

Reciprocating internal combustion engines — Exhaust emission measurement

Part 1: Test-bed measurement of gaseous and particulate exhaust emissions

ICS 13.040.50; 27.020

National foreword

This British Standard is the UK implementation of ISO 8178-1:2006. It supersedes BS EN ISO 8178-1:1996 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/14/-/3, RIC engines - Emissions.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Part 1: Test-bed measurement of gaseous and particulate exhaust emissions

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gaz d'échappement —*

*Partie 1: Mesurage des émissions de gaz et de particules au banc
d'essai*



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Contents

Page

Foreword.....	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions.....	2
4 Symbols and abbreviations	4
4.1 General symbols	4
4.2 Symbols for fuel composition	5
4.3 Symbols and abbreviations for the chemical components.....	6
4.4 Abbreviations	7
5 Test conditions	7
5.1 Engine test conditions	7
5.2 Engines with charge air cooling.....	8
5.3 Power	8
5.4 Specific test conditions.....	9
6 Test fuels	10
7 Measurement equipment and data to be measured.....	10
7.1 General.....	10
7.2 Dynamometer specification	11
7.3 Exhaust gas flow.....	11
7.4 Accuracy.....	13
7.5 Determination of the gaseous components.....	14
7.6 Particulate determination.....	18
8 Calibration of the analytical instruments	21
8.1 General requirements.....	21
8.2 Calibration gases	21
8.3 Operating procedure for analysers and sampling system	22
8.4 Leakage test	22
8.5 Calibration procedure.....	22
8.6 Calibration of tracer gas analyser for exhaust flow measurement	24
8.7 Efficiency test of the NO _x converter	24
8.8 Adjustment of the FID.....	26
8.9 Interference effects with CO, CO ₂ , NO _x , O ₂ , NH ₃ and N ₂ O analysers.....	29
8.10 Calibration intervals	33
9 Calibration of the particulate measuring system	33
9.1 General.....	33
9.2 Calibration procedure.....	33
9.3 Checking the partial-flow conditions.....	33
9.4 Calibration intervals	34
10 Calibration of the CVS full-flow dilution system	34
10.1 General.....	34
10.2 Calibration of the Positive Displacement Pump (PDP)	34
10.3 Calibration of the Critical-Flow Venturi (CFV)	35
10.4 Calibration of the Subsonic Venturi (SSV)	36
10.5 Total system verification.....	38
11 Running conditions (test cycles)	38

12	Test run	38
12.1	Preparation of the sampling filters.....	38
12.2	Installation of the measuring equipment.....	38
12.3	Starting the dilution system and the engine	39
12.4	Adjustment of the dilution ratio.....	39
12.5	Determination of test points	39
12.6	Checking of the analysers.....	39
12.7	Test cycles	40
12.8	Re-checking the analysers.....	41
12.9	Test report.....	41
13	Data evaluation for gaseous and particulate emissions.....	41
13.1	Gaseous emissions	41
13.2	Particulate emissions	41
14	Calculation of the gaseous emissions.....	42
14.1	General.....	42
14.2	Determination of the exhaust gas flow	42
14.3	Dry/wet correction.....	43
14.4	NO _x correction for humidity and temperature	44
14.5	Calculation of the emission mass flow rates	45
14.6	Calculation of the specific emission.....	49
15	Calculation of the particulate emission	50
15.1	Particulate correction factor for humidity	50
15.2	Partial-flow dilution system	50
15.3	Full-flow dilution system	51
15.4	Calculation of the particulate mass flow rate.....	52
15.5	Calculation of the specific emissions	53
15.6	Effective weighting factor	53
16	Determination of the gaseous emissions.....	53
16.1	General.....	53
16.2	Main exhaust components CO, CO ₂ , HC, NO _x , O ₂	54
16.3	Ammonia analysis.....	58
16.4	Methane analysis	60
16.5	Methanol analysis	63
16.6	Formaldehyde analysis	63
17	Determination of the particulates	65
17.1	General.....	65
17.2	Dilution system	65
17.3	Particulate sampling system.....	82
Annex A	(normative) Calculation of the exhaust gas mass flow and/or of the combustion air mass flow	86
Annex B	(informative) Example program for calculation of exhaust mass flows.....	106
Annex C	(informative) Heat calculation (transfer tube)	110
Annex D	(informative) Determination of system equivalence.....	114
Annex E	(informative) Fuel specific parameters	116
Annex F	(normative) Carbon flow check.....	120
Bibliography		122

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 8178-1 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This second edition cancels and replaces the first edition (ISO 8178-1:1996), which has been technically revised.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust 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 test*
- *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

This part of ISO 8178 is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of reciprocating internal combustion (RIC) engines for non-automotive use. Its purpose is to provide a map of an engine's emissions characteristics which, through use of the proper weighting factors, can be used as an indication of that engine's emission levels under various applications. The emission results are expressed in units of grams per kilowatt-hour and represent the mass rate of emissions per unit of work accomplished.

Although this part of ISO 8178 is designed for non-automotive engines, it shares many principles with particulate and gaseous emission measurements that have been in use for many years for on-road engines. One test procedure that shares many of these principles is the full-flow dilution method as currently specified for certification of 1985 and later heavy-duty truck engines in the USA. Another is the procedure for direct measurement of the gaseous emissions in the undiluted exhaust gas, as currently specified for the certification of heavy-duty truck engines in Japan and Europe.

Many of the procedures described in this part of ISO 8178 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.

