viscosity of exhaust gas

Table 1 (*continued*)

Symbol	**Unit**	**Term**
H_a	g/kg	Absolute humidity of the intake air
i	—	Subscript denoting an instantaneous measurement (e.g. 1 Hz)
k_f	—	Fuel specific factor
$k_{h,D}$	—	Humidity correction factor for NO_x for CI engines
k_w	—	Dry to wet correction factor for the raw exhaust gas
λ	—	Excess air ratio
m_{edf}	kg	Mass of equivalent diluted exhaust gas over the cycle
m_f	mg	Particulate sample mass collected
m_{gas}	g	Mass of gaseous emissions (over the test cycle)
m_{PM}	g	Mass of particulate emissions (over the test cycle)
m_{se}	kg	Exhaust sample mass over the cycle
m_{sed}	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	kg	Mass of diluted exhaust gas passing the particulate collection filters
M_{gas}	g/kWh	Specific emission of gaseous emissions
M_{PM}	g/kWh	Specific emission of particulate emissions
n	—	Number of measurements
p_a	kPa	Saturation vapor pressure of the engine intake air
p_b	kPa	Total atmospheric pressure
p_r	kPa	Water vapor pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
P	—	Particle penetration
q_{mad}	kg/s	Intake air mass flow rate on dry basis
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	kg/s	Carbon mass flow rate into the engine
q_{mCp}	kg/s	Carbon mass flow rate in the partial flow dilution system
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	kg/s	Dilution air mass flow rate on wet basis
q_{medf}	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	kg/s	Fuel mass flow rate
q_{vs}	l/min	System flow rate of exhaust analyser system
q_{vt}	cm³/min	Tracer gas flow rate
r_d	—	Dilution ratio
r_h	—	Hydrocarbon response factor of the FID
r_m	—	Methanol response factor of the FID

Table 1 (*continued*)

Symbol	Unit	Term
r_s	—	Average sample ratio
ρ	kg/m^3	Density
ρ_e	kg/m^3	Exhaust gas density
ρ_PM	kg/m^3	Particle density
σ		Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
t_{10}	s	Time between step input and 10 % of final reading
t_{50}	s	Time between step input and 50 % of final reading
t_{90}	s	Time between step input and 90 % of final reading
τ	s	Particle relaxation time
u	—	Ratio between densities of gas component and exhaust gas
V_s	l	Total volume of exhaust analyser system
W_act	kWh	Actual cycle work of the respective test cycle
υ_e	m/s	Gas velocity in the exhaust pipe
υ_p	m/s	Gas velocity in the sampling probe

4.2 Symbols and abbreviations for the fuel composition

w_ALF	hydrogen content of fuel, % mass
w_BET	carbon content of fuel, % mass
w_GAM	sulfur content of fuel, % mass
w_DEL	nitrogen content of fuel, % mass
w_EPS	oxygen content of fuel, % mass
α	molar hydrogen ratio (H/C)
β	molar carbon ratio (C/C)
γ	molar sulfur ratio (S/C)
δ	molar nitrogen ratio (N/C)
ε	molar oxygen ratio (O/C)

referring to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$

4.3 Symbols and abbreviations for the chemical components

ACN	Acetonitrile
C1	Carbon 1 equivalent hydrocarbon
CH_4	Methane
CH_3OH	Methanol
C_2H_6	Ethane
C_3H_8	Propane
CO	Carbon monoxide
CO_2	Carbon dioxide
DNPH	Dinitrophenyl hydrazine
DOP	Di-octylphtalate
HC	Hydrocarbons
HCHO	Formaldehyde
H_2O	Water
NMHC	Non-methane hydrocarbons
NO_x	Oxides of nitrogen
NO	Nitric oxide
NO_2	Nitrogen dioxide
PM	Particulate matter
RME	Rapeseed oil methylester

4.4 Abbreviations

CLD	Chemiluminescent Detector
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared (Analyser)
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
HPLC	High Pressure Liquid Chromatograph
MW	Molecular Mass
NDIR	Non-Dispersive Infrared (Analyser)
NMC	Non-Methane Cutter
NRTC	Non Road Transient Cycle
% FS	Percent of full scale
SIMS	Soft Ionization Mass Spectrometer
Stk	Stokes number

5 Test conditions

5.1 Engine test conditions

5.1.1 Test condition parameter

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 "Vee" engine configuration, the average temperature of the distinct groups shall be taken.

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0,7} \tag{1}$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,5} \tag{2}$$

NOTE Equations (1) and (2) are identical with the exhaust emissions legislation from ECE, EEC and EPA, but different from the ISO power correction equations.

5.1.2 Test validity

For a test to be recognized as valid, the parameter f_a shall be such that: $0,93 \leqslant f_a \leqslant 1,07$.

NOTE It is recommended that the test be conducted with the parameter f_a between 0,96 and 1,06.

5.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of rated power and full load, within ± 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 ± 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 1937:1995.

5.3 Power

The basis of specific emissions measurement is uncorrected brake power as defined in ISO 14396. The engine shall be submitted for testing with the auxiliaries needed for operating the engine.

If it is impossible or inappropriate to install the auxiliaries on the test bench, the power absorbed by them shall be determined and subtracted from the measured engine power over the whole operating area of the test cycle.

Certain auxiliaries necessary only for the operation of the machine and which may be mounted on the engine should be removed for the test. The following incomplete list is given as an example:

- air compressor for brakes,

- power steering compressor,
- air conditioning compressor, and
- pumps for hydraulic actuators.

For further details see ISO 14396 and ISO 15550, Table 1.

Where auxiliaries have not been removed, the power absorbed by them shall be determined and added to the measured engine power over the whole operating area of the test cycle, except for engines where such auxiliaries form an integral part of the engine (e.g. cooling fans for air cooled engines).

The correction equation for converting the measured power or measured cycle work, as determined according to 6.6.2, to uncorrected brake power or uncorrected cycle work, shall be submitted by the engine manufacturer for the whole operating area of the cycle, and agreed by the parties involved.

5.4 Engine air intake system

An engine air intake system or a test shop system shall be used presenting an air intake restriction within ± 300 Pa of the maximum value specified by the manufacturer for a clean air cleaner at the speed of rated power and full load.

If the engine is equipped with an integral air inlet system, it shall be used for testing.

5.5 Engine exhaust system

An engine exhaust system or a test shop system shall be used presenting an exhaust backpressure within ± 650 Pa of the maximum value specified by the manufacturer at the speed of rated power and full load. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in 9.4.2 and 16.2 of ISO 8178-1.

If the engine is equipped with an exhaust aftertreatment 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 aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment device 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 aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

5.6 Cooling system

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

5.7 Lubricating oil

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

5.8 Test fuel

Fuel characteristics influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test should be determined, recorded and presented with the results of the test. Where fuels designated in ISO 8178-5 as reference fuels are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in ISO 8178-5.

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.

The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties, the fuel shall be selected in accordance with Table 2. When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

Table 2 — Selection of fuel

Test purpose	Interested parties	Fuel selection
Type approval (Certification)	1. Certification body 2. Manufacturer or supplier	Reference fuel, if one is defined Commercial fuel if no reference fuel is defined
Acceptance test	1. Manufacturer or supplier 2. Customer or inspector	Commercial fuel as specified by the manufacturer [a]
Research/development	One or more of: Manufacturer, research organization, fuel and lubricant supplier, etc.	To suit the purpose of the test

[a] Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels.

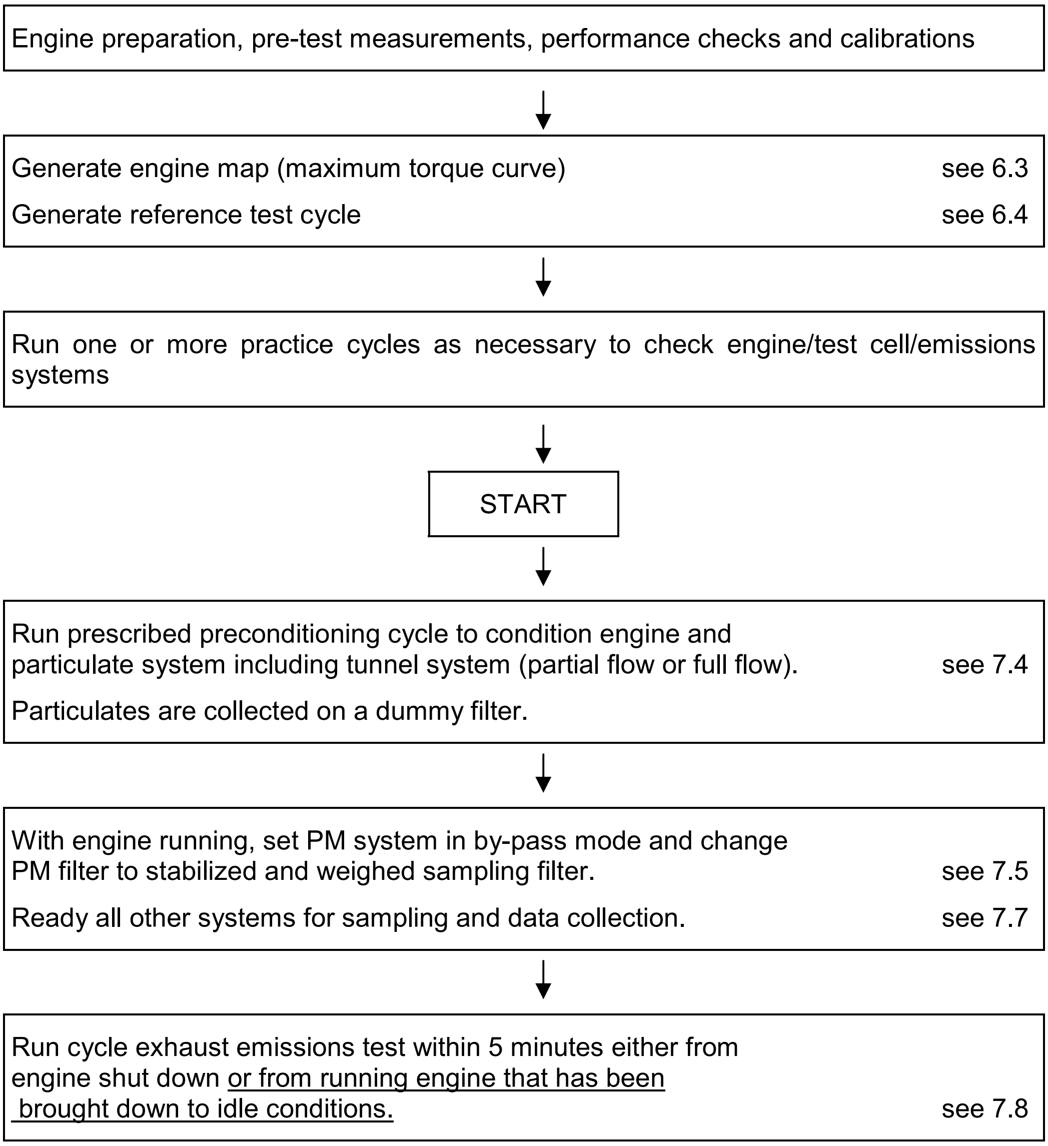
6 Test cycle

6.1 General

The nonroad transient cycle (NRTC) is listed in Annex A as a second-by-second sequence of normalized speed and torque values applicable to all engines covered by this International Standard. In order to perform the test on an engine test cell, the normalized values shall be converted to the reference values for the individual engine under test based on the engine mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those reference speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test. For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work must be within prescribed limits of the cycle work of the reference cycle (reference cycle work).

6.2 General test sequence

The following flow chart outlines the general guidance that should be followed during testing. The details of each step are described in the relevant clauses. Deviations from the guidance are permitted where appropriate, but the specific requirements of the relevant clauses are mandatory.



Engine preparation, pre-test measurements, performance checks and calibrations

Generate engine map (maximum torque curve) see 6.3

Generate reference test cycle see 6.4

Run one or more practice cycles as necessary to check engine/test cell/emissions systems

START

Run prescribed preconditioning cycle to condition engine and particulate system including tunnel system (partial flow or full flow). see 7.4

Particulates are collected on a dummy filter.

With engine running, set PM system in by-pass mode and change PM filter to stabilized and weighed sampling filter. see 7.5

Ready all other systems for sampling and data collection. see 7.7

Run cycle exhaust emissions test within 5 minutes either from engine shut down or from running engine that has been brought down to idle conditions. see 7.8

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

6.3 Engine mapping procedure

6.3.1 General

For generating the NRTC on the test cell, the engine shall be mapped prior to the run of the test cycle for determining the speed vs. torque curve.

6.3.2 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 smaller.

6.3.3 Engine mapping curve

The engine shall be warmed up 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 either of the following procedures.

6.3.3.1 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 ± 1 /min/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.

6.3.3.2 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 ± 20 /min 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.

6.3.4 Mapping curve generation

All data points recorded under 6.3.3 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 A into reference torque values for the test cycle, as described in 6.4.3.

6.3.5 Alternative mapping

If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternative mapping techniques may be used. These alternative techniques must 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 section for reasons of safety or representativeness shall be approved by the parties involved 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.

6.3.6 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:

- an unreasonable amount of time has transpired since the last map, as determined by engineering judgement

or

- physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

6.4 Generation of the reference test cycle

6.4.1 Reference speed

The reference speed (n_{ref}) corresponds to the 100 % normalized speed values specified in the engine dynamometer schedule of Annex A. The actual engine cycle resulting from denormalization to the reference speed depends on the selection of the reference speed. The reference speed shall be defined as follows:

$$n_{ref} = \text{low speed} + 0{,}95 \times (\text{high speed} - \text{low speed})$$

where

- high speed is the highest engine speed where 70 % of the rated power is delivered, and
- low speed is the lowest engine speed where 50 % of the rated power is delivered.

If the measured reference speed is within ± 3 % 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.

6.4.2 Denormalization of engine speed

The speed shall be denormalized using the following equation:

$$\text{Reference speed} = \frac{\%\,\text{speed} \times (\text{reference speed} - \text{idle speed})}{100} + \text{idle speed} \tag{3}$$

6.4.3 Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex A 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 6.3.3, as follows:

$$\text{Reference torque} = \frac{\%\,\text{torque} \times \text{max. torque}}{100} \tag{4}$$

for the respective reference speed as determined in 6.4.2.

6.4.4 Example of denormalization procedure

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

% speed = 43 %

% torque = 82 %

Given the following values:

reference speed = 2 200 /min

idle speed = 600 /min

results in

$$\text{actual speed} = \frac{43 \times (2\,200 - 600)}{100} + 600 = 1\,288\ /\text{min}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1 288 /min:

$$\text{actual torque} = \frac{82 \times 700}{100} = 574 \text{ Nm}$$

6.5 Dynamometer

6.5.1 General

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.