Evaluating emissions from off-road engines is more complicated than the same task for on-road engines due to the diversity of off-road applications. For example, on-road applications primarily consist of moving a load from one point to another on a paved roadway. The constraints of the paved roadways, maximum acceptable pavement loads and maximum allowable grades of fuel, narrow the scope of on-road vehicle and engine sizes. Off-road engines and vehicles include a wider range of size, including the engines that power the equipment. Many of the engines are large enough to preclude the application of test equipment and methods that were acceptable for on-road purposes. In cases where the application of dynamometers is not possible, the tests must be made at site or under appropriate conditions.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1: Test-bed measurement of gaseous and particulate exhaust emissions

1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines under steady-state conditions on a test bed, necessary for determining one weighted value for each exhaust gas pollutant. Various combinations of engine load and speed reflect different engine applications (see ISO 8178-4).

This part of ISO 8178 is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used, for example, for earth-moving machines, generating sets and for other applications.

In limited instances, the engine can be tested on the test bed in accordance with ISO 8178-2, the field test document. This can only occur with the agreement of the parties involved. It should be recognized that data obtained under these circumstances may not agree completely with previous or future data obtained under the auspices of this part of ISO 8178. Therefore, it is recommended that this option be exercised only with engines built in very limited quantities such as very large marine or generating set engines.

For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for powerplants), additional test conditions and special evaluation methods may apply.

Where it is not possible to use a test bed or where information is required on the actual emissions produced by an in-service engine, the site test procedures and calculation methods specified in ISO 8178-2 are appropriate.

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 31-0:1992, *Quantities and units — Part 0: General principles*

ISO 3046-1:2002, *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods — Additional requirements for engines for general use*

ISO 5167-1:2003, *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 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

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 8178-4:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications*

ISO 8178-5:1997, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 8178-6:2000, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Report of measuring results and test*

ISO 9000:2005, *Quality management systems — Fundamentals and vocabulary*

ISO 9096:2003, *Stationary source emissions — Manual determination of mass concentration of particulate matter*

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 15550:2002, *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 1088:1993, *Test procedure for the measurement of gaseous exhaust emissions from small utility engines*

SAE J 1151:1991, *Methane measurement using gas chromatography*

3 Terms and definitions

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

3.1 particulates

material collected on a specified filter medium after diluting exhaust gases 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 primary filter

NOTE 1 Particulates consist primarily of carbon, condensed hydrocarbons, and sulfates and associated water.

NOTE 2 Particulates defined in this part of ISO 8178 are substantially different in composition and weight from particulates or dust sampled directly from the undiluted exhaust gas using a hot filter method (e.g. ISO 9096). Particulates measurement as described in this part of ISO 8178 is conclusively proven to be effective for fuel sulphur levels up to 0,8 %.

NOTE 3 The filter temperature requirement has been changed compared to ISO 8178-1:1996 to reflect the latest legal requirements in the USA and European Union. Existing systems built in compliance with the requirements of ISO 8178-1:1996 may still be used.

3.2

partial-flow dilution method

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

NOTE See 17.2.1, Figures 10 to 18.

3.3

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 (see 17.2.2, Figure 19).

3.4

isokinetic sampling

process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the probe equal to the exhaust stream mean velocity

3.5

non-isokinetic sampling

process of controlling the flow of the exhaust sample independently of the exhaust stream velocity

3.6

multiple-filter method

process of using one pair of filters for each of the individual test cycle modes

NOTE The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

3.7

single-filter method

process of using one pair of filters for all test cycle modes

NOTE Modal weighting factors must be accounted for during the particulate sampling phase of the test cycle by adjusting sample flow rate and/or sampling time. This method dictates that particular attention be given to sampling duration and flow rates.

3.8

specific emissions

mass emissions expressed in grams per kilowatt-hour

NOTE For many engine types within the scope of this part of ISO 8178, the auxiliaries which will be fitted to the engine in service will not be known at the time of manufacture or certification.

When it is not appropriate to test the engine in the conditions as defined in ISO 14396 (e.g. if the engine and transmission form a single integral unit), the engine can only be tested with other auxiliaries fitted. In this case the dynamometer settings should be determined in accordance with 5.3 and 12.5. The auxiliary losses should not exceed 5 % of the maximum observed power. Losses exceeding 5 % must be approved by the parties involved prior to the test.

3.9

brake power

observed power measured at the crankshaft or its equivalent, the engine being equipped only with the standard auxiliaries necessary for its operation on the test bed

NOTE See 5.3 and ISO 14396.

3.10

auxiliaries

equipment and devices listed in ISO 14396

4 Symbols and abbreviations

4.1 General symbols

Symbol	Term	Unit
A/F_{st}	Stoichiometric air-to-fuel ratio	1
A_p	Cross-sectional area of the isokinetic sampling probe	m ²
A_r	Atomic mass	g
A_x	Cross-sectional area of the exhaust pipe	m ²
c_c	Background corrected concentration	ppm % (V/V)
c_d	Concentration in the dilution air	ppm % (V/V)
c_x	Concentration in the exhaust (with suffix of the component nominating)	ppm % (V/V)
D	Dilution factor	1
E_{CO_2}	CO ₂ quench of NO _x analyser	%
E_E	Ethane efficiency	%
E_{H_2O}	Water quench of NO _x analyser	%
E_M	Methane efficiency	%
E_{NO_x}	Efficiency of NO _x converter	%
e_{PT}	Particulate emission	g/kW·h
e_x	Gas emission (with subscript denoting compound)	g/kW·h
λ	Excess air factor ([kg dry air] / ([kg fuel] * $[A/F_{st}]$))	1
λ_{Ref}	Excess air factor at reference conditions	1
f_a	Laboratory atmospheric factor	1
f_c	Carbon factor	1
f_{fd}	Fuel specific factor for exhaust flow calculation on dry basis	1
f_{fh}	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	1
f_{fw}	Fuel specific factor for exhaust flow calculation on wet basis	1
H_a	Absolute humidity of the intake air (g water / kg dry air)	g/kg
H_d	Absolute humidity of the dilution air (g water / kg dry air)	g/kg
i	Subscript denoting an individual mode	1
k_f	Fuel specific factor for the carbon balance calculation	1
k_{hd}	Humidity correction factor for NO _x for diesel engines	1
k_{hp}	Humidity correction factor for NO _x for gasoline (petrol) engines	1
k_p	Humidity correction factor for particulates	1
k_{wa}	Dry to wet correction factor for the intake air	1
k_{wd}	Dry to wet correction factor for the dilution air	1
k_{we}	Dry to wet correction factor for the diluted exhaust gas	1
k_{wr}	Dry to wet correction factor for the raw exhaust gas	1
M	Percent torque related to the maximum torque for the test engine speed	%
M_r	Molecular mass	g
m_d	Mass of the dilution air sample passed through the particulate sampling filters	kg
$m_{f,d}$	Particulate sample mass of the dilution air collected	mg
m_f	Particulate sample mass collected	mg
m_{sep}	Mass of the diluted exhaust sample passed through the particulate sampling filters	kg
P_A	Absolute outlet pressure at pump outlet	kPa

Symbol	Term	Unit
p_a	Saturation vapour pressure of the engine intake air	kPa
p_b	Total barometric pressure	kPa
p_d	Saturation vapour pressure of the dilution air	kPa
p_r	Water vapour pressure after cooler	kPa
p_s	Dry atmospheric pressure	kPa
P	Uncorrected brake power	kW
P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by ISO 14396	kW
P_m	Maximum measured or declared power at the test engine speed under test conditions (see 12.5)	kW
q_{mad}	Intake air mass flow rate on dry basis	kg/h
q_{maw}	Intake air mass flow rate on wet basis	kg/h
q_{mdw}	Dilution air mass flow rate on wet basis	kg/h
q_{medf}	Equivalent diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mew}	Exhaust gas mass flow rate on wet basis	kg/h
q_{mf}	Fuel mass flow rate	kg/h
q_{mdew}	Diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mgas}	Emission mass flow rate of individual gas	g/h
q_{mPT}	Particle mass flow rate	g/h
r_d	Dilution ratio	1
r_a	Ratio of cross-sectional areas of isokinetic probe and exhaust pipe	1
R_a	Relative humidity of the intake air	%
R_d	Relative humidity of the dilution air	%
r_h	FID response factor	1
r_m	FID response factor for methanol	1
r_x	Ratio of the SSV throat to inlet absolute, static pressure	1
r_y	Ratio of the SSV throat diameter, d , to the inlet pipe inner diameter	1
ρ	Density	kg/m ³
S	Dynamometer setting	kW
T_a	Absolute temperature of the intake air	K
T_d	Absolute dewpoint temperature	K
T_{ref}	Absolute reference temperature (of combustion air: 298 K)	K
T_c	Absolute temperature of the intercooled air	K
T_{cref}	Absolute intercooled air reference temperature	K
V_m	Molar volume	l
W_f	Weighting factor	1
W_{fe}	Effective weighting factor	1

4.2 Symbols for fuel composition

w_{ALF}	H content of fuel, % mass
w_{BET}	C content of fuel, % mass
w_{GAM}	S content of fuel, % mass
w_{DEL}	N content of fuel, % mass

w_{EPS}	O content of fuel, % mass
α	molar ratio (H/C)
β	molar ratio (C/C)
γ	molar ratio (S/C)
δ	molar ratio (N/C)
ε	molar ratio (O/C)

NOTE The conversion between mass content and molar ratio is given in Equations A.3 to A.12 of Annex A.

4.3 Symbols and abbreviations for the chemical components

ACN	acetonitrile
C1	carbon 1 equivalent hydrocarbon
CH ₄	methane
C ₂ H ₆	ethane
C ₃ H ₈	propane
CH ₃ OH	methanol
CO	carbon monoxide
CO ₂	carbon dioxide
DNPH	dinitrophenyl hydrazine
DOP	dioctyl phthalate
HC	hydrocarbons
HCHO	formaldehyde
H ₂ O	water
NH ₃	ammonia
NMHC	non-methane hydrocarbons
NO	nitric oxide
NO ₂	nitrogen dioxide
NO _x	oxides of nitrogen
N ₂ O	dinitrogen oxide
O ₂	oxygen
RME	rapeseed oil methylester
SO ₂	sulphur dioxide
SO ₃	sulphur trioxide

4.4 Abbreviations

CFV	critical flow venturi
CLD	chemiluminescent detector
CVS	constant volume sample
ECS	electrochemical sensor
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
NDIR	non-dispersive infrared analyser
NMC	non-methane cutter
PDP	positive displacement pump
PMD	paramagnetic detector
PT	particulates
UVD	ultraviolet detector
ZRDO	zirconium dioxide sensor

5 Test conditions

5.1 Engine test conditions

5.1.1 Test condition parameter

The absolute temperature T_a of the engine intake air expressed in Kelvin and the dry atmospheric pressure p_s expressed in kilopascals shall be measured, and the parameter f_a shall be determined according to the following provisions.

a) Compression-ignition engines

Naturally aspirated and mechanically pressure-charged engines:

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

Turbocharged engines with or without cooling of the intake air:

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

b) Spark-ignition engines

$$f_a = \left(\frac{99}{p_s} \right)^{1,2} \times \left(\frac{T_a}{298} \right)^{0,6} \quad (3)$$

NOTE Formulae (1) to (3) are identical with the exhaust emissions legislation from ECE, EEC and EPA, but different from the ISO power correction formulae.