6.5.2 Eddy-current dynamometer

If the engine is tested with an eddy-current dynamometer, the dynamometer inertia must be adapted to the engine size. Therefore, 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 % of the engine's maximum negative torque, does not exceed 30

where

T_{sp} is the demanded torque;

$\dot{n}_{sp}$ is the derivative of the engine speed;

Θ_D is the rotational inertia of the eddy-current dynamometer.

6.6 Verification of the test run

6.6.1 Data shift

To minimize the biasing effect of the time lag between the actual 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 actual signals are shifted, both speed and torque must be shifted the same amount in the same direction.

6.6.2 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. This shall be done after any actual data shift has occurred, if this option is selected. 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 9.3.7, 9.4.7, 10.3.7, 10.4.5). The same methodology shall be used for integrating both reference and actual engine power. If values are to be determined between adjacent reference or adjacent measured values, linear interpolation shall be used.

In integrating the actual cycle work, any 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 % and + 5 % of W_{ref}.

6.6.3 Validation statistics of the test cycle

Linear regressions of the actual 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 in accordance with the equations given in Annex G:

$$y = a_1 {}^{*}x + a_0 \tag{5}$$

where

y is the actual value of speed (min^{-1}), torque (Nm), or power (kW);

a_1 is the slope of the regression line;

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

a_0 is the y intercept of the regression line.

The standard error of estimate ($S_{y.x}$) 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 Hertz. For a test to be considered valid, the criteria of Table 3 must be met.

Table 3 — Regression line tolerances

	Speed	Torque	Power
Standard error of estimate ($S_{y.x}$) of y on x	max 100 min^{-1}	max 13 % of power map maximum engine torque	max 8 % of power map maximum engine power
Slope of the regression line, a_1	0,95 to 1,03	0,83 - 1,03	0,89 - 1,03
Coefficient of determination, r^2	min 0,9700	min 0,880 0	min 0,910 0
y intercept of the regression line, a_0	± 50 min^{-1}	± 20 Nm or ± 2 % of max torque, whichever is greater	± 4 kW or ± 2 % of max power, whichever is greater

For regression purposes only, point deletions are permitted where noted in Table 4 before doing the regression calculation. However, those points must 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 % and a normalized reference speed of 0,1 %. Point deletion may be applied to the whole or to any part of the cycle.

Table 4 — Permitted point deletions from regression analysis

Condition	Points to be deleted
First 24 ± 1 seconds and last 25 ± 1 seconds	Speed, torque, power
Full load demand and torque feedback $<$ 95 % torque reference	Torque and/or power
Full load demand and speed feedback $<$ 95 % speed reference	Speed and/or power
No load, speed feedback $>$ idle speed + 50 min^{-1}, and torque feedback $>$ 105 % torque reference	Torque and/or power
No load, speed feedback $\leqslant$ idle speed + 50 min^{-1}, and torque feedback = manufacturer defined/measured idle torque ± 2 % of max. torque	Speed and/or power
No load and speed feedback $>$ 105 % speed reference	Speed and/or power

7 Emissions test run

7.1 General

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons or non-methane 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.

The above pollutants shall be examined during the prescribed transient cycle (NRTC) at warmed-up engine operating conditions. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to 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 9.3.4, or in the diluted exhaust gas of a CVS full flow dilution system by integration or by bag sampling in accordance with 10.3.4. For particulates, a proportional sample shall be collected from the diluted exhaust gas on a specified filter by either partial flow dilution (see 9.4.2) or full flow dilution (see 10.4.3). 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 get the grams of each pollutant emitted per kilowatt hour.

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

7.2 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 tare 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.

7.3 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.

7.4 Starting and preconditioning the dilution system and the engine

The dilution system and the engine shall be started and warmed up. The sampling system shall be preconditioned by operating the engine at a condition of rated speed, 100 % torque for a minimum of 20 min while simultaneously operating either the partial flow dilution system or the full flow dilution system with secondary dilution system. Dummy particulate emissions samples may be collected. Those sample filters need not be stabilized or weighed, and may be discarded. Filter media may be changed during conditioning as long as the total sampled time through the filters and sampling system exceeds 20 min. Flow rates shall be set at the approximate flow rates selected for transient testing. Torque shall be reduced from 100 % torque while maintaining the rated speed condition as necessary to prevent exceeding the 464 K (191 °C) maximum sample zone temperature specifications, if a full flow dilution system is used.

7.5 Starting the particulate sampling system

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by sampling the dilution air prior to the entrance of the exhaust gas into the dilution tunnel. 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 at the beginning and at the end of the cycle may be done, and the values averaged. If a different sampling system is used for background measurement, the measurement shall be done over the period of the test run.

7.6 Adjustment of the dilution system

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).

7.7 Checking the analysers

The emission analysers shall be set at zero and spanned. If sample bags are used, they shall be evacuated.

7.8 Engine starting procedure

The stabilized engine shall be started within 5 min after completion of warm-up according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer. Optionally, the test may start directly from the engine preconditioning phase without shutting the engine off, within 5 min after the engine has been brought to idle condition.

7.9 Cycle run

7.9.1 Test sequence

The test sequence shall be started at the start of the engine or within 5 minutes after the engine has reached idle speed, when starting directly from the preconditioning phase. The test shall be performed according to the reference cycle as set out in 6.4. 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.

7.9.2 Analyser response

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the measuring equipment shall be started, and simultaneously:

- start collecting or analysing dilution air, if a full flow dilution system is used;
- start collecting or analysing raw or diluted exhaust gas, depending on the method used;
- start measuring the amount of diluted exhaust gas and the required temperatures and pressures;
- start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;
- 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_x) 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_x 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, CO_2, and NMHC 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 collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

7.9.3 Particulate sampling

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, 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 ± 5 % of the set flow rate. If flow compensation (i.e. proportional control of sample flow) is used, it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 5 % of its set value (except for the first 10 seconds of sampling). The average temperature and pressure at the gas meter or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within ± 5 %) 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.

7.9.4 Engine stalling

If the engine stalls anywhere during the test cycle, the engine shall be preconditioned and 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.

7.9.5 Operations after test

At the completion 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 min 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 % 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.

8 Principles of emissions measurement

8.1 General

In this International Standard, two measurement principles are described that are functionally equivalent, but can lead to slight differences in emissions results:

- 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; and
- the gaseous components and the particulates are determined using a full flow dilution system (CVS system).

Any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted.

8.2 Equivalence

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 11 and 12. These clauses describe the recommended analytical systems for the gaseous emissions (Clause 11) and the recommended particulate dilution and sampling systems (Clause 12).

Other systems or analysers may be accepted if they yield equivalent results. 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 accepted systems of this International Standard. 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 test cycle to be used shall be the appropriate cycle the engine will be run on. The equivalency of the sample pair averages shall be determined by t-test statistics as described in Annex B obtained under these laboratory, test cell and engine conditions. Outliers shall be determined in accordance with ISO 5725-2 and excluded from the database. The systems to be used for correlation testing shall be declared prior to the test and shall be agreed upon by the parties involved.

For introduction of a new system into the International Standard, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-2.

8.3 Accuracy

The equipment described in this document shall be used for emissions tests of engines. This document does not contain details of flow, pressure and temperature measuring equipment. Instead, only the accuracy requirements of such equipment necessary for conducting an emissions test are given in this clause. The instruments shall be calibrated as required by internal audit procedures or by the instrument manufacturer.

The calibration of all measuring instruments shall be traceable to national (or international) standards and comply with the requirements given in Table 5.

Table 5 — Calibration accuracy of instruments

No.	Measurement 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
6	Temperatures $\leqslant$ 600 K	± 2 K absolute
7	Temperatures $>$ 600 K	± 1 % of reading
8	Exhaust gas pressure	± 0,2 kPa absolute
9	Intake air depression	± 0,05 kPa absolute
10	Atmospheric pressure	± 0,1 kPa absolute
11	Other pressures	± 0,1 kPa absolute
12	Absolute humidity	± 5 % of reading
13	Dilution air flow	± 2 % of reading
14	Diluted exhaust gas flow	± 2 % of reading

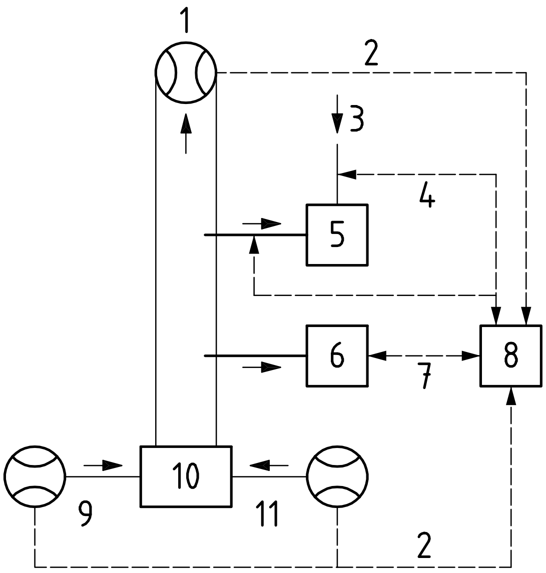
9 Determination of gaseous components in the raw exhaust gas and of the particulates with a partial flow dilution system

9.1 General

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 9.2.4 (intake air and fuel flow measurement), 9.2.5 (tracer method) or 9.2.6 (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 as described in 9.3.3.

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 9.4.3.

The complete test set up is schematically shown in Figure 2.



Key

━━━━━━━ exhaust sample
——————— flow measurement
- - - - - - - - - signal for system control and computation

1 exhaust flow
2 flow values
3 dilution air
4 flow control
5 partial flow dilution system
6 exhaust gas analyser
7 computation
8 control unit
9 fuel flow
10 engine
11 intake air flow

Figure 2 — Schematic of the raw/partial flow measurement system

9.2 Determination of exhaust gas mass flow

9.2.1 General

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, either of the methods described in 9.2.3 to 9.2.6 may be used.

9.2.2 Response time

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 11.3.2.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, a response time of $\leqslant 0{,}3$ seconds 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 $\leqslant 5$ seconds with a rise time of $\leqslant 1$ second 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 9.4.3.

9.2.3 Direct measurement method

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

- pressure differential devices, like flow nozzle (details see ISO 5167),
- ultrasonic flowmeter, and
- vortex flowmeter.

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 must not be affected by the installation of the device.

The flowmeters shall meet the accuracy specifications of 8.3.

9.2.4 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow with suitable flowmeters. The calculation of the instantaneous exhaust gas flow is as follows:

$$q_{m\mathrm{ew,i}} = q_{m\mathrm{aw,i}} + q_{m\mathrm{f,i}} \text{ (for wet exhaust mass)} \tag{6}$$

The flowmeters shall meet the accuracy specifications of 8.3, but shall be accurate enough to also meet the accuracy specifications for the exhaust gas flow.

9.2.5 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:

$$q_{m\mathrm{ew,i}} = \frac{q_{v\mathrm{t}} \times \rho_\mathrm{e}}{60 \times \left(c_{\mathrm{mix,i}} - c_\mathrm{a}\right)} \tag{7}$$

where

$q_{m\mathrm{ew,i}}$ is the instantaneous exhaust mass flow, kg/s;

$q_{v\mathrm{t}}$ is the tracer gas flow, cm^3/min;

$c_{\mathrm{mix.i}}$ is the instantaneous concentration of the tracer gas after mixing, ppm;

ρ_e is the density of the exhaust gas, $\mathrm{kg/m}^3$ (cf. Table 1); and

c_a is the background concentration of the tracer gas in the intake air, ppm.

The background concentration of the tracer gas (c_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 % of the concentration of the tracer gas after mixing ($c_{\mathrm{mix.i}}$) 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 11.3.4.

9.2.6 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 is as follows:

$$q_{m\mathrm{ew,i}} = q_{m\mathrm{aw,i}} \times \left(1 + \frac{1}{A/F_\mathrm{st} \times \lambda_\mathrm{i}}\right) \tag{8}$$

with

$$A/F_\mathrm{st} = \frac{138{,}0 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12{,}011 \times \beta + 1{,}007\,94 \times \alpha + 15{,}999\,4 \times \varepsilon + 14{,}006\,7 \times \delta + 32{,}065 \times \gamma} \tag{9}$$

$$\lambda_\mathrm{i} = \frac{\beta \times \left(100 - \frac{c_\mathrm{CO} \times 10^{-4}}{2} - c_\mathrm{HC} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_\mathrm{CO} \times 10^{-4}}{3{,}5 \times c_\mathrm{CO2}}}{1 + \frac{c_\mathrm{CO} \times 10^{-4}}{3{,}5 \times c_\mathrm{CO2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}\right) \times \left(c_\mathrm{CO2} + c_\mathrm{CO} \times 10^{-4}\right)}{4{,}764 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times \left(c_\mathrm{CO2} + c_\mathrm{CO} \times 10^{-4} + c_\mathrm{HC} \times 10^{-4}\right)} \tag{10}$$

where

A/F_{st} is the stoichiometric air to fuel ratio, kg/kg;

λ is the excess air ratio;

c_{CO2} is the dry CO_2 concentration, %;

c_{CO} is the dry CO concentration, ppm; and

c_{HC} is the HC concentration, ppm.

NOTE β can be 1 for fuels containing carbon and 0 for hydrogen fuel.

The air flowmeter shall meet the accuracy specifications of 8.3, the CO_2 analyser used shall meet the specifications of 11.1, 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 which meets the specifications of 11.2.9.

9.3 Determination of the gaseous components

9.3.1 General

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in Clause 11. They shall be determined in the raw exhaust gas. Data evaluation and calculation procedures are described in 9.3.3 and 9.3.4.

9.3.2 Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or 3 times the diameter of the exhaust pipe, whichever is larger, upstream of the exit of the exhaust gas system but 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 “Vee” engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest CO_2 emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation, the total exhaust mass flow shall be used.

If the engine is equipped with an exhaust aftertreatment system, the exhaust sample shall be taken downstream of the exhaust aftertreatment system.

9.3.3 Data evaluation

For the evaluation of the gaseous emissions, the raw emission concentrations (HC, CO and NO_x) and the exhaust gas mass flow rate shall be recorded 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.

For calculation of the mass emission of the gaseous components the traces of the recorded concentrations and the trace of the exhaust gas mass flow rate shall be time aligned by the transformation time as defined in Clause 3. Therefore, the response time of each gaseous emissions analyser and of the exhaust gas mass flow system shall be determined according to 11.3.2 and 9.2.2, respectively, and recorded.

9.3.4 Calculation of mass emission

9.3.4.1 General

The mass of the pollutants (g/test) shall be preferably determined by calculating the instantaneous mass emissions from the raw concentrations of the pollutants, the u values from Table 6 and the exhaust mass flow, aligned for the transformation time as determined in accordance with 9.3.3, and integrating the instantaneous values over the cycle in accordance with 9.3.4.2. Preferably, the concentrations should be measured on a wet basis. If measured on a dry basis, the dry/wet correction according to 9.3.5 shall be applied to the instantaneous concentration values before any further calculation is done.