5.1.2 Test validity

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

$$0,93 \leq f_a \leq 1,07 \quad (4)$$

Tests should 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 the declared 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 rated 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.

5.3 Power

The basis of specific emissions measurement is uncorrected brake power as defined in ISO 14396. The engine shall be submitted with auxiliaries needed for operating the engine (e.g. fan, water pump). 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.

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,
- pumps for hydraulic actuators.

For further details, see 3.9 and ISO 14396.

Where auxiliaries have not been removed, the power absorbed by them at the test speeds shall be determined in order to calculate the dynamometer settings in accordance with 12.5, except for engines where such auxiliaries form an integral part of the engine (e.g. cooling fans for air-cooled engines).

5.4 Specific test conditions

5.4.1 Engine air inlet 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.

NOTE The restrictions are to be set at rated speed and full load.

5.4.2 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 7.5.5, 17.2.1, EP and 17.2.2, EP.

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

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.

NOTE The restrictions are to be set at rated speed and full load.

5.4.3 Cooling system

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

5.4.4 Lubricating oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

5.4.5 Adjustable carburettors

For engines with limited adjustable carburettors, test of the engines shall be performed at both extremes of the adjustment.

5.4.6 Crankcase breather

When it is required to measure the crankcase emissions of an open crankcase system as part of the total emissions from the engine, they shall be introduced into the exhaust system downstream of any aftertreatment system, if used, and upstream of the sampling point. Sufficient distance shall be allowed to ensure mixing of the crankcase emissions with the exhaust gas.

6 Test fuels

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 involved, the fuel shall be selected in accordance with Table 1. 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 1 — 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 the following: 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.		

7 Measurement equipment and data to be measured

7.1 General

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 16 and 17. These clauses describe the recommended analytical systems for the gaseous emissions (Clause 16) and the recommended particulate dilution and sampling systems (Clause 17).

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 part of ISO 8178. "Results" refers 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. The tests should be run concurrently. The test cycle to be used shall be the appropriate cycle as found in ISO 8178-4, or the C1 cycle as found in ISO 8178-4. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics (see Annex D), with outliers excluded, obtained under the laboratory cell and the engine conditions described above. 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 standard, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-1 and ISO 5725-2.

The following equipment shall be used for emissions tests of engines on engine dynamometers. This part of ISO 8178 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 7.4.

7.2 Dynamometer specification

An engine dynamometer with adequate characteristics to perform the appropriate test cycle described in ISO 8178-4 shall be used.

The instrumentation for torque and speed measurement shall allow the measurement accuracy of the shaft power within the given limits. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the maximum tolerances of the figures given in 7.4 are not exceeded.

7.3 Exhaust gas flow

7.3.1 General

The exhaust gas flow shall be determined by one of the methods given in 7.3.2 to 7.3.6.

7.3.2 Direct measurement method

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

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

Precautions shall be taken to avoid measurement errors which will impact on 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. In particular, engine performance and emissions shall not be affected by the installation of the device.

The flowmeters shall meet the accuracy specifications of 7.4.

7.3.3 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flowmeters and fuel flowmeters with an accuracy defined in 7.4 shall be used. The calculation of the exhaust gas flow is as follows:

$$q_{mew} = q_{maw} + q_{mf} \quad (5)$$

7.3.4 Fuel flow and carbon balance method

This involves exhaust mass calculation from fuel consumption, fuel composition and exhaust gas concentrations using the carbon balance method, as given with the following formulae (see A.3.2.3.1):

$$q_{mew} = q_{mf} \times \left(\left(\frac{w_{BET} \times w_{BET} \times 1,4}{\left(\frac{1,4 \times w_{BET}}{f_C} + w_{ALF} \times 0,08936 - 1 \right) \times \frac{1}{1,293} + f_{fd}} \right) + w_{ALF} \times 0,08936 - 1 \right) \times \left(1 + \frac{H_a}{1000} \right) + 1 \quad (6)$$

where

f_{fd} is according to Equations A.20 to A.23;

H_a is the g water per kg dry air;

f_c is according to Equation A.64:

$$f_c = (c_{\text{CO2d}} - c_{\text{CO2ad}}) \times 0,544 \, 1 + \frac{c_{\text{COd}}}{18 \, 522} + \frac{c_{\text{HCw}}}{17 \, 355} \quad (7)$$

where

c_{CO2d} is the dry CO_2 concentration in the raw exhaust [%];

c_{CO2ad} is the dry CO_2 concentration in the ambient air [%];

c_{COd} is the dry CO concentration in the raw exhaust [ppm];

c_{HCw} is the wet HC concentration in the raw exhaust [ppm].

NOTE Optionally, the oxygen balance method may be used. See A.3.3.

7.3.5 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 trace gas concentration after mixing becomes lower than the full scale of the trace gas analyser.

The calculation of the exhaust gas flow is as follows:

$$q_{mew} = \frac{q_{rt} \times \rho_{ew}}{60 \times (c_{mix} - c_a)} \quad (8)$$

where

q_{mew} is the exhaust mass flow [kg/s];

q_{rt} is the tracer gas flow rate [cm^3/min];

c_{mix} is the concentration of the tracer gas after mixing [ppm];

ρ_{ew} is the density of the exhaust gas [kg/m^3];

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 the test run and after the test run.

When the background concentration is less than 1 % of the concentration of the tracer gas after mixing (c_{mix}) at maximum exhaust flow, the background concentration may be neglected.

The total system shall meet the accuracy specifications for the exhaust gas flow, and shall be calibrated according to 8.6.

7.3.6 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:

$$q_{mew} = q_{maw} \times \left(1 + \frac{1}{A/F_{st} \times \lambda} \right) \quad (9)$$

where

$$A/F_{st} = \frac{138,0 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12,011 \times \beta + 1,007\,94 \times \alpha + 15,999\,4 \times \varepsilon + 14,006\,7 \times \delta + 32,065 \times \gamma} \quad (10)$$

$$\lambda = \frac{\beta \times \left(100 - \frac{c_{CO} \times 10^{-4}}{2} - c_{HC} \times 10^{-4} \right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{CO} \times 10^{-4}}{3,5 \times c_{CO_2}}}{1 + \frac{c_{CO} \times 10^{-4}}{3,5 \times c_{CO_2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2} \right) \times (c_{CO_2} + c_{CO} \times 10^{-4})}{4,764 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right) \times (c_{CO_2} + c_{CO} \times 10^{-4} + c_{HC} \times 10^{-4})} \quad (11)$$

where

A/F_{st} is the stoichiometric air-to-fuel ratio [kg/kg];

λ is the excess air ratio;

c_{CO_2} is the dry CO_2 concentration [%];

c_{CO} is the dry CO concentration [ppm];

c_{HC} is the HC concentration [ppm].

NOTE Fuel composition $C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon$ with $\beta = 1$. For fuels without carbon (e.g. hydrogen) Equations (10) and (11) cannot be used.

The air flowmeter shall meet the accuracy specifications of 7.4, the CO_2 analyser used shall meet the specifications of 7.5.4.2, 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, which meets the specifications of 7.5.4.12 may be used for the measurement of the excess air ratio.

7.3.7 Total dilute exhaust gas flow

When using a full-flow dilution system, the total flow of the dilute exhaust (q_{mdew}) shall be measured with a PDP or CFV (see 17.2.2). The accuracy shall conform to the provisions of 9.2.

7.4 Accuracy

The calibration of all measuring instruments shall be traceable to national (international) standards and comply with the requirements given in Tables 2 and 3.

NOTE Calibration requirements for analysers are given in 8.5.

The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements. The deviations given in Tables 2 and 3 refer to the final recorded value, which includes the data acquisition system.

Table 2 — Permissible deviations of instruments for engine-related parameters

No.	Measurement instrument	Permissible deviation
1	Engine speed	$\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger
2	Torque	$\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger
3	Fuel consumption ^a	$\pm 2\%$ of engine's max. value
4	Air consumption ^a	$\pm 2\%$ of reading or $\pm 1\%$ of engine's max. value, whichever is larger
5	Exhaust gas flow ^a	$\pm 2,5\%$ of reading or $\pm 1,5\%$ of engine max. value, whichever is larger

^a The calculations of the exhaust emissions as described in this part of ISO 8178 are, in some cases, based on different measurement and/or calculation methods. Because of limited total tolerances for the exhaust emission calculation, the allowable values for some items, used in the appropriate equations, must be smaller than the allowed tolerances given in ISO 15550:2002, Table 4.

Table 3 — Permissible deviations of instruments for other essential parameters

No.	Parameter	Permissible deviation
1	Temperatures ≤ 600 K	± 2 K absolute
2	Temperatures > 600 K	$\pm 1\%$ of reading
3	Exhaust gas pressure	$\pm 0,2$ kPa absolute
4	Intake air depressions	$\pm 0,05$ kPa absolute
5	Atmospheric pressure	$\pm 0,1$ kPa absolute
6	Other pressures	$\pm 0,1$ kPa absolute
7	Relative humidity	$\pm 3\%$ absolute
8	Absolute humidity	$\pm 5\%$ of reading
9	Dilution air flow	$\pm 2\%$ of reading
10	Diluted exhaust gas flow	$\pm 2\%$ of reading

7.5 Determination of the gaseous components

7.5.1 General analyser specifications

7.5.1.1 General specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (see 7.5.1.2). The analysers should be operated such that the measured concentration falls between 15 % and 100 % of full scale.

If the full-scale value is 155 ppm (or ppmC) or less or if read-out systems (computers, data loggers) that provide sufficient accuracy and resolution below 15 % of full scale are used, concentrations below 15 % of full scale are also acceptable. In this case, additional calibrations are to be made to ensure the accuracy of the calibration curves.

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

7.5.1.2 Accuracy

The analyser shall not deviate from the nominal calibration point by more than $\pm 2\%$ of the reading over the whole measurement range (except zero) or $\pm 0,3\%$ of full scale, whichever is larger. The accuracy shall be determined according to the calibration requirements laid down in 8.5.5.

NOTE For the purposes of this part of ISO 8178, accuracy is defined as the deviation of the analyser reading from the nominal calibration values using a calibration gas (= true value).

7.5.1.3 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than $\pm 1\%$ of full-scale concentration for each range used above 100 ppm (or ppmC) or $\pm 2\%$ of each range used below 100 ppm (or ppmC).

7.5.1.4 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.

7.5.1.5 Zero drift

Zero response is defined as the mean response, including noise, to a zero gas during a 30 s time interval. The drift of the zero response during a 1 h period shall be less than 2 % of full scale on the lowest range used.