Optionally, the mass emissions may be calculated using the exact equations of 9.3.4.3 with the prior agreement of the parties involved. The exact equations must be used if the fuel used for the test is not specified in Table 6, under multi-fuel operation or in case of dispute.

An example of the calculation procedures is given in Annex E.

9.3.4.2 Calculation method based on tabulated values

The following equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^{i=n} u_{\text{gas}} \times c_{\text{gas,i}} \times q_{m\text{ew,i}} \times \frac{1}{f} \text{ (in g/test)} \tag{11}$$

where

u_{gas} is the ratio between density of exhaust component and density of exhaust gas;

$c_{\text{gas,i}}$ is the instantaneous concentration of the respective component in the raw exhaust gas, ppm;

$q_{m\text{ew,i}}$ is the instantaneous exhaust mass flow, kg/s;

f is the data sampling rate, Hz; and

n is the number of measurements.

For the calculation of NO_x, the humidity correction factor $k_{\text{h,D}}$ as applicable, as determined according to 9.3.6, shall be used.

The instantaneously measured concentration shall be converted to a wet basis according to 9.3.5, if not already measured on a wet basis.

Values for u are given in Table 6 for selected components based on ideal gas properties and a range of fuels.

Table 6 — Values of u in the raw exhaust gas and density for various exhaust components

Gas		NO_x	CO	HC	CO_2	O_2	CH_4	HCHO	CH_3OH
ρ_{gas} [kg/m^3]		2,053	1,250	[a]	1,963 6	1,427 7	0,716	1,340	1,430
FUEL	ρ_e	**Coefficient u_{gas}** [b]							
Diesel	1,294 3	0,001 586	0,000 966	0,000 479	0,001 517	0,001 103	0,000 553	0,001 035	0,001 104
RME	1,295 0	0,001 585	0,000 965	0,000 536	0,001 516	0,001 102	0,000 553	0,001 035	0,001 104
Methanol	1,261 0	0,001 628	0,000 991	0,001 133	0,001 557	0,001 132	0,000 568	0,001 062	0,001 134
Ethanol	1,275 7	0,001 609	0,000 980	0,000 805	0,001 539	0,001 119	0,000 561	0,001 050	0,001 121
Natural gas [c]	1,266 1	0,001 621	0,000 987	0,000 558 [d]	0,001 551	0,001 128	0,000 565	0,001 058	0,001 129
Propane	1,280 5	0,001 603	0,000 976	0,000 512	0,001 533	0,001 115	0,000 559	0,001 046	0,001 116
Butane	1,283 2	0,001 600	0,000 974	0,000 505	0,001 530	0,001 113	0,000 558	0,001 044	0,001 114
Gasoline	1,297 7	0,001 582	0,000 963	0,000 481	0,001 513	0,001 100	0,000 552	0,001 032	0,001 102

[a] Depending on fuel.

[b] At $\lambda = 2$, wet air, 273 K, 101,3 kPa.

[c] u accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %.

[d] NMHC on the basis of $CH_{2,93}$ (for total HC the u_{gas} coefficient of CH_4 is used).

9.3.4.3 Calculation method based on exact equations

The mass emission shall be calculated using Equation (11). Instead of using the tabulated values, the following equations shall be applied for the calculation of u_{gas}. It is assumed in the following equations that the concentration c_{gas} in Equation (11) is measured in or converted to ppm.

$$u_{gas,i} = \text{GAS}/(M_{r,e,i} \times 1\,000) \tag{12}$$

or

$$u_{gas,i} = \rho_{gas} / (\rho_{e,i} \times 1\,000) \tag{13}$$

where $\rho_{gas} = \text{GAS} / 22{,}41$ is optionally taken from Table 6. (14)

The densities, ρ_{gas}, are given for a number of exhaust gas components in Table 6. The molecular mass of the exhaust, $M_{r,e}$, shall be derived for a general fuel composition $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ under the assumption of complete combustion, as follows:

$$M_{r,e,i} = \frac{1+\dfrac{q_{mf,i}}{q_{maw,i}}}{\dfrac{q_{mf,i}}{q_{maw,i}} \times \dfrac{\dfrac{\alpha}{4}+\dfrac{\varepsilon}{2}+\dfrac{\delta}{2}}{12{,}011\times\beta+1{,}007\,94\times\alpha+15{,}999\,4\times\varepsilon+14{,}006\,7\times\delta+32{,}065\times\gamma} + \dfrac{\dfrac{H_a\times10^{-3}}{2\times1{,}007\,94+15{,}999\,4}+\dfrac{1}{M_{r,air}}}{1+H_a\times10^{-3}}} \tag{15}$$

The exhaust density ρ_e shall be derived, as follows:

$$\rho_{e,i} = \frac{1\,000 + H_a + 1\,000 \times (q_{mf,i}/q_{mad,i})}{773{,}4 + 1{,}243\,4 \times H_a + k_f \times 1\,000 \times (q_{mf,i}/q_{mad,i})} \tag{16}$$

where

$$k_f = 0{,}055\,584 \times w_{ALF} - 0{,}000\,108\,3 \times w_{BET} - 0{,}000\,156\,2 \times w_{GAM} + 0{,}007\,993\,6 \times w_{DEL} + 0{,}006\,997\,8 \times w_{EPS} \tag{17}$$

9.3.4.4 Calculation of NMHC and CH4 with the non-methane cutter

The concentration of NMHC and CH_4 shall be calculated as follows:

$$c_{\mathrm{NMHC}} = \frac{c_{\mathrm{HC(w/oCutter)}} \times \left(1 - E_{\mathrm{M}}\right) - c_{\mathrm{HC(w/Cutter)}}}{E_{\mathrm{E}} - E_{\mathrm{M}}} \tag{18}$$

$$c_{\mathrm{CH4}} = \frac{c_{\mathrm{HC(w/Cutter)}} - c_{\mathrm{HC(w/oCutter)}} \times \left(1 - E_{\mathrm{E}}\right)}{E_{\mathrm{E}} - E_{\mathrm{M}}} \tag{19}$$

where

$c_{\mathrm{HC(w/Cutter)}}$ is the HC concentration with the sample gas flowing through the NMC;

$c_{\mathrm{HC(w/oCutter)}}$ is the HC concentration with the sample gas bypassing the NMC;

E_{M} is the methane efficiency as determined per ISO 8178-1, 8.8.4.2;

E_{E} is the ethane efficiency as determined per ISO 8178-1, 8.8.4.3.

NOTE If a non-methane cutter is used, the system response time may exceed 10 s.

9.3.5 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 equations.

$$c_{\mathrm{wet}} = k_{\mathrm{W}} \times c_{\mathrm{dry}} \tag{20}$$

$$k_{\mathrm{W}} = \left(1 - \frac{1{,}243\,4 \times H_{\mathrm{a}} + 111{,}12 \times w_{\mathrm{ALF}} \times \dfrac{q_{m\mathrm{f,i}}}{q_{m\mathrm{ad,i}}}}{773{,}4 + 1{,}243\,4 \times H_{\mathrm{a}} + \dfrac{q_{m\mathrm{f,i}}}{q_{m\mathrm{ad,i}}} \times k_{\mathrm{f}} \times 1\,000}\right) \times 1{,}008 \tag{21}$$

or

$$k_{\mathrm{W}} = \left(1 - \frac{1{,}243\,4 \times H_{\mathrm{a}} + 111{,}12 \times w_{\mathrm{ALF}} \times \dfrac{q_{m\mathrm{f,i}}}{q_{m\mathrm{ad,i}}}}{773{,}4 + 1{,}243\,4 \times H_{\mathrm{a}} + \dfrac{q_{m\mathrm{f,i}}}{q_{m\mathrm{ad,i}}} \times k_{\mathrm{f}} \times 1\,000}\right) \Bigg/ \left(1 - \frac{p_{\mathrm{r}}}{p_{\mathrm{b}}}\right) \tag{22}$$

or

$$k_{\mathrm{W}} = \frac{1}{1 + \alpha \times 0{,}005 \times \left(c_{\mathrm{CO2}} + c_{\mathrm{CO}}\right)} - k_{\mathrm{W2}} \tag{23}$$

with

$$k_{\mathrm{W2}} = \frac{1{,}608 \times H_{\mathrm{a}}}{1\,000 + \left(1{,}608 * H_{\mathrm{a}}\right)} \tag{24}$$

where

p_r is the water vapor pressure after cooling bath, kPa;

p_b is the total atmospheric pressure, kPa;

α is the molar hydrogen ratio of the fuel;

c_{CO2} is the dry CO_2 concentration, %;

c_{CO} is the dry CO concentration, %;

H_a is the intake air humidity, g water per kg dry air;

k_f is the $0{,}055\,584 \times w_{ALF} - 0{,}000\,108\,3 \times w_{BET} - 0{,}000\,156\,2 \times w_{GAM} + 0{,}007\,993\,6 \times w_{DEL} + 0{,}006\,997\,8 \times w_{EPS}$.

NOTE Equations (21) and (22) are principally identical with the factor 1,008 in Equation (21) being an approximation for the more accurate denominator in Equation (22).

9.3.6 NO_x correction for humidity and temperature

As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for humidity and ambient air temperature with the factors given in either of the following equations.

a) for compression ignition engines:

$$k_{h,D} = \frac{1}{1 - 0{,}018\,2 \times (H_a - 10{,}71) + 0{,}004\,5 \times (T_a - 298)} \quad (25)$$

where

T_a is the temperature of the intake air, K;

H_a is the humidity of the intake air, g water per kg dry air.

H_a may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted equations.

b) For compression ignition engines with intermediate air cooler the following alternative equation may be used:

$$k_{h,D} = \frac{1}{1 - 0{,}012 \times (H_a - 10{,}71) - 0{,}002\,75 \times (T_a - 298) + 0{,}002\,85 \times (T_{SC} - T_{SCRef})} \quad (26)$$

where

T_{SC} is the temperature of the intercooled air;

T_{SCRef} is the intercooled air reference temperature, to be specified by the manufacturer.

NOTE For an explanation of the other variables, see under a).

H_a may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted equations.

9.3.7 Calculation of the specific emissions

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

$$M_{\text{gas}} = m_{\text{gas}}/W_{\text{act}} \tag{27}$$

where W_{act} is the actual cycle work as determined according to 6.6.2, kWh.

9.4 Particulate determination

9.4.1 General

The determination of the particulates requires a dilution system. In this clause, dilution shall be accomplished by a partial 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. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15 °C) in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system shall 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 between 315 K (42 °C) and 325 K (52 °C) at the test filter. For this it is essential that the dilution ratio or the sampling ratio r_{dil} or r_{s} be determined such that the accuracy limits of 9.4.2 are fulfilled. Different extraction methods can be applied, whereby the type of extraction used dictates to a significant degree the sampling hardware and procedures to be used.

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. The details of the system are described in Clause 12.

9.4.2 Particulate sampling

In general, the particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference. Therefore, the installation provisions of 9.3.2 also apply to particulate sampling. The sampling line shall conform to the requirements of 16.2 of ISO 8178-1.

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 “Vee” engine configuration, it is recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest particulate emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation, the total exhaust mass flow shall be used.

9.4.3 System response time

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 in 12.3.3. If the combined transformation time of the exhaust flow measurement (see 9.2.2) and the partial flow system is less than 0,3 sec, online control may be used. If the transformation time exceeds 0,3 sec, look ahead control based on a pre-recorded test run shall be used. In this case, the rise time shall be $\leqslant$ 1 sec and the delay time of the combination $\leqslant$ 10 sec.

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

- The correlation coefficient r^2 of the linear regression between $q_{m\mathrm{p,i}}$ and $q_{m\mathrm{ew,i}}$ shall not be less than 0,95.
- The standard error of estimate of $q_{m\mathrm{p,i}}$ on $q_{m\mathrm{ew,i}}$ shall not exceed 5 % of $q_{m\mathrm{p}}$ maximum.
- $q_{m\mathrm{p}}$ intercept of the regression line shall not exceed ± 2 % of $q_{m\mathrm{p}}$ maximum.

Optionally, a pretest may be run, and the exhaust mass flow signal of the pretest 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 $t_{50,\mathrm{P}}$ or/and the transformation time of the exhaust mass flow signal $t_{50,\mathrm{F}}$ are $>$ 0,3 sec. A correct control of the partial dilution system is obtained, if the time trace of $q_{m\mathrm{ew,pre}}$ of the pretest, which controls $q_{m\mathrm{p}}$, is shifted by a "look-ahead" time of $t_{50,\mathrm{P}} + t_{50,\mathrm{F}}$.

For establishing the correlation between $q_{m\mathrm{p,i}}$ and $q_{m\mathrm{ew,i}}$ the data taken during the actual test shall be used, with $q_{m\mathrm{ew,i}}$ time aligned by $t_{50,\mathrm{F}}$ relative to $q_{m\mathrm{p,i}}$ (no contribution from $t_{50,\mathrm{P}}$ to the time alignment). That is, the time shift between $q_{m\mathrm{ew}}$ and $q_{m\mathrm{p}}$ is the difference in their transformation times that were determined in 12.3.3.

9.4.4 Data evaluation

The tare weight of the filter, as determined according to 7.2, shall be subtracted from the gross weight of the filter, as determined according to 7.9.5, which results in the particulate sample mass m_f. For the evaluation of the particulate concentration, the total sample mass (m_sep) through the filters over the test cycle shall be recorded.

With the prior approval of the parties involved, the particulate mass may be corrected for the particulate level of the dilution air, as determined in 7.5, in line with good engineering practice and the specific design features of the particulate measurement system used.

9.4.5 Calculation of mass emission

The mass of particulates shall be calculated by either of the following methods. An example of the calculation procedures is given in Annex E.

a)

$$m_\mathrm{PM} = \frac{m_\mathrm{f}}{m_\mathrm{sep}} \times \frac{m_\mathrm{edf}}{1\,000} \tag{28}$$

where

m_f is the particulate mass sampled over the cycle, mg;

m_sep is the mass of diluted exhaust gas passing the particulate collection filters, kg;

m_edf is the mass of equivalent diluted exhaust gas over the cycle, kg.

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

$$m_\mathrm{edf} = \sum_{i=1}^{i=n} q_{m\mathrm{edf,i}} \times \frac{1}{f} \tag{29}$$

$$q_{m\mathrm{edf,i}} = q_{m\mathrm{ew,i}} \times r_\mathrm{dil,i} \tag{30}$$

$$r_{\text{dil,i}} = \frac{q_{m\text{dew,,i}}}{\left(q_{m\text{dew,,i}} - q_{m\text{dw,,i}}\right)} \tag{31}$$

where

$q_{m\text{edf,i}}$	is the instantaneous equivalent diluted exhaust mass flow rate, kg/s;
$q_{m\text{ew,i}}$	is the instantaneous exhaust mass flow rate, kg/s;
$r_{\text{dil,i}}$	is the instantaneous dilution ratio;
$q_{m\text{dew,i}}$	is the instantaneous diluted exhaust mass flow rate through dilution tunnel, kg/s;
$q_{m\text{dw,i}}$	is the instantaneous dilution air mass flow rate, kg/s;
f	is the data sampling rate, Hz; and
n	is the number of measurements.

b)

$$m_{\text{PM}} = m_{\text{f}} / (r_{\text{s}} \times 1\,000) \tag{32}$$

where

m_{f}	is the particulate mass sampled over the cycle, mg;
r_{s}	is the average sample ratio over the test cycle.

with

$$r_{\text{s}} = \frac{m_{\text{se}}}{m_{\text{ew}}} \times \frac{m_{\text{sep}}}{m_{\text{sed}}} \tag{33}$$

where

m_{se}	is the sample mass over the cycle, kg;
m_{ew}	is the total exhaust mass flow over the cycle, kg;
m_{sep}	is the mass of diluted exhaust gas passing the particulate collection filters, kg;
m_{sed}	is the mass of diluted exhaust gas passing the dilution tunnel, kg.

NOTE In case of the total sampling type system, m_{sep} and m_{sed} are identical.

9.4.6 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 Kp given in the following equations.

Reference values for humidity other than 10,71 g/kg may be used and shall be reported with the results by agreement of the parties involved.

Other correction equations may be used if they can be justified or validated.

$$k_{\mathrm{p}} = \frac{1}{\left[1 + 0{,}0133 \times \left(H_{\mathrm{a}} - 10{,}71\right)\right]} \tag{34}$$

where H_{a} is the humidity of the intake air in g water per kg dry air.

9.4.7 Calculation of the specific emissions

The particulate emission (g/kWh) shall be calculated in the following way:

$$M_{\mathrm{PM}} = m_{\mathrm{PM}} * k_{\mathrm{p}} / W_{\mathrm{act}} \tag{35}$$

where W_{act} is the actual cycle work as determined according to 6.6.2, kWh.

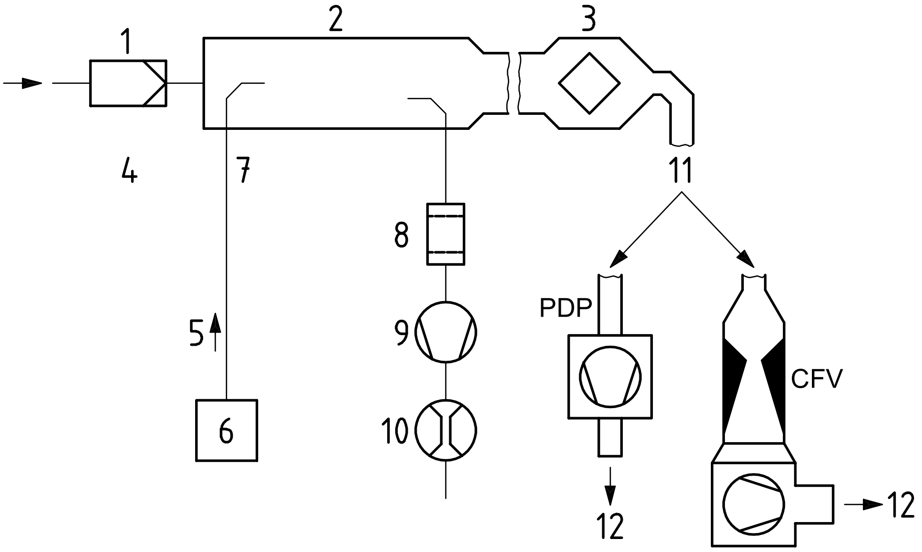
10 Determination of gaseous and particulate components with a full flow dilution system

10.1 General

The concentration signals, either by integration over the cycle or by bag sampling, of the gaseous components are used for the calculation of the mass emissions by multiplication with the diluted exhaust mass flow rate. 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 particulates, a proportional sample is taken from the diluted exhaust gas of the CVS system.

The complete test set up is schematically shown in Figure 3.



Key

1 filter
2 dilution tunnel
3 heat exchanger
4 dilution air
5 exhaust
6 engine
7 exhaust pipe
8 particulate filter
9 sample pump
10 flowmeter
11 or
12 vent

Figure 3 — Schematic of the CVS full flow dilution system

10.2 Determination of the diluted exhaust gas flow

10.2.1 General

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,Y for SSV) by either of the methods described in 10.2.2 to 10.2.4 may be used. If the total sample mass of particulates (m_{sep}) and gaseous pollutants exceeds 0,5 % of the total CVS flow (m_{ed}), the CVS flow shall be corrected for m_{sep} or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

10.2.2 PDP-CVS system

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

$$m_{ed} = 1{,}293 * V_0 * N_P * (p_B - p_1) * 273 / (101{,}3 * T) \tag{36}$$

where

V_0 is the volume of gas pumped per revolution under test conditions, m^3/rev;

N_P is the total revolutions of pump per test;

p_B is the atmospheric pressure in the test cell, kPa;

p_1 is the pressure depression below atmospheric at pump inlet, kPa;

T is the 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:

$$m_{ed,i} = 1{,}293 * V_0 * N_{P,i} * (p_B - p_1) * 273 / (101{,}3. T) \tag{37}$$

where $N_{P,i}$ is the total revolutions of pump per time interval.

10.2.3 CFV-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within ± 11 K over the cycle by using a heat exchanger.

$$m_{ed} = 1{,}293 * t * K_V * p_A / T^{0{,}5} \tag{38}$$

where

t is the cycle time, in s;

K_V is the calibration coefficient of the critical flow venturi for standard conditions;

p_A is the absolute pressure at venturi inlet, kPa;

T is the 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:

$$m_{\mathrm{ed,i}} = 1{,}293 * \Delta t_{\mathrm{i}} * K_{\mathrm{V}} * p_{\mathrm{A}} / T^{0{,}5} \tag{39}$$

where Δt_{i} is the time interval, in s.

10.2.4 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 ± 11 K over the cycle by using a heat exchanger.

$$m_{\mathrm{ed}} = 1{,}293 * Q_{\mathrm{SSV}} \tag{40}$$

where

$$Q_{\mathrm{SSV}} = A_0 d^2 C_d P_A \sqrt{\left[\frac{1}{T}\left(r^{1{,}428\,6} - r^{1{,}714\,3}\right) \cdot \left(\frac{1}{1-\beta^4 r^{1{,}428\,6}}\right)\right]} \tag{41}$$

where

A_0 is the collection of constants and units conversions

$= 0{,}006\,111$ in SI units of $\left(\frac{m^3}{\min}\right)\left(\frac{K^{\frac{1}{2}}}{kPa}\right)\left(\frac{1}{mm^2}\right)$

d is the diameter of the SSV throat, in m;

C_{d} is the discharge coefficient of the SSV;

P_{A} is the absolute pressure at venturi inlet, kPa;

T is the temperature at the venturi inlet, K.

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

r_{y} = 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:

$$m_{\mathrm{ed}} = 1{,}293 * Q_{\mathrm{SSV}} * \Delta t_{\mathrm{i}} \tag{42}$$

where

$$Q_{\mathrm{SSV}} = A_0 d^2 C_d P_A * \sqrt{\left[\frac{1}{T}\left(r^{1{,}428\,6} - r^{1{,}714\,3}\right)\left(\frac{1}{1-\beta^4 r^{1{,}428\,6}}\right)\right]} \tag{43}$$

Δt_{i} is the time interval, in s.

The real time calculation shall be initialized with either a reasonable value for C_d, such as 0,98, or a reasonable value of Q_{SSV}. If the calculation is initialized 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 must be in the range of Reynolds numbers used to derive the calibration curve developed in this clause.

10.3 Determination of the gaseous components

10.3.1 General

The gaseous components emitted by the engine submitted for testing shall be measured by the methods described in 10.3.2. They shall be determined in the diluted exhaust gas. Data evaluation and calculation procedures are described in 10.3.3 and 10.3.4.

10.3.2 Sampling for gaseous emissions

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of ISO 8178-1. 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:

- the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test; for HC, the sample bag must be heated to 464 ± 11 K (191 ± 11 °C), for NO_x, the sample bag temperature must be above the dew point temperature;
- the pollutants are sampled continuously and integrated over the cycle; this method shall be used for HC and NO_x, unless the above conditions are fulfilled.

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 10.3.4.2.

10.3.3 Data evaluation

For the evaluation of the gaseous emissions, the emission concentrations (HC, CO and NOx) and the diluted exhaust gas mass flow rate shall be recorded and stored with at least 1 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 will be recorded, and the calibration data may be applied online or offline during the data evaluation.

10.3.4 Calculation of mass emission

10.3.4.1 Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants shall be determined from the following equation:

$$m_{gas} = u_{gas} \times c_{gas} \times m_{ed} \tag{44}$$

where

u_{gas} is the ratio between density of exhaust component and density of air;

c_{gas} is the average background corrected concentration of the respective component, ppm;

m_{ed} is the total diluted exhaust mass over the cycle, kg.

For the calculation of NO_x, the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as applicable, as determined according to 10.3.6, shall be used.

The measured concentration shall be converted to a wet basis according to 10.3.5, if not already measured on a wet basis.

Values for u are given in Table 7 below for selected components.

Table 7 — Values of u in the diluted exhaust gas

Gas		NO_x	CO	HC	CO_2	O_2	CH_4	HCHO	CH_3OH
ρ_{gas} [kg/m³]		2,053	1,250	[a]	1,963 6	1,427 7	0,716	1,340	1,430
FUEL		ρ_{air} = 1,293 kg/m³		**Coefficient u_{gas}** [b]					
Diesel		0,001 588	0,000 967	0,000 480	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
RME		0,001 588	0,000 967	0,000 537	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Methanol		0,001 588	0,000 967	0,001 105	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Ethanol		0,001 588	0,000 967	0,000 795	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Natural gas [c]		0,001 588	0,000 967	0,000 584 [d]	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Propane		0,001 588	0,000 967	0,000 507	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Butane		0,001 588	0,000 967	0,000 501	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106
Gasoline		0,001 588	0,000 967	0,000 483	0,001 519	0,001 104	0,000 553	0,001 036	0,001 106

[a] Depending on fuel.

[b] At $\lambda = 2$, dry air, 273 K, 101,3 kPa.

[c] u accurate within 0,2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %.

[d] NMHC on the basis of $CH_{2,93}$ (for total HC the u_{gas} coefficient of CH_4 shall be used).

NOTE For calculating the u_{gas} values, the density of the diluted exhaust gas has been assumed to be equal to air density. Therefore, the u_{gas} values are identical for single gas components, but different for HC. It is not recommended to apply the exact calculation, as for the raw exhaust gas measurement, since dilution ratio and therefore the density of the diluted exhaust gas vary during the cycle.

10.3.4.2 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 equation shall be used.

$$c = c_e - c_d \times (1 - (1/DF)) \tag{45}$$

where

c_e is the concentration of the respective pollutant measured in the diluted exhaust gas, ppm;

c_d is the concentration of the respective pollutant measured in the dilution air, ppm; and

DF is the dilution factor.

The dilution factor shall be calculated as follows:

a) for diesel and LPG fuelled gas engines

$$DF = \frac{F_{\mathrm{S}}}{\mathrm{CO}_{2\mathrm{conce}} + \left(\mathrm{HC}_{\mathrm{conce}} + \mathrm{CO}_{\mathrm{conce}}\right) * 10^{-4}} \tag{46}$$

b) for NG fuelled gas engines

$$DF = \frac{F_{\mathrm{S}}}{\mathrm{CO}_{2\mathrm{conce}} + \left(\mathrm{NMHC}_{\mathrm{conce}} + \mathrm{CO}_{\mathrm{conce}}\right) * 10^{-4}} \tag{47}$$

where

$\mathrm{CO}_{2,\mathrm{conce}}$ is the concentration of CO_2 in the diluted exhaust gas, % vol;

$\mathrm{HC}_{\mathrm{conce}}$ is the concentration of HC in the diluted exhaust gas, ppm C1;

$\mathrm{NMHC}_{\mathrm{conce}}$ is the concentration of NMHC in the diluted exhaust gas, ppm C1;

$\mathrm{CO}_{\mathrm{conce}}$ is the concentration of CO in the diluted exhaust gas, ppm; and

F_{S} is the stoichiometric factor.

Concentrations measured on dry basis shall be converted to a wet basis in accordance with 10.3.5.

The stoichiometric factor shall be calculated as follows:

$$F_{\mathrm{S}} = 100 \times \frac{x}{x + \frac{y}{2} + 3{,}76 \times \left(x + \frac{y}{4}\right)} \tag{48}$$

where x, y is the fuel composition $\mathrm{C}_x\mathrm{H}_y$.

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

— F_{S} (diesel) = 13,4;

— F_{S} (LPG) = 11,6;

— F_{S} (NG) = 9,5.

10.3.4.3 Systems with flow compensation

For systems without heat exchanger, the mass of the pollutants (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 equations shall be applied:

$$m_{gas} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left[\left(m_{\mathrm{ed,i}} \times c_{\mathrm{e}} \times u_{\mathrm{gas}}\right)\right] - \left[\left(m_{\mathrm{ed}} \times c_{\mathrm{d}} \times \left(1 - 1/DF\right) \times u_{\mathrm{gas}}\right)\right] \tag{49}$$

where

c_e is the concentration of the respective pollutant measured in the diluted exhaust gas, ppm;

c_d is the concentration of the respective pollutant measured in the dilution air, ppm;

$m_{ed,i}$ is the instantaneous mass of the diluted exhaust gas, kg;

m_{ed} is the total mass of diluted exhaust gas over the cycle, kg;

u_{gas} is the tabulated value from Table 7;

DF is the dilution factor.

10.3.4.4 Calculation of NMHC and CH_4 with the non-methane cutter

The concentration of NMHC and CH_4 shall be calculated as follows:

$$c_{\mathrm{NMHC}} = \frac{c_{\mathrm{HC(w/oCutter)}} \times (1 - E_{\mathrm{M}}) - c_{\mathrm{HC(w/Cutter)}}}{E_{\mathrm{E}} - E_{\mathrm{M}}} \tag{50}$$

$$c_{\mathrm{CH4}} = \frac{c_{\mathrm{HC(w/Cutter)}} - c_{\mathrm{HC(w/oCutter)}} \times (1 - E_{\mathrm{E}})}{E_{\mathrm{E}} - E_{\mathrm{M}}} \tag{51}$$

where

$c_{\mathrm{HC(w/Cutter)}}$ is the HC concentration with the sample gas flowing through the NMC;

$c_{\mathrm{HC(w/oCutter)}}$ is the HC concentration with the sample gas bypassing the NMC;

E_{M} is the methane efficiency as determined per ISO 8178-1, 8.8.4.2;

E_{E} is the ethane efficiency as determined per ISO 8178-1, 8.8.4.3.