7.5.1.6 Span drift

Span response is defined as the mean response, including noise, to a span gas during a 30 s time interval. The drift of the span response during a 1 h period shall be less than 2 % of full scale on the lowest range used.

7.5.2 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 driers are not an acceptable method of removing water from the sample.

7.5.3 Analysers

7.5.3.1 General

7.5.3.2 to 7.5.3.12 define the measurement principles to be used. A detailed description of the measurement systems is given in Clause 16. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

7.5.3.2 Carbon monoxide (CO) analysis

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

7.5.3.3 Carbon dioxide (CO₂) analysis

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

7.5.3.4 Oxygen (O₂) analysis

Oxygen analysers shall be of the paramagnetic detector (PMD), zirconium dioxide (ZRDO) or electrochemical sensor (ECS) type.

Zirconium dioxide sensors should not be used when HC and CO concentrations are high, such as for lean-burn spark-ignited engines.

Electrochemical sensors shall compensate for CO₂ and NO_x interference.

7.5.3.5 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 $463\text{ K} \pm 10\text{ K}$ ($190\text{ °C} \pm 10\text{ °C}$). For methanol-fuelled engines, the temperature requirements of 7.5.3.12.3 apply. Optionally, for gas-fuelled engines and for the dilute testing of spark-ignition engines, the hydrocarbon analyser may be of the non-heated flame ionization detector (FID) type.

7.5.3.6 Non-methane hydrocarbon (NMHC) analysis

7.5.3.6.1 General

Depending on the methane (CH₄) concentration, this method is more relevant for gaseous than for liquid fuels.

7.5.3.6.2 Gas chromatographic (GC) method

Non-methane hydrocarbons shall be determined by subtraction of the methane analysed with a gas chromatograph (GC) conditioned at 423 K (150 °C) from the hydrocarbons measured according to 7.5.3.5.

7.5.3.6.3 Non-methane cutter (NMC) method

The determination of the non-methane fraction shall be performed with an NMC operated in line with an FID as per 7.5.3.5 by subtraction of the methane from the hydrocarbons.

7.5.3.7 Oxides of nitrogen (NO_x) analysis

The oxides of nitrogen analyser shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with an NO₂/NO converter, if measured on a dry basis. If measured on a wet basis, an HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see 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.

7.5.3.8 Sulphur dioxide (SO₂) analysis

The SO₂ emission shall be calculated from the sulphur content of the fuel used, since experience has shown that using the direct measurement method for SO₂ does not give more precise results:

$$q_{m\text{SO}_2} = q_{mf} \times w_{\text{GAM}} \times 20 \quad (12)$$

NOTE The application of the calculation method for SO₂ assumes a 100 % sulphur conversion and is limited to engines without aftertreatment systems. In this case SO₂ may be measured in accordance with the instructions of the instrument suppliers. Since SO₂ measurement is a difficult task and has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.5.3.9 Ammonia (NH₃) analysis

Ammonia shall be determined with a CLD, as described in 7.5.3.7, by using two different converters. For the total amount of NO_x and NH₃, a high-temperature converter of 973 K (700 °C) shall be used.

For the NO_x only, a low-temperature converter of 573 K (300 °C) shall be used. The difference between these measurements is the ammonia concentration. This method has a long response time (approx. 10 min).

Alternatively, an FTIR (Fourier transform infrared) analyser or NDUVR (non-dispersive ultraviolet resonance) analyser may be used in accordance with the instrument supplier's instructions. Since the technology has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required. The response time of this method is considerably shorter than with the double converter method.

7.5.3.10 Dinitrogen oxide (N₂O) analysis

An FTIR analyser or an NDIR (non-dispersive infrared) analyser may be used in accordance with the instrument supplier's instructions. Since the technology has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.5.3.11 Formaldehyde (HCHO) analysis

Formaldehyde shall be determined by passing an exhaust sample, preferably from the diluted exhaust gas, 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.

Optionally, an FTIR analyser may be used in accordance with the instrument supplier's instructions.

7.5.3.12 Methanol (CH₃OH) analysis

7.5.3.12.1 General

An FTIR analyser may be used in accordance with the instrument supplier's instructions. Since the technology has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.5.3.12.2 Gas chromatographic (GC) method

Methanol shall be determined by passing an exhaust sample through an impinger containing de-ionized water. The sample shall be analysed by a GC with FID.

7.5.3.12.3 HFID method

The HFID calibrated on propane shall be operated at $385\text{ K} \pm 10\text{ K}$ ($112\text{ °C} \pm 10\text{ °C}$). The methanol response factor shall be determined at several concentrations in the range of concentrations in the sample, according to 8.8.5.

7.5.3.13 Air-to-fuel measurement

The air-to-fuel measurement equipment used to determine the exhaust gas flow as specified in 7.3.6 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 as follows:

$\pm 3\%$ of reading for	$\lambda < 2$
$\pm 5\%$ of reading for	$2 \leq \lambda < 5$
$\pm 10\%$ of reading for	$5 \leq \lambda$

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

7.5.4 Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or three times the diameter of the exhaust pipe – whichever is the larger – upstream of the exit of the exhaust gas system but sufficiently close to the engine so as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

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

If the composition of the exhaust gas is influenced by any exhaust aftertreatment system, the exhaust sample shall be taken downstream of this device.