10.3.5 Dry/wet correction

If the concentration is measured on a dry basis, it shall be converted to a wet basis according to the following equation.

$$c_{\mathrm{wet}} = k_{\mathrm{W}} \times c_{\mathrm{dry}} \tag{21}$$

$$k_{\mathrm{w}} = \left(1 - \frac{\alpha \times \%\ \mathrm{conc}_{\mathrm{CO2}}\,(\mathrm{wet})}{200}\right) - k_{\mathrm{w,1}} \tag{52}$$

where

$$k_{\mathrm{w,1}} = \frac{1{,}608 \times H_a}{1\,000 + (1{,}608 \times H_{\mathrm{a}})} \tag{53}$$

10.3.6 NO_x correction for humidity and temperature

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

a) for compression-ignition engines:

$$k_{\mathrm{h,D}} = \frac{1}{1 - 0{,}0182 \times \left(H_{\mathrm{a}} - 10{,}71\right) + 0{,}0045 \times \left(T_{\mathrm{a}} - 298\right)} \tag{54}$$

where

T_{a} is the temperature of the intake air, K;

H_{a} is the humidity of the intake air, g water per kg dry air.

H_{a} may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted equations.

b) For compression ignition engines with intermediate air cooler, the following alternative equation may be used:

$$k_{h,\mathrm{D}} = \frac{1}{1 - 0{,}012 \times (H_a - 10{,}71) - 0{,}002\,75 \times (T_a - 298) + 0{,}002\,85 \times (T_{\mathrm{SC}} - T_{\mathrm{SCRef}})} \tag{55}$$

where

T_{SC} is the temperature of the intercooled air;

T_{SCRef} is the intercooled air reference temperature, to be specified by the manufacturer.

NOTE For an explanation of the other variables, see under a).

H_{a} is the humidity of the intake air, g water per kg dry air, where H_{a} may be derived from relative humidity measurement, dewpoint measurement, vapor pressure measurement or dry/wet bulb measurement using the generally accepted equations.

10.3.7 Calculation of the specific emissions

The emissions (g/kWh) shall be calculated for all components, except NO_x, in the following way:

$$M_{\mathrm{gas}} = m_{\mathrm{gas}} / W_{\mathrm{act}} \tag{56}$$

for NO_x

$$M_{\mathrm{gas}} = m_{\mathrm{gas}} * k_h / W_{\mathrm{act}} \tag{57}$$

where W_{act} is the actual cycle work as determined according to 6.6.2, kWh.

10.4 Particulate determination

10.4.1 General

The determination of the particulates requires a dilution system. In this clause, dilution shall be accomplished by 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. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be higher than 288 K (15 °C) in close proximity to the entrance into the dilution tunnel.

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. The details of the system are described in Clause 12.

10.4.2 Particulate sampling

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference, in the dilution tunnel. Therefore, the installation provisions of 9.3.2 also apply to particulate sampling. The sampling line shall conform to the requirements of ISO 8178-1.

10.4.3 Calculation of mass emission

The particulate mass (g/test) shall be calculated as follows:

$$m_{\mathrm{PM}} = \frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} \times \frac{m_{\mathrm{ed}}}{1000} \qquad (58)$$

where

m_{f} is the particulate mass sampled over the cycle, mg;

m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters, kg;

m_{ed} is the mass of diluted exhaust gas over the cycle, kg.

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.

$$m_{\mathrm{sep}} = m_{\mathrm{set}} - m_{\mathrm{ssd}} \qquad (59)$$

where

m_{set} is the mass of double diluted exhaust gas through particulate filter, kg;

m_{ssd} is the mass of secondary dilution air, kg.

If the particulate background level of the dilution air is determined in accordance with 7.5, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{\mathrm{PM}} = \left[\frac{m_{\mathrm{f}}}{m_{\mathrm{sep}}} - \left(\frac{m_{\mathrm{b}}}{m_{\mathrm{sd}}} \times \left(1 - \frac{1}{DF} \right) \right) \right] \times \frac{m_{\mathrm{ed}}}{1000} \qquad (60)$$

where

m_{PM}, m_{sep}, m_{ed} (see above);

m_{sd} is the mass of primary dilution air sampled by background particulate sampler, kg;

m_{b} is the mass of the collected background particulates of the primary dilution air, mg;

DF is the dilution factor as determined in 10.3.4.2.

10.4.4 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 equation.

Reference values for humidity other than 10,71 g/kg may be used and shall be reported with the results by agreement of the parties involved.

Other correction equations may be used if they can be justified or validated.

$$k_p = \frac{1}{\left[1+0{,}0133\times\left(H_a-10{,}71\right)\right]} \tag{61}$$

where H_a is the humidity of the intake air in g water per kg dry air.

10.4.5 Calculation of the specific emissions

The particulate emission (g/kWh) shall be calculated in the following way:

$$M_{PM} = m_{PM} * k_p / W_{act} \tag{62}$$

where W_{act} is the actual cycle work as determined according to 6.6.2, in kWh.

11 Measurement equipment for the gaseous components

11.1 General analyser specifications

11.1.1 General

The analysers shall have a measuring range and response time appropriate for the accuracy required to measure the concentrations of the exhaust gas components under transient conditions. The analyser range shall be selected such that the average concentration measured over the test cycle falls between 15 % and 100 % of full scale, except the accuracy of the analyser does not exceed ± 2 % of reading for the average concentration.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 % of full scale, measurements below 15 % of full scale are also acceptable. In this case, additional calibrations of at least four non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to 8.5.5 of ISO 8178-1.

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

11.1.2 Accuracy

The analyser shall not deviate from the nominal calibration point by more than ± 2 % of the reading or ± 0,3 % of full scale, whichever is larger. The accuracy shall be determined according to the calibration requirements in ISO 8178-1, 8.5.

NOTE For the purpose of this International Standard, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas (true value).

11.1.3 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be not greater than 1 % of full scale concentration for each range used above 155 ppm (or ppmC) or 2 % of each range used below 155 ppm (or ppmC).

11.1.4 Noise

The analyser peak-to-peak response to zero and calibration or span gases over any 10-second period shall not exceed 2 % of full scale on all ranges used.

11.1.5 Zero drift

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

11.1.6 Span drift

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

11.1.7 Rise time

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_x analysers. The determination of the total system response time is described in 11.3.2.

11.1.8 Gas drying

Exhaust gases may be measured wet or dry. A gas drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

11.2 Analysers

11.2.1 General

11.2.2 to 11.2.9 describe the measurement principles to be used. A detailed description of the measurement systems is given in ISO 8178-1, Clause 15. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

11.2.2 Carbon monoxide (CO) analysis

The carbon monoxide analyser shall be of the non-dispersive infrared (NDIR) absorption type.

11.2.3 Carbon dioxide (CO_2) analysis

The carbon dioxide analyser shall be of the NDIR absorption type.

11.2.4 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 ± 10 K (190 ± 10 °C).

11.2.5 Non-methane hydrocarbon (NMHC) analysis

The determination of the non-methane hydrocarbon fraction shall be performed with a heated non-methane cutter (NMC) operated in line with an FID as per 16.4.2 of ISO 8178-1, by subtraction of the methane from the hydrocarbons.

11.2.6 Oxides of nitrogen (NO_x) analysis

If measured on a dry basis, the oxides of nitrogen analyser shall be of the chemiluminescent detector (CLD or heated chemiluminescent detector (HCLD) type with an NO_2/NO converter. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see ISO 8178-1, 8.9.3.2) is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55 °C to 200 °C) up to the converter for dry measurement, and up to the analyser for wet measurement.

11.2.7 Formaldehyde (HCHO) analysis

For continuous measurement in the raw exhaust gas, an FTIR (Fourier transform infrared) or a SIMS (soft ionization mass spectrometric) analyser shall be used in accordance with the instrument suppliers' instructions.

The FTIR analyser shall be equipped with an algorithm to generate interference-free concentration values from an infrared spectrum. The FTIR analyser shall also be equipped with a dedicated spectral database for each instrument, in order to avoid interference caused by differences of the spectra between the instruments.

The SIMS analyser shall be equipped with a control library to generate interference decoupled values of the formaldehyde concentration. The internal energy of the ionizing ion shall be above 11,6 eV (e.g. Xe^+ with an internal energy of 12,2 eV). If measured on mass 30, the interference from NO_2 shall be compensated with the help of the known ionization efficiency ratio of NO_2 for masses 46 and 30. The interference decoupling shall be performed with a cycle time of at most 300 msec. Measurement of formaldehyde on mass 29 is acceptable if the additional signal due to higher aldehydes is either desired, accepted or compensated (measurement on mass 29 gives an upper limit for the formaldehyde concentration).

If measured in the dilute exhaust gas of a partial flow dilution system, formaldehyde shall be determined by passing the diluted exhaust sample with a constant flow rate through an impinger containing an acetonitrile (ACN) solution of DNPH reagent or through a silica cartridge coated with 2,4-DNPH. The sample collected shall be analysed by a high pressure liquid chromatograph (HPLC) using UV detection at 365 nm (for details see 16.6 of ISO 8178-1). The provisions for the accuracy of the flow measurement outlined in 12.1.4. must be met by the procedure given in 12.1.4.3, if the dilute gas is sampled from a total sampling type partial flow dilution system.

11.2.8 Methanol (CH_3OH) analysis

For continuous measurement in the raw exhaust gas, an FTIR (Fourier transform infrared) or a SIMS (soft ionization mass spectrometric) analyser shall be used in accordance with the instrument suppliers' instructions.

The FTIR analyser shall be equipped with an algorithm to generate interference-free concentration values from an infrared spectrum. The FTIR analyser shall also be equipped with a dedicated spectral data base for each instrument, in order to avoid interference caused by differences of the spectra between the instruments.

The SIMS analyser shall be equipped with a control library to generate interference decoupled values of the methanol concentration. The internal energy of the ionizing ion shall be above 11,2 eV (e.g. Xe^+ with an internal energy of 12,2 eV). This enables measurement of methanol on mass 31. The only substances interfering on this mass could be fragments of ethanol and propanol, substances which usually do not occur in exhaust gases. For an accurate measurement of methanol, the interference decoupling shall nevertheless be performed with the help of the known ionization efficiency ratios of these substances on their unfragmented masses and mass 31.

Optionally, methanol may be determined with an HFID. In this case, the HFID calibrated on propane shall be operated at 385 K ± 10 K (112 °C ± 10 °C). The methanol response factor shall be determined at several concentrations in the range of concentrations in the sample, according to 8.8.5 of ISO 8178-1.

If measured in the dilute exhaust gas of partial flow dilution system, methanol shall be determined by passing the diluted exhaust sample with a constant flow rate through an impinger containing deionized water. The sample shall be analysed by a gas chromatograph (GC) with FID (for details see 16.5 of ISO 8178-1). The provisions for the accuracy of the flow measurement outlined in 12.1.4. must be met by the procedure given in 12.1.4.3, if the dilute gas is sampled from a total sampling type partial flow dilution system.

11.2.9 Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in 9.2.6 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 % of reading $\lambda < 2$;
- ± 5 % of reading $2 \leqslant \lambda < 5$;
- ± 10 % of reading $5 \leqslant \lambda$.

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

11.3 Calibration

11.3.1 General

Each analyser shall be calibrated as often as necessary to fulfill the accuracy requirements of this International Standard. The calibration method that shall be used is described in detail in ISO 8178-1, Clause 8. Only calibration procedures specific to transient testing are described in this part of ISO 8178.

11.3.2 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 second. The gases used for the test shall cause a concentration change of at least 60 % FS.

The concentration trace of each single gas component shall be recorded. The response time is defined to be 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 % of the final reading (t_{10}). The rise time is defined as the time between 10 % and 90 % 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 % of the final reading (t_{50}).

The system response time shall be $\leqslant$ 10 seconds with a rise time $\leqslant$ 2,5 seconds in accordance with 11.1.7 for all limited components (CO, NO_x, HC or NMHC) and all ranges used.

11.3.3 Verification of the calibration curve

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

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

If, for the two points considered, the value found does not differ by more than ± 4 % of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, the span gas shall be verified or a new calibration curve shall be established in accordance with 8.5 of ISO 8178-1.

11.3.4 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 % of analyser's full scale and the rest are in between 20 % to 100 % of the full scale. The calibration curve is calculated by the method of least squares.

The calibration curve shall not differ by more than ± 1 % of the full scale from the nominal value of each calibration point, in the range from 20 % to 100 % of the full scale. It also shall not differ by more than ± 2 % of reading from the nominal value in the range from 4 % to 20 % 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 % of the analyser full scale.

11.3.5 Calibration intervals

The analysers shall be calibrated according to 8.5 of ISO 8178-1 at least every 3 months or whenever a system repair or change is made that could influence calibration.

11.4 Analytical system

The analytical system is described in detail in ISO 8178-1, Clause 16.

12 Measurement equipment for particulates

12.1 General specifications

12.1.1 General

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. The particulate sampling system shall be designed to ensure a representative sample of the particulates proportional to the raw or diluted exhaust flow, whatever is applicable, under transient engine operating conditions in accordance with 9.4.2.

12.1.2 Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of 12.1.2.1 and 12.1.2.2 during the test sequence.

12.1.2.1 Filter specification

Fluorocarbon coated glass fiber filters or fluorocarbon membrane filters are required. All filter types shall have a 0,3 µm DOP (di-octylphthalate) collection efficiency of at least 99 % at a gas face velocity between 35 and 100 cm/s.

12.1.2.2 Filter size

Particulate filters with a diameter of 47 mm are recommended. Larger diameter filters are acceptable (see 12.1.2.4), but smaller diameter filters are not permitted.

12.1.2.3 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.

12.1.2.4 Filter loading

The required minimum filter loadings for the most common filter sizes are shown in Table 8. For larger filter sizes, the minimum filter loading shall be 0,065 mg/1 000 mm^2 filter area.

Table 8 — Minimum filter loadings

Filter diameter (mm)	**Minimum loading** (mg)
47	0,11
70	0,25
90	0,41
110	0,62

If, based on previous testing, the required minimum filter loading is unlikely to be reached on a test cycle after optimization of flow rates and dilution ratio, a lower filter loading may be acceptable, with the agreement of the parties involved, if it can be shown to meet the accuracy requirements of 12.1.3.2, e.g. with a 0,1 µg balance.

12.1.3 Weighing chamber and analytical balance specifications

12.1.3.1 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 ± 3 K (22 °C ± 3 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of 282,5 K ± 3 K (9,5 °C ± 3 °C) and a relative humidity of 45 % ± 8 %.

12.1.3.2 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 12.1.3.1 will be allowed if the duration of the disturbances does not exceed 30 min. The weighing room should meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters shall be weighed within 4 h of, but preferably at the same time as the sample filter weighings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters changes between sample filter weighings 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 12.1.3.1 is not met, but the reference filter weighings 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 rerunning the test.

12.1.3.3 Analytical balance

The analytical balance used to determine the filter weight shall have a precision (standard deviation) of at least 2 µg and a resolution of at least 1 µg (1 digit = 1 µg) specified by the balance manufacturer.

12.1.3.4 Elimination of static electricity effects

If unstable or irreproducible filter weighings are observed due to the effects of static electricity, the filters shall be neutralized prior to weighing, e.g. by a Polonium neutralizer or a device of similar effect.

12.1.4 Specifications for flow measurement

12.1.4.1 General requirements

Absolute accuracies of flow meter or flow measurement instrumentation shall be as specified in 8.3.

12.1.4.2 Special provisions for partial flow dilution systems

For partial flow dilution systems, the accuracy of the sample flow $q_{m\mathrm{p}}$ is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{m\mathrm{p}} = q_{m\mathrm{dew}} - q_{m\mathrm{dw}} \tag{63}$$

In this case an accuracy of ± 2 % for $q_{m\mathrm{dew}}$ and $q_{m\mathrm{dw}}$ is not sufficient to guarantee acceptable accuracies of $q_{m\mathrm{p}}$. If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of $q_{m\mathrm{p}}$ is within ± 5 % 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 $q_{m\mathrm{p}}$ can be obtained by any of the following methods:

a) The absolute accuracies of $q_{m\mathrm{dew}}$ and $q_{m\mathrm{dw}}$ are ± 0,2 % which guarantees an accuracy of $q_{m\mathrm{p}}$ of $\leqslant$ 5 % at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.

b) Calibration of $q_{m\mathrm{dw}}$ relative to $q_{m\mathrm{dew}}$ is carried out such that the same accuracies for $q_{m\mathrm{p}}$ as in a) are obtained. For the details of such a calibration see 12.3.2.

c) The accuracy of $q_{m\mathrm{p}}$ 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 $q_{m\mathrm{p}}$ are required.

d) The absolute accuracy of $q_{m\mathrm{dew}}$ and $q_{m\mathrm{dw}}$ is within ± 2 % of full scale, the maximum error of the difference between $q_{m\mathrm{dew}}$ and $q_{m\mathrm{dw}}$ is within 0,2 %, and the linearity error is within ± 0,2 % of the highest $q_{m\mathrm{dew}}$ observed during the test.

12.1.4.3 Correction for sample flow (partial flow dilution system only)

If measurement of methanol or formaldehyde is done with a total sampling type partial flow dilution system, it is necessary to extract a sample flow $q_{m\mathrm{ex}}$ from the tunnel, i.e. before the flow measuring device for $q_{m\mathrm{dew}}$. $q_{m\mathrm{ex}}$ shall be determined with the flow measurement device and will usually be much smaller than $q_{m\mathrm{dew}}$, but not negligible ($q_{m\mathrm{ex}} > 0{,}01 \times q_{m\mathrm{dew}}$).

In order to guarantee an accuracy of $q_{m\mathrm{p}}$ as requested in 12.1.4.2 and 12.3.2.1, any of the methods outlined in these clauses may be used, but with $q_{m\mathrm{dew}}$ replaced by $q_{m\mathrm{dew}} + q_{m\mathrm{ex}}$.

For the calculation of the PM mass emission (see 9.4.5), the mass of $q_{m\mathrm{ex}}$ extracted from the tunnel shall be taken into account by correcting the particulate mass m_f, as follows:

$$m_{\mathrm{f,corrected}} = m_\mathrm{f} \times \frac{q_{m\mathrm{dew}}}{\left(q_{m\mathrm{dew}} - q_{m\mathrm{ex}}\right)} \tag{64}$$

12.1.5 Additional specifications

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.

12.2 Dilution and sampling system

The dilution and sampling system is described in detail in ISO 8178-1, Clause 17.

12.3 Calibration

12.3.1 General

The calibration of the particulate measurement is limited to the flow meters used to determine sample flow and dilution ratio. Each flow meter shall be calibrated as often as necessary to fulfill the accuracy requirements of this part of ISO 8178. The calibration method that shall be used is described in 12.3.2.

12.3.2 Flow measurement

12.3.2.1 Periodical calibration

To fulfill the absolute accuracy of the flow measurements as specified in 8.3, the flow meter or the flow measurement instrumentation shall be calibrated with an accurate flow meter traceable to international and/or national standards.

If the sample gas flow is determined by differential flow measurement the flow meter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow $q_{m\mathrm{p}}$ into the tunnel shall fulfill the accuracy requirements of 12.1.4:

a) The flow meter for $q_{m\mathrm{dw}}$ is connected in series to the flow meter for $q_{m\mathrm{dew}}$, the difference between the two flow meters is calibrated for at least five set points with flow values equally spaced between the lowest $q_{m\mathrm{dw}}$ value used during the test and the value of $q_{m\mathrm{dew}}$ used during the test The dilution tunnel may be bypassed.

b) A calibrated mass flow device is connected in series to the flowmeter for $q_{m\mathrm{dew}}$ 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 $q_{m\mathrm{dw}}$, and the accuracy is checked for at least five settings corresponding to dilution ratio between 3 and 50, relative to $q_{m\mathrm{dew}}$ used during the test.

c) The transfer tube TT is disconnected from the exhaust, and a calibrated flow measuring device with a suitable range to measure $q_{m\mathrm{p}}$ is connected to the transfer tube. Then $q_{m\mathrm{dew}}$ is set to the value used during the test, and $q_{m\mathrm{dw}}$ 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 as in the actual test.

d) A tracer gas is fed into the transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x. After dilution in the tunnel the tracer gas component 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 ration r_{dil}:

$$q_{m\mathrm{p}} = q_{m\mathrm{dew}} / r_{\mathrm{dil}} \tag{65}$$

The accuracies of the gas analysers shall be taken into account to guarantee the accuracy of $q_{m\mathrm{p}}$.

12.3.2.2 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 % or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex D shall be applied. The carbon flow rates shall be calculated according to equations D-1, D-2 and D-3. All carbon flow rates should agree to within 6 %.

12.3.2.3 Pre-test check

A pre-test check shall be performed within 2 h 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 12.3.2.1) for at least two points, including flow values of $q_{m\mathrm{dw}}$ that correspond to dilution ratios between 5 and 15 for the $q_{m\mathrm{dew}}$ value used during the test.

If it can be demonstrated by records of the calibration procedure under 12.3.2.1 that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

12.3.3 Determination of the transformation time (partial flow dilution system only)

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 flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system, 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 % of full scale. The trigger for the step change should be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50 % point of the flowmeter response. In a similar manner, the transformation times of the $q_{m\mathrm{p}}$ signal of the partial flow dilution system and of the $q_{m\mathrm{ew,i}}$ signal of the exhaust flow meter shall be determined. These signals are used in the regression checks performed after each test (see 9.4.3).

The calculation shall be repeated for at least five rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 msec) of the reference flowmeter 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 9.4.3., if the transformation time is greater than 0,3 s.

12.3.4 Calibration of the CVS system (full flow dilution system only)

12.3.4.1 General

The CVS system shall be calibrated by using an accurate flowmeter and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow.

Various type of flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbinemeter.

The CVS calibration is described in detail in ISO 8178-1, Clause 9.

12.3.4.2 Total system verification

12.3.4.2.1 General

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 10.3.4.1 except in the case of propane, where a factor of 0,000 472 is used in place of 0,000 479 for HC. Either of the following two techniques shall be used.

12.3.4.2.2 Metering with a critical flow orifice

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 min. 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 ± 3 % of the known mass of the gas injected.

12.3.4.2.3 Metering by means of a gravimetric technique

The weight of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0,01 gram. For about 5 to 10 min, 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 ± 3 % of the known mass of the gas injected.

12.3.5 Calibration intervals

The instruments shall be calibrated as required by internal audit procedures or by the instrument manufacturer.

Annex A
(normative)

NRTC engine dynamometer schedule

Time s	Norm. speed %	Norm. torque %
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	1	3
25	1	3
26	1	3
27	1	3
28	1	3
29	1	3
30	1	6
31	1	6
32	2	1
33	4	13
34	7	18
35	9	21
36	17	20
37	33	42
38	57	46
39	44	33
40	31	0
41	22	27
42	33	43
43	80	49
44	105	47
45	98	70
46	104	36
47	104	65
48	96	71
49	101	62
50	102	51
51	102	50
52	102	46
53	102	41
54	102	31
55	89	2
56	82	0
57	47	1
58	23	1
59	1	3
60	1	8
61	1	3
62	1	5
63	1	6
64	1	4
65	1	4
66	0	6
67	1	4
68	9	21
69	25	56
70	64	26
71	60	31
72	63	20
73	62	24
74	64	8
75	58	44
76	65	10
77	65	12
78	68	23
79	69	30
80	71	30
81	74	15
82	71	23
83	73	20
84	73	21
85	73	19
86	70	33
87	70	34
88	65	47
89	66	47
90	64	53
91	65	45
92	66	38
93	67	49
94	69	39
95	69	39
96	66	42
97	71	29
98	75	29
99	72	23

Time s	Norm. speed %	Norm. torque %
100	74	22
101	75	24
102	73	30
103	74	24
104	77	6
105	76	12
106	74	39
107	72	30
108	75	22
109	78	64
110	102	34
111	103	28
112	103	28
113	103	19
114	103	32
115	104	25
116	103	38
117	103	39
118	103	34
119	102	44
120	103	38
121	102	43
122	103	34
123	102	41
124	103	44
125	103	37
126	103	27
127	104	13
128	104	30
129	104	19
130	103	28
131	104	40
132	104	32
133	101	63
134	102	54
135	102	52
136	102	51
137	103	40
138	104	34
139	102	36
140	104	44
141	103	44
142	104	33
143	102	27
144	103	26
145	79	53
146	51	37
147	24	23
148	13	33
149	19	55
150	45	30
151	34	7
152	14	4
153	8	16
154	15	6
155	39	47
156	39	4
157	35	26
158	27	38
159	43	40
160	14	23
161	10	10
162	15	33
163	35	72
164	60	39
165	55	31
166	47	30
167	16	7
168	0	6
169	0	8
170	0	8
171	0	2
172	2	17
173	10	28
174	28	31
175	33	30
176	36	0
177	19	10
178	1	18
179	0	16
180	1	3
181	1	4
182	1	5
183	1	6
184	1	5
185	1	3
186	1	4
187	1	4
188	1	6
189	8	18
190	20	51
191	49	19
192	41	13
193	31	16
194	28	21
195	21	17
196	31	21
197	21	8
198	0	14
199	0	12
200	3	8
201	3	22
202	12	20
203	14	20
204	16	17
205	20	18
206	27	34
207	32	33
208	41	31
209	43	31
210	37	33
211	26	18
212	18	29
213	14	51
214	13	11
215	12	9
216	15	33

Time s	Norm. speed %	Norm. torque %
217	20	25
218	25	17
219	31	29
220	36	66
221	66	40
222	50	13
223	16	24
224	26	50
225	64	23
226	81	20
227	83	11
228	79	23
229	76	31
230	68	24
231	59	33
232	59	3
233	25	7
234	21	10
235	20	19
236	4	10
237	5	7
238	4	5
239	4	6
240	4	6
241	4	5
242	7	5
243	16	28
244	28	25
245	52	53
246	50	8
247	26	40
248	48	29
249	54	39
250	60	42
251	48	18
252	54	51
253	88	90
254	103	84
255	103	85
256	102	84
257	58	66
258	64	97
259	56	80
260	51	67
261	52	96
262	63	62
263	71	6
264	33	16
265	47	45
266	43	56
267	42	27
268	42	64
269	75	74
270	68	96
271	86	61
272	66	0
273	37	0
274	45	37
275	68	96
276	80	97
277	92	96
278	90	97
279	82	96
280	94	81
281	90	85
282	96	65
283	70	96
284	55	95
285	70	96
286	79	96
287	81	71
288	71	60
289	92	65
290	82	63
291	61	47
292	52	37
293	24	0
294	20	7
295	39	48
296	39	54
297	63	58
298	53	31
299	51	24
300	48	40
301	39	0
302	35	18
303	36	16
304	29	17
305	28	21
306	31	15
307	31	10
308	43	19
309	49	63
310	78	61
311	78	46
312	66	65
313	78	97
314	84	63
315	57	26
316	36	22
317	20	34
318	19	8
319	9	10
320	5	5
321	7	11
322	15	15
323	12	9
324	13	27
325	15	28
326	16	28
327	16	31
328	15	20
329	17	0
330	20	34
331	21	25
332	20	0
333	23	25

Time s	Norm. speed %	Norm. torque %
334	30	58
335	63	96
336	83	60
337	61	0
338	26	0
339	29	44
340	68	97
341	80	97
342	88	97
343	99	88
344	102	86
345	100	82
346	74	79
347	57	79
348	76	97
349	84	97
350	86	97
351	81	98
352	83	83
353	65	96
354	93	72
355	63	60
356	72	49
357	56	27
358	29	0
359	18	13
360	25	11
361	28	24
362	34	53
363	65	83
364	80	44
365	77	46
366	76	50
367	45	52
368	61	98
369	61	69
370	63	49
371	32	0
372	10	8

Time s	Norm. speed %	Norm. torque %
373	17	7
374	16	13
375	11	6
376	9	5
377	9	12
378	12	46
379	15	30
380	26	28
381	13	9
382	16	21
383	24	4
384	36	43
385	65	85
386	78	66
387	63	39
388	32	34
389	46	55
390	47	42
391	42	39
392	27	0
393	14	5
394	14	14
395	24	54
396	60	90
397	53	66
398	70	48
399	77	93
400	79	67
401	46	65
402	69	98
403	80	97
404	74	97
405	75	98
406	56	61
407	42	0
408	36	32
409	34	43
410	68	83
411	102	48

Time s	Norm. speed %	Norm. torque %
412	62	0
413	41	39
414	71	86
415	91	52
416	89	55
417	89	56
418	88	58
419	78	69
420	98	39
421	64	61
422	90	34
423	88	38
424	97	62
425	100	53
426	81	58
427	74	51
428	76	57
429	76	72
430	85	72
431	84	60
432	83	72
433	83	72
434	86	72
435	89	72
436	86	72
437	87	72
438	88	72
439	88	71
440	87	72
441	85	71
442	88	72
443	88	72
444	84	72
445	83	73
446	77	73
447	74	73
448	76	72
449	46	77
450	78	62