For spark-ignition engines the exhaust sampling probe should be in a high-pressure side of the muffler, but as far from the exhaust port as possible. To ensure complete mixing of the engine exhaust before sample extraction, a mixing chamber may be optionally inserted between the muffler outlet and the sample probe. The internal volume of the mixing chamber shall be not less than 10 times the cylinder displacement of the engine under test and should be roughly equal dimensions in height, width and depth. The mixing chamber size should be kept as small as practicable and should be coupled as close as possible to the engine. The exhaust line leaving the mixing chamber should extend at least 610 mm beyond the sample probe location and be of sufficient size to minimize back pressure. The temperature of the inner surface of the mixing chamber shall be maintained above the dew point of the exhaust gases and a minimum temperature of 65 °C is recommended.

For marine engines the inlet of the probe shall be located so as to avoid ingestion of water which is injected into the exhaust system for the purpose of cooling, tuning or noise reduction.

When a full-flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe in the dilution tunnel (see 17.2.2, Figure 19, DT and PSP).

For compression-ignition engines, HC and NO_x shall be measured by direct sampling from the dilution tunnel. CO and CO₂ may optionally be determined by direct measurement or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

For spark-ignition engines and gas-fuelled engines, all components may optionally be measured directly in the dilution tunnel, or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

7.6 Particulate determination

7.6.1 General

The determination of the particulates requires a dilution system. Dilution shall be accomplished by a partial-flow or a full-flow dilution system. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42 °C) and 325 K (52 °C) immediately upstream of the filter holders. Humidity control of the dilution air before entering the dilution system is permitted; dehumidification, in particular, is 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.

Existing systems established in accordance with ISO 8178-1:1996 do not have to comply with the above filter temperature requirements.

For a partial-flow dilution system, the particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in 7.5.4 and in accordance with 17.2.1, Figures 10 to 18, EP and SP.

The partial-flow system shall be designed to extract a raw exhaust sample from the engine exhaust stream, introduce dilution air into this sample and subsequently measure the particulates in the diluted sample. From that it is essential that the dilution ratio be determined very accurately. Different sampling methods can be applied, whereby the type of sampling used dictates the hardware and procedures to be used (see 17.2.1).

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance, and a temperature- and humidity-controlled weighing chamber are required. For particulate sampling, the following two methods may be applied.

The multiple-filter method dictates that one pair of filters (see 7.6.2.3) is used for each of the individual modes of the test cycle. This method allows more lenient sample procedures but uses more filters.

The single-filter method uses one pair of filters (see 7.6.2.3) for all modes of the test cycle. Considerate attention shall be paid to sampling times and flows during the sampling phase of the test; however, only one pair of filters will be required for the test cycle.

7.6.2 Particulate sampling filters

7.6.2.1 Filter specification

Fluorocarbon coated glass-fibre filters or fluorocarbon membrane filters are required. All filter types shall have a 0,3 µm DOP (di-octylphthalate) collection efficiency of at least 95 % at a gas face velocity of 35 cm/s and at least 99 % at 100 cm/s. When performing correlation tests between laboratories or between a manufacturer and a regulatory agency, filters of identical quality shall be used.

7.6.2.2 Filter size

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (see 7.6.2.5).

7.6.2.3 Primary and back-up filters

The diluted exhaust shall be sampled during the test sequence by one filter if the collection efficiency is > 99 % (see 7.6.2.1), or a pair of filters placed in series (one primary and one back-up filter) if the collection efficiency is between 95 % and 99 %. The back-up filter shall be located no more than 100 mm downstream of the primary filter and shall not be in contact with the primary filter. The filters may be weighed separately or as a pair with the filters placed stain side to stain side.

7.6.2.4 Filter face velocity

A gas face velocity through the filter of 35 cm/s 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.

7.6.2.5 Filter loading

The filter loading should be 0,338 µg/mm² filter area for the single-filter method. The required minimum filter loading shall be 0,065 µg/mm² filter area. For the most common filter sizes the values are given in Table 4.

For the multiple-filter method, the filter loading for the sum of all filters is the product of the appropriate value above and the square root of the total number of modes.

Table 4 — Minimum filter loading

Filter diameter mm	Recommended loading mg	Required minimum loading mg
47	0,6	0,11
70	1,3	0,25
90	2,1	0,41
110	3,2	0,62

7.6.3 Weighing chamber and analytical balance specifications

7.6.3.1 Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within $295\text{ K} \pm 3\text{ K}$ ($22\text{ °C} \pm 3\text{ °C}$) during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of $282,5\text{ K} \pm 3\text{ K}$ ($9,5\text{ °C} \pm 3\text{ °C}$) and a relative humidity of $45\% \pm 8\%$.

7.6.3.2 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 7.6.3.1 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 or reference filter pairs shall be weighed within 4 h of (but preferably at the same time as) the sample filter (pair) weighings. They shall be the same size and material as the sample filters.

If the average mass of the reference filters or reference filter pairs changes between sample filter weighings by more than $10\text{ }\mu\text{g} + 5\%$ of particulate loading at the actual test with an absolute upper limit of $40\text{ }\mu\text{g}$, then all sample filters shall be discarded and the emissions test repeated. Optionally, the cycle may be repeated on the same filter to get a higher particulate loading with correspondingly higher reference filter tolerances.

If the weighing room stability criteria outlined in 7.6.3.1 are not met, but the reference filter (pair) weighings meet the above criteria, the engine manufacturer has the option of accepting the sample filter masses or voiding the tests, fixing the weighing room control system and rerunning the test.

7.6.3.3 Analytical balance

The analytical balance used to determine the masses of all filters shall have a precision (standard deviation) of $20\text{ }\mu\text{g}$ and a resolution of $10\text{ }\mu\text{g}$ (1 digit = $10\text{ }\mu\text{g}$). For filters less than 70 mm in diameter, the precision and resolution shall be $2\text{ }\mu\text{g}$ and $1\text{ }\mu\text{g}$, respectively.