Time s	Norm. speed %	Norm. torque %
451	79	35
452	82	38
453	81	41
454	79	37
455	78	35
456	78	38
457	78	46
458	75	49
459	73	50
460	79	58
461	79	71
462	83	44
463	53	48
464	40	48
465	51	75
466	75	72
467	89	67
468	93	60
469	89	73
470	86	73
471	81	73
472	78	73
473	78	73
474	76	73
475	79	73
476	82	73
477	86	73
478	88	72
479	92	71
480	97	54
481	73	43
482	36	64
483	63	31
484	78	1
485	69	27
486	67	28
487	72	9
488	71	9
489	78	36
490	81	56
491	75	53
492	60	45
493	50	37
494	66	41
495	51	61
496	68	47
497	29	42
498	24	73
499	64	71
500	90	71
501	100	61
502	94	73
503	84	73
504	79	73
505	75	72
506	78	73
507	80	73
508	81	73
509	81	73
510	83	73
511	85	73
512	84	73
513	85	73
514	86	73
515	85	73
516	85	73
517	85	72
518	85	73
519	83	73
520	79	73
521	78	73
522	81	73
523	82	72
524	94	56
525	66	48
526	35	71
527	51	44
528	60	23
529	64	10
530	63	14
531	70	37
532	76	45
533	78	18
534	76	51
535	75	33
536	81	17
537	76	45
538	76	30
539	80	14
540	71	18
541	71	14
542	71	11
543	65	2
544	31	26
545	24	72
546	64	70
547	77	62
548	80	68
549	83	53
550	83	50
551	83	50
552	85	43
553	86	45
554	89	35
555	82	61
556	87	50
557	85	55
558	89	49
559	87	70
560	91	39
561	72	3
562	43	25
563	30	60
564	40	45
565	37	32
566	37	32
567	43	70

Time s	Norm. speed %	Norm. torque %
568	70	54
569	77	47
570	79	66
571	85	53
572	83	57
573	86	52
574	85	51
575	70	39
576	50	5
577	38	36
578	30	71
579	75	53
580	84	40
581	85	42
582	86	49
583	86	57
584	89	68
585	99	61
586	77	29
587	81	72
588	89	69
589	49	56
590	79	70
591	104	59
592	103	54
593	102	56
594	102	56
595	103	61
596	102	64
597	103	60
598	93	72
599	86	73
600	76	73
601	59	49
602	46	22
603	40	65
604	72	31
605	72	27
606	67	44
607	68	37
608	67	42
609	68	50
610	77	43
611	58	4
612	22	37
613	57	69
614	68	38
615	73	2
616	40	14
617	42	38
618	64	69
619	64	74
620	67	73
621	65	73
622	68	73
623	65	49
624	81	0
625	37	25
626	24	69
627	68	71
628	70	71
629	76	70
630	71	72
631	73	69
632	76	70
633	77	72
634	77	72
635	77	72
636	77	70
637	76	71
638	76	71
639	77	71
640	77	71
641	78	70
642	77	70
643	77	71
644	79	72
645	78	70
646	80	70
647	82	71
648	84	71
649	83	71
650	83	73
651	81	70
652	80	71
653	78	71
654	76	70
655	76	70
656	76	71
657	79	71
658	78	71
659	81	70
660	83	72
661	84	71
662	86	71
663	87	71
664	92	72
665	91	72
666	90	71
667	90	71
668	91	71
669	90	70
670	90	72
671	91	71
672	90	71
673	90	71
674	92	72
675	93	69
676	90	70
677	93	72
678	91	70
679	89	71
680	91	71
681	90	71
682	90	71
683	92	71
684	91	71

Time s	Norm. speed %	Norm. torque %
685	93	71
686	93	68
687	98	68
688	98	67
689	100	69
690	99	68
691	100	71
692	99	68
693	100	69
694	102	72
695	101	69
696	100	69
697	102	71
698	102	71
699	102	69
700	102	71
701	102	68
702	100	69
703	102	70
704	102	68
705	102	70
706	102	72
707	102	68
708	102	69
709	100	68
710	102	71
711	101	64
712	102	69
713	102	69
714	101	69
715	102	64
716	102	69
717	102	68
718	102	70
719	102	69
720	102	70
721	102	70
722	102	62
723	104	38
724	104	15
725	102	24
726	102	45
727	102	47
728	104	40
729	101	52
730	103	32
731	102	50
732	103	30
733	103	44
734	102	40
735	103	43
736	103	41
737	102	46
738	103	39
739	102	41
740	103	41
741	102	38
742	103	39
743	102	46
744	104	46
745	103	49
746	102	45
747	103	42
748	103	46
749	103	38
750	102	48
751	103	35
752	102	48
753	103	49
754	102	48
755	102	46
756	103	47
757	102	49
758	102	42
759	102	52
760	102	57
761	102	55
762	102	61
763	102	61
764	102	58
765	103	58
766	102	59
767	102	54
768	102	63
769	102	61
770	103	55
771	102	60
772	102	72
773	103	56
774	102	55
775	102	67
776	103	56
777	84	42
778	48	7
779	48	6
780	48	6
781	48	7
782	48	6
783	48	7
784	67	21
785	105	59
786	105	96
787	105	74
788	105	66
789	105	62
790	105	66
791	89	41
792	52	5
793	48	5
794	48	7
795	48	5
796	48	6
797	48	4
798	52	6
799	51	5
800	51	6
801	51	6

Time s	Norm. speed %	Norm. torque %
802	52	5
803	52	5
804	57	44
805	98	90
806	105	94
807	105	100
808	105	98
809	105	95
810	105	96
811	105	92
812	104	97
813	100	85
814	94	74
815	87	62
816	81	50
817	81	46
818	80	39
819	80	32
820	81	28
821	80	26
822	80	23
823	80	23
824	80	20
825	81	19
826	80	18
827	81	17
828	80	20
829	81	24
830	81	21
831	80	26
832	80	24
833	80	23
834	80	22
835	81	21
836	81	24
837	81	24
838	81	22
839	81	22
840	81	21
841	81	31
842	81	27
843	80	26
844	80	26
845	81	25
846	80	21
847	81	20
848	83	21
849	83	15
850	83	12
851	83	9
852	83	8
853	83	7
854	83	6
855	83	6
856	83	6
857	83	6
858	83	6
859	76	5
860	49	8
861	51	7
862	51	20
863	78	52
864	80	38
865	81	33
866	83	29
867	83	22
868	83	16
869	83	12
870	83	9
871	83	8
872	83	7
873	83	6
874	83	6
875	83	6
876	83	6
877	83	6
878	59	4
879	50	5
880	51	5
881	51	5
882	51	5
883	50	5
884	50	5
885	50	5
886	50	5
887	50	5
888	51	5
889	51	5
890	51	5
891	63	50
892	81	34
893	81	25
894	81	29
895	81	23
896	80	24
897	81	24
898	81	28
899	81	27
900	81	22
901	81	19
902	81	17
903	81	17
904	81	17
905	81	15
906	80	15
907	80	28
908	81	22
909	81	24
910	81	19
911	81	21
912	81	20
913	83	26
914	80	63
915	80	59
916	83	100
917	81	73
918	83	53

Time s	Norm. speed %	Norm. torque %
919	80	76
920	81	61
921	80	50
922	81	37
923	82	49
924	83	37
925	83	25
926	83	17
927	83	13
928	83	10
929	83	8
930	83	7
931	83	7
932	83	6
933	83	6
934	83	6
935	71	5
936	49	24
937	69	64
938	81	50
939	81	43
940	81	42
941	81	31
942	81	30
943	81	35
944	81	28
945	81	27
946	80	27
947	81	31
948	81	41
949	81	41
950	81	37
951	81	43
952	81	34
953	81	31
954	81	26
955	81	23
956	81	27
957	81	38
958	81	40
959	81	39
960	81	27
961	81	33
962	80	28
963	81	34
964	83	72
965	81	49
966	81	51
967	80	55
968	81	48
969	81	36
970	81	39
971	81	38
972	80	41
973	81	30
974	81	23
975	81	19
976	81	25
977	81	29
978	83	47
979	81	90
980	81	75
981	80	60
982	81	48
983	81	41
984	81	30
985	80	24
986	81	20
987	81	21
988	81	29
989	81	29
990	81	27
991	81	23
992	81	25
993	81	26
994	81	22
995	81	20
996	81	17
997	81	23
998	83	65
999	81	54
1000	81	50
1001	81	41
1002	81	35
1003	81	37
1004	81	29
1005	81	28
1006	81	24
1007	81	19
1008	81	16
1009	80	16
1010	83	23
1011	83	17
1012	83	13
1013	83	27
1014	81	58
1015	81	60
1016	81	46
1017	80	41
1018	80	36
1019	81	26
1020	86	18
1021	82	35
1022	79	53
1023	82	30
1024	83	29
1025	83	32
1026	83	28
1027	76	60
1028	79	51
1029	86	26
1030	82	34
1031	84	25
1032	86	23
1033	85	22
1034	83	26
1035	83	25

Time s	Norm. speed %	Norm. torque %
1036	83	37
1037	84	14
1038	83	39
1039	76	70
1040	78	81
1041	75	71
1042	86	47
1043	83	35
1044	81	43
1045	81	41
1046	79	46
1047	80	44
1048	84	20
1049	79	31
1050	87	29
1051	82	49
1052	84	21
1053	82	56
1054	81	30
1055	85	21
1056	86	16
1057	79	52
1058	78	60
1059	74	55
1060	78	84
1061	80	54
1062	80	35
1063	82	24
1064	83	43
1065	79	49
1066	83	50
1067	86	12
1068	64	14
1069	24	14
1070	49	21
1071	77	48
1072	103	11
1073	98	48
1074	101	34

Time s	Norm. speed %	Norm. torque %
1075	99	39
1076	103	11
1077	103	19
1078	103	7
1079	103	13
1080	103	10
1081	102	13
1082	101	29
1083	102	25
1084	102	20
1085	96	60
1086	99	38
1087	102	24
1088	100	31
1089	100	28
1090	98	3
1091	102	26
1092	95	64
1093	102	23
1094	102	25
1095	98	42
1096	93	68
1097	101	25
1098	95	64
1099	101	35
1100	94	59
1101	97	37
1102	97	60
1103	93	98
1104	98	53
1105	103	13
1106	103	11
1107	103	11
1108	103	13
1109	103	10
1110	103	10
1111	103	11
1112	103	10
1113	103	10

Time s	Norm. speed %	Norm. torque %
1114	102	18
1115	102	31
1116	101	24
1117	102	19
1118	103	10
1119	102	12
1120	99	56
1121	96	59
1122	74	28
1123	66	62
1124	74	29
1125	64	74
1126	69	40
1127	76	2
1128	72	29
1129	66	65
1130	54	69
1131	69	56
1132	69	40
1133	73	54
1134	63	92
1135	61	67
1136	72	42
1137	78	2
1138	76	34
1139	67	80
1140	70	67
1141	53	70
1142	72	65
1143	60	57
1144	74	29
1145	69	31
1146	76	1
1147	74	22
1148	72	52
1149	62	96
1150	54	72
1151	72	28
1152	72	35

Time s	Norm. speed %	Norm. torque %
1153	64	68
1154	74	27
1155	76	14
1156	69	38
1157	66	59
1158	64	99
1159	51	86
1160	70	53
1161	72	36
1162	71	47
1163	70	42
1164	67	34
1165	74	2
1166	75	21
1167	74	15
1168	75	13
1169	76	10
1170	75	13
1171	75	10
1172	75	7
1173	75	13
1174	76	8
1175	76	7
1176	67	45
1177	75	13
1178	75	12
1179	73	21
1180	68	46
1181	74	8
1182	76	11
1183	76	14
1184	74	11
1185	74	18
1186	73	22
1187	74	20
1188	74	19
1189	70	22
1190	71	23
1191	73	19
1192	73	19
1193	72	20
1194	64	60
1195	70	39
1196	66	56
1197	68	64
1198	30	68
1199	70	38
1200	66	47
1201	76	14
1202	74	18
1203	69	46
1204	68	62
1205	68	62
1206	68	62
1207	68	62
1208	68	62
1209	68	62
1210	54	50
1211	41	37
1212	27	25
1213	14	12
1214	0	0
1215	0	0
1216	0	0
1217	0	0
1218	0	0
1219	0	0
1220	0	0
1221	0	0
1222	0	0
1223	0	0
1224	0	0
1225	0	0
1226	0	0
1227	0	0
1228	0	0
1229	0	0
1230	0	0
1231	0	0
1232	0	0
1233	0	0
1234	0	0
1235	0	0
1236	0	0
1237	0	0
1238	0	0

Annex B
(normative)

Determination of system equivalence

According to 8.2, other systems or analysers (candidates) may be accepted if they yield equivalent results. The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the candidate system and one of the accepted reference systems of this part of ISO 8178 using the appropriate test cycle. The equivalency criteria to be applied shall be the F-test and the two-sided Student t-test.

This statistical method examines the hypothesis that the population mean value for an emission measured with the candidate system does not differ from the population mean value for that emission measured with the candidate system. The hypothesis shall be tested on the basis of a 5 % significance level of the F and t values. The critical F and t values for seven to ten sample pairs are given in Table B.1. If the F and t values calculated according to the formulae below are greater than the critical F and t values, the candidate system is not equivalent.

The following procedure shall be applied. The indices R and C refer to the reference and candidate system, respectively.

a) Conduct at least seven tests with the candidate and reference systems preferably operated in parallel. The number of tests is referred to as n_{R} and n_{C}.

b) Calculate the mean values $\overline{x_{\mathrm{R}}}$ and $\overline{x_{\mathrm{C}}}$ and the standard deviations s_{R} and s_{C}.

c) Calculate the F value, as follows:

$$F = \frac{s_{\mathrm{major}}^2}{s_{\mathrm{minor}}^2} \tag{B.1}$$

(The greater of the two standard deviations s_{R} or s_{C} shall be in the numerator.)

d) Calculate the t value as follows:

$$t = \frac{\left|\overline{x_{\mathrm{C}}} - \overline{x_{\mathrm{R}}}\right|}{\sqrt{\left(n_{\mathrm{C}} - 1\right) \times s_{\mathrm{C}}^2 + \left(n_{\mathrm{R}} - 1\right) \times s_{\mathrm{R}}^2}} \times \sqrt{\frac{n_{\mathrm{C}} \times n_{\mathrm{R}} \times \left(n_{\mathrm{C}} + n_{\mathrm{R}} - 2\right)}{n_{\mathrm{C}} + n_{\mathrm{R}}}} \tag{B.2}$$

e) Compare the calculated F and t values with the critical F and t values corresponding to the respective number of tests indicated in Table B.1. If larger sample sizes are selected, consult statistical tables for 5 % significance (95 % confidence) level.

f) Determine the degrees of freedom (df), as follows:

- for the F-test: $\mathrm{df} = n_{\mathrm{R}} - 1 / n_{\mathrm{C}} - 1$;
- for the t-test: $\mathrm{df} = n_{\mathrm{C}} + n_{\mathrm{R}} - 2$.

g) Determine the equivalency, as follows:

- If $F < F_{\text{crit}}$ and $t < t_{\text{crit}}$, then candidate system is equivalent to reference system of this part of ISO 8178.
- If $F \geqslant F_{\text{crit}}$ and $t \geqslant t_{\text{crit}}$, then candidate system is different from reference system of this part of ISO 8178.

Table B.1 — t and F values for selected sample sizes

Sample size	**F-test**		**t-test**	
	df	F_{crit}	df	t_{crit}
7	6/6	4,284	12	2,179
8	7/7	3,787	14	2,145
9	8/8	3,438	16	2,120
10	9/9	3,179	18	2,101

Annex C
(normative)

Determination of system sampling error

An empirical equation for estimating the particulate sampling error was developed by Belyaev and Levin (1974) and published in Aerosol Mechanics, by W. Hinds.

This reference gives the following equation for the penetration of a particle P when sampled from a larger flow stream by a coaxial sampling probe.

$$P = 1 + \left(\frac{\upsilon_\mathrm{e}}{\upsilon_\mathrm{p}} - 1 \right) \cdot \left[1 - \frac{1}{1 + \left(2 + 0{,}62 \cdot \frac{\upsilon_\mathrm{p}}{\upsilon_\mathrm{e}} \right) \cdot Stk} \right] \tag{C.1}$$

where

υ_e is the gas velocity in the exhaust pipe, m/s;

υ_p is the gas velocity in the sampling probe, m/s;

Stk is the Stokes number for target particles.

The parameters for Equation (C.1) shall be calculated, as follows:

$$\upsilon_\mathrm{e} = \frac{q_{m\mathrm{ew}} \times 4}{\rho_\mathrm{e} \times \pi \times d_\mathrm{e}^2} \quad \text{(gas velocity in the exhaust pipe)} \tag{C.2}$$

$$\upsilon_\mathrm{p} = \frac{q_{m\mathrm{p}} \times 4}{\rho_\mathrm{e} \times \pi \times d_\mathrm{p}^2} \quad \text{(gas velocity in the sampling probe)} \tag{C.3}$$

$$Stk = \frac{\tau \cdot \upsilon_\mathrm{e}}{d_\mathrm{p}} \quad \text{(Stokes number)} \tag{C.4}$$

$$\tau = \frac{\rho_\mathrm{PM} \cdot d_\mathrm{PM}^2 \cdot C_c}{18 \cdot \eta} \quad \text{(particle relaxation time)} \tag{C.5}$$

where

$q_{m\mathrm{ew}}$ is the exhaust gas mass flow rate, in kg/s;

ρ_e is the exhaust gas density, in kg/m^3;

d_e is the exhaust pipe diameter, in m;

$q_{m\mathrm{p}}$ is the sample mass flow rate, in kg/s;

d_p is the sampling probe diameter, in m;

ρ_PM is the particle density, in kg/m^3;

d_{PM} is the particle diameter, in m;

C_c is the slip factor;

η is the dynamic viscosity of exhaust gas, in Pa*s.

For the purposes of this part of ISO 8178, the following constants apply:

— $\rho_{PM} = 1\ 000$ kg/m^3;

— $d_{PM} = 1{,}7*10^{-7}$ m;

— $C_c = 4{,}35$.

Further information on these parameters is to be found in the following references:

Belyaev, S. P., and Levin, L. M., “Techniques for collection of representative aerosol samples,” *J. Aerosol Sci.*, 5, 325-338 (1974) W. C. Hinds, Aerosol Technology, John Wiley.

Annex D
(normative)

Carbon flow check

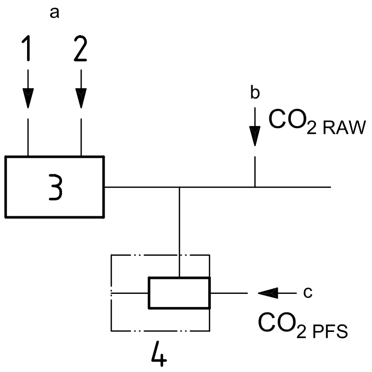
D.1 General

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO_2. This is the basis for a system verification check based on CO_2 measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO_2 concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

The following diagram 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 below.



Key

1 air

2 fuel

3 engine

4 partial flow system

[a] Location 1.

[b] Location 2.

[c] Location 3.

Figure D.1 — Measuring points for carbon flow check

D.2 Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine for a fuel $C_\beta H_\alpha O_\varepsilon$ is given by:

$$q_{m\mathrm{Cf}} = \frac{12\beta}{12\beta + \alpha + 16\varepsilon} \cdot q_{m\mathrm{f}} \tag{D.1}$$

where $q_{m\mathrm{f}}$ is the fuel mass flow rate, kg/s.

D.3 Carbon flow rate in the raw exhaust (location 2)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{m\mathrm{Ce}} = \left(\frac{c_{\mathrm{CO2,r}} - c_{\mathrm{CO2,a}}}{100}\right) \cdot q_{m\mathrm{ew}} \cdot \frac{12}{M_{\mathrm{r,\,e}}} \tag{D.2}$$

where

$c_{\mathrm{CO2,r}}$ is the wet CO_2 concentration in the raw exhaust gas, %;

$c_{\mathrm{CO2,a}}$ is the wet CO_2 concentration in the ambient air, % (around 0,04 %);

$q_{m\mathrm{ew}}$ is the exhaust gas mass flow rate on wet basis, kg/s;

$M_{\mathrm{r,\,e}}$ is the molecular mass of exhaust gas.

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to 9.3.5.

D.4 Carbon flow rate in the partial flow dilution system (location 3)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{m\mathrm{Cp}} = \left(\frac{c_{\mathrm{CO2,d}} - c_{\mathrm{CO2,a}}}{100}\right) \cdot q_{m\mathrm{dew}} \cdot \frac{12}{M_{\mathrm{r,\,e}}} \cdot \frac{q_{m\mathrm{ew}}}{q_{m\mathrm{p}}} \tag{D.3}$$

where

$c_{\mathrm{CO2,d}}$ is the wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel, %;

$c_{\mathrm{CO2,a}}$ is the wet CO_2 concentration in the ambient air, % (around 0,04 %);

$q_{m\mathrm{ew}}$ is the exhaust gas mass flow rate on wet basis, kg/s;

$q_{m\mathrm{p}}$ is the sample flow of exhaust gas into partial flow dilution system, kg/s;

$M_{\mathrm{r,\,e}}$ is the molecular mass of exhaust gas.

If CO_2 is measured on a dry basis, it shall be converted to a wet basis according to 9.3.5.

Annex E
(informative)

Example of calculation procedure (raw/partial flow)

E.1 Basic data for stoichiometric calculations

Atomic mass of hydrogen	1,007 94	g/atom
Atomic mass of carbon	12,011	
Atomic mass of sulfur	32,065	
Atomic mass of nitrogen	14,006 7	
Atomic mass of oxygen	15,999 4	
Molar mass of water	18,015 34	g/mol
Molar mass of carbon dioxide	44,01	g/mol
Molar mass of carbon monoxide	28,011	g/mol
Molar mass of oxygen	31,998 8	g/mol
Molar mass of nitrogen	28,011	g/mol
Molar mass of nitric oxide	30,008	g/mol
Molar mass of nitrogen dioxide	46,01	g/mol
Molar mass of sulfur dioxide	64,066	g/mol
Molar volume of water	22,414	l/mol
Molar volume of carbon dioxide	22,414	l/mol
Molar volume of oxygen	22,414	l/mol
Molar volume of nitrogen	22,414	l/mol
Molar volume of nitric oxide	22,414	l/mol
Molar volume of nitrogen dioxide	22,414	l/mol
Molar volume of sulfur dioxide	22,414	l/mol

NOTE If the above basic component values are used in the emissions calculation according to 9.3.4.3, the final results might be slightly different from the results calculated on the basis of the tabulated u values according to 9.3.4.2.

E.2 Gaseous emissions (diesel fuel)

The measurement data of an individual point of the test cycle (data sampling rate of 1 Hz) for the calculation of the instantaneous mass emission are shown below. In this example, CO and NO_x are measured on a dry basis, HC on a wet basis. The HC concentration is given in propane equivalent (C3) and has to be multiplied by three to result in the C1 equivalent. The calculation procedure is identical for the other points of the cycle.

$T_{a,i}$ (K)	$H_{a,i}$ (g/kg)	W_{act} kWh	$q_{mew,i}$ (kg/s)	$q_{maw,i}$ (kg/s)	$q_{mf,i}$ (kg/s)	$c_{HC,i}$ (ppm)	$c_{CO,i}$ (ppm)	$c_{NOx,i}$ (ppm)
295	8,0	40	0,155	0,150	0,005	30	100	500

The following fuel composition is considered:

Component	**Molar ratio**	**% Mass**
H	α = 1,852 9	w_{ALF} = 13,45
C	β = 1,000 0	w_{BET} = 86,50
S	γ = 0,000 2	w_{GAM} = 0,050
N	δ = 0,000 0	w_{DEL} = 0,000
O	ε = 0,000 0	w_{EPS} = 0,000

Step 1: Dry/wet correction (see 9.3.5):

Equation (17): $k_f = 0{,}055\,584 \times 13{,}45 - 0{,}000\,108\,3 \times 86{,}5 - 0{,}000\,156\,2 \times 0{,}05 = 0{,}738\,2$

Equation (21):
$$k_W = \left(1 - \frac{1{,}243\,4 \times 8 + 111{,}12 \times 13{,}45 \times \dfrac{0{,}005}{0{,}148}}{773{,}4 + 1{,}243\,4 \times 8 + \dfrac{0{,}005}{0{,}148} \times 0{,}738\,2 \times 1\,000}\right) \times 1{,}008\,5 = 0{,}933\,1$$

Equation (20): $c_{CO,i}$ (wet) $= 100 \times 0{,}933\,1 = 93{,}3$ ppm

$c_{NOx,i}$ (wet) $= 500 \times 0{,}933\,1 = 466{,}6$ ppm

Step 2: NO_x correction for temperature and humidity (see 9.3.6):

Equation (25):
$$k_{h,D} = \frac{1}{1 - 0{,}018\,2 \times (8{,}00 - 10{,}71) + 0{,}004\,5 \times (295 - 298)} = 0{,}965\,4$$

Step 3: Calculation of the instantaneous mass emission using u values from Table 6 (see 9.3.4.2):

Equation (11): $m_{HC,i} = 0{,}000\,478 \times 30 \times 3 \times 0{,}155 = 0{,}006\,67$ g/s;

$m_{CO,i} = 0{,}000\,966 \times 93{,}3 \times 0{,}155 = 0{,}013\,97$ g/s;

$m_{Nox,i} = 0{,}001\,587 \times 466{,}6 \times 0{,}965\,4 \times 0{,}155 = 0{,}110\,8$ g/s.

Step 4: Integration of the instantaneous mass emission over the cycle (see 9.3.4.2):

The following calculation for the NRTC (1238 s) assumes the same emission in each point of the cycle.

Equation (11): $$m_{\mathrm{HC}} = \sum_{i=1}^{1238} 0{,}006\,67 = 8{,}26 \text{ g/test;}$$

$$m_{\mathrm{CO}} = \sum_{i=1}^{1238} 0{,}013\,97 = 17{,}29 \text{ g/test;}$$

$$m_{\mathrm{NOx}} = \sum_{i=1}^{1238} 0{,}110\,8 = 137{,}17 \text{ g/test.}$$

Step 5: Calculation of the specific emissions (see 9.3.7):

Equation (27): $\mathrm{HC} = 8{,}26 / 40 = 0{,}207$ g/kWh;

$\mathrm{CO} = 17{,}29 / 40 = 0{,}432$ g/kWh;

$\mathrm{NO_x} = 137{,}17 / 40 = 3{,}43$ g/kWh.

E.3 Particulate emission (diesel fuel)

Particulate measurement is based on the principle of sampling the particulates over the complete cycle, but determining the sample and flow rates ($q_{m\mathrm{ew,i}}$ and $q_{m\mathrm{edf,i}}$) during the individual points of the cycle. The calculation of $q_{m\mathrm{edf,i}}$ depends on the system used. In the following example, a system with flow measurement according to 9.4.5, method a) is used.

The following measurement data are assumed in this example:

W_{act} kWh	$q_{m\mathrm{ew,i}}$ (kg/s)	$q_{m\mathrm{f,i}}$ (kg/s)	$q_{m\mathrm{dw,i}}$ (kg/s)	$q_{m\mathrm{dew,i}}$ (kg/s)	m_{f} (mg)	m_{sep} (kg)
40	0,155	0,005	0,001 5	0,002 0	2,500	1,515

Step 1: Calculation of m_{edf} (see 9.4.5):

Equation (30): $$r_{\mathrm{dil,i}} = \frac{0{,}002}{(0{,}002 - 0{,}001\,5)} = 4;$$

Equation (29): $$q_{m\mathrm{edf,i}} = 0{,}155 \times 4 = 0{,}62 \text{ kg/s;}$$

Equation (28): $$m_{\mathrm{edf}} = \sum_{i=1}^{1238} 0{,}62 = 767{,}6 \text{ kg/test.}$$

Step 2: Calculation of the particulate mass emission (see 9.4.5):

Equation (27): $$m_{\mathrm{PM}} = \frac{2{,}5}{1{,}515} \times \frac{767{,}6}{1\,000} = 1{,}267 \text{ g/test.}$$

Step 3: Calculation of the specific emissions (see 9.4.7):

Equation (34): $PM = 1{,}267 / 40 = 0{,}032$ g/kWh.

Annex F
(informative)

Ramped modal cycle (RMC)

Table F.1 — Ramped modal cycle

			30 min. cycle
Mode	**Speed**	**Torque (%)**	**Time (s)**
1	Idle	No load	126
2	Intermediate	100	159
3	Intermediate	50	160
4	Intermediate	75	162
5	Rated	100	246
6	Rated	10	164
7	Rated	75	248
8	Rated	50	247
9	Idle	No load	128

Annex G
(normative)

Statistical equations

This annex contains equations for statistics that are used in this part of ISO 8178.

a) Arithmetic mean: Calculate the arithmetic mean $\bar{x}$ as follows:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \text{(G.1)}$$

b) Standard deviation: Calculate the standard deviation s as follows:

$$s = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n-1}} \qquad \text{(G.2)}$$

c) Slope: Calculate the least-squares regression slope a_1, as follows:

$$a_1 = \frac{\sum_{i=1}^{n} \left(y_i - \bar{y}\right) \times \left(x_i - \bar{x}\right)}{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)} \qquad \text{(G.3)}$$

d) Intercept: Calculate the least-squares regression intercept a_0, as follows:

$$a_0 = \bar{y} - \left(a_1 \times \bar{x}\right) \qquad \text{(G.4)}$$

e) Standard error of estimate: Calculate the standard error of estimate $S_{y.x}$, as follows:

$$S_{y.x} = \sqrt{\frac{\sum_{i=1}^{n} \left[y_i - a_0 - \left(a_1 - x_i\right)\right]^2}{n-2}} \qquad \text{(G.5)}$$

f) Coefficient of determination: Calculate the coefficient of determination r^2, as follows:

$$r^2 = \sqrt{\frac{\sum_{i=1}^{n} \left[y_i - a_0 - \left(a_1 - x_i\right)\right]^2}{\sum_{i=1}^{n} \left(y_i - \bar{y}\right)^2}} \qquad \text{(G.6)}$$

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