7.6.3.4 Elimination of static electricity effects

To eliminate 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.

7.6.4 Additional specifications for particulate measurement

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition or alteration of the particulates. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

8 Calibration of the analytical instruments

8.1 General requirements

Each analyser shall be calibrated as often as necessary to fulfil the accuracy requirements of this part of ISO 8178. The calibration method that shall be used is described below for the analysers indicated in 7.5.3.

8.2 Calibration gases

8.2.1 General

The shelf life of all calibration gases shall be respected.

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

8.2.2 Pure gas

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

- purified nitrogen (contamination ≤ 1 ppmC, ≤ 1 ppmCO, ≤ 400 ppmCO₂, $\leq 0,1$ ppmNO);
- purified oxygen (purity $> 99,5$ % vol. O₂);
- hydrogen–helium mixture (40 % $\pm$ 2 % hydrogen, balance helium) (contamination ≤ 1 ppmC, ≤ 400 ppmCO₂);
- purified synthetic air (contamination ≤ 1 ppmC, ≤ 1 ppmCO, ≤ 400 ppmCO₂, $\leq 0,1$ ppmNO) (oxygen content 18 % – 21 % vol.).

8.2.3 Calibration and span gases

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

- C₃H₈ and purified synthetic air (see 8.2.2);
- CO and purified nitrogen;
- NO_x and purified nitrogen (the amount of NO₂ contained in this calibration gas shall not exceed 5 % of the NO content);
- O₂ and purified nitrogen;
- CO₂ and purified nitrogen;
- CH₄ and purified synthetic air;
- C₂H₆ and purified synthetic air.

NOTE Other gas combinations are allowed provided the gases do not react with one another.

The true concentration of a calibration and span gas shall be within ± 2 % of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

8.2.4 Use of gas dividers

The gases used for calibration and span may also be obtained by means of precision blending devices (gas dividers), diluting with purified N₂ or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the blended calibration gases is accurate to within ± 2 %. This accuracy implies

that primary gases used for blending must be known to an accuracy of at least $\pm 1\%$, traceable to national or international gas standards. The verification shall be performed at between 15 % and 50 % of full scale for each calibration incorporating a blending device.

Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The blending device shall be checked at the used settings and the nominal value shall be compared to the measured concentration of the instrument. This difference shall in each point be within $\pm 1\%$ of the nominal value. But this linearity check of the gas divider shall not be performed with a gas analyser which was previously linearized with the same gas divider.

8.2.5 Oxygen interference gases

Oxygen interference check gases shall contain propane with $350 \text{ ppmC} \pm 75 \text{ ppmC}$ hydrocarbon. The concentration value shall be determined to calibration gas tolerances by chromatographic analysis of total hydrocarbons plus impurities or by dynamic blending. Nitrogen shall be the predominant diluent with the balance oxygen. Blends required for gasoline-fuelled and diesel engine testing are listed in Table 5:

Table 5 — Oxygen interference check gases

Applicability	O ₂ concentration	Balance
Diesel	21 (20 to 22)	Nitrogen
Diesel and gasoline	10 (9 to 11)	Nitrogen
Diesel and gasoline	5 (4 to 6)	Nitrogen
Gasoline	0 (0 to 1)	Nitrogen

8.3 Operating procedure for analysers and sampling system

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in 8.4 to 8.9 shall be included. For laboratory instruments such as GC and HPLC, only 8.5.4 applies.

8.4 Leakage test

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilization period all flow meters should read zero. If not, the sampling lines shall be checked and the fault corrected.

The maximum allowable leakage rate on the vacuum side shall be 0,5 % of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If after an adequate period of time the reading shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

8.5 Calibration procedure

8.5.1 Instrument assembly

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

8.5.2 Warm-up time

The warm-up time should be according to the recommendations of the manufacturer. If not specified, a minimum of 2 h is recommended for warming up the analysers.

8.5.3 NDIR and HFID analyser

Tune the NDIR analyser as necessary, and optimize the combustion flame of the HFID analyser (see 8.8.1)

8.5.4 GC and HPCL

Calibrate both instruments according to good laboratory practice and the recommendations of the manufacturer.

8.5.5 Establishment of the calibration curve

- a) Each normally used operating range shall be calibrated.
- b) Using purified synthetic air (or nitrogen), the CO, CO₂, NO_x and HC analysers shall be set at zero.
- c) The appropriate calibration gases shall be introduced to the analysers, the values recorded, and the calibration curve established.
- d) The calibration curve shall be established by at least six calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 % of full scale.
- e) The calibration curve shall be calculated by the method of least squares. A best-fit linear or non-linear equation may be used.
- f) The calibration points shall not differ from the least squares best-fit line by more than ± 2 % of reading or $\pm 0,3$ % of full scale, whichever is larger.
- g) The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

8.5.6 Alternative calibration methods

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

8.5.7 Verification of the calibration

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

The calibration is checked by using a zero gas and a span gas whose nominal value is more than 80 % 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 8.5.5.

8.6 Calibration of tracer gas analyser for exhaust flow measurement

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

The calibration curve shall be established by at least six calibration points (excluding zero) approximately equally spaced over the operating range. The highest nominal concentration shall be equal to or higher than 90 % of full scale. The calibration curve is calculated by the method of least squares.

The calibration points shall not differ from the least-squares best-fit line by more than ± 2 % of reading or $\pm 0,3$ % of full scale, whichever is larger.

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.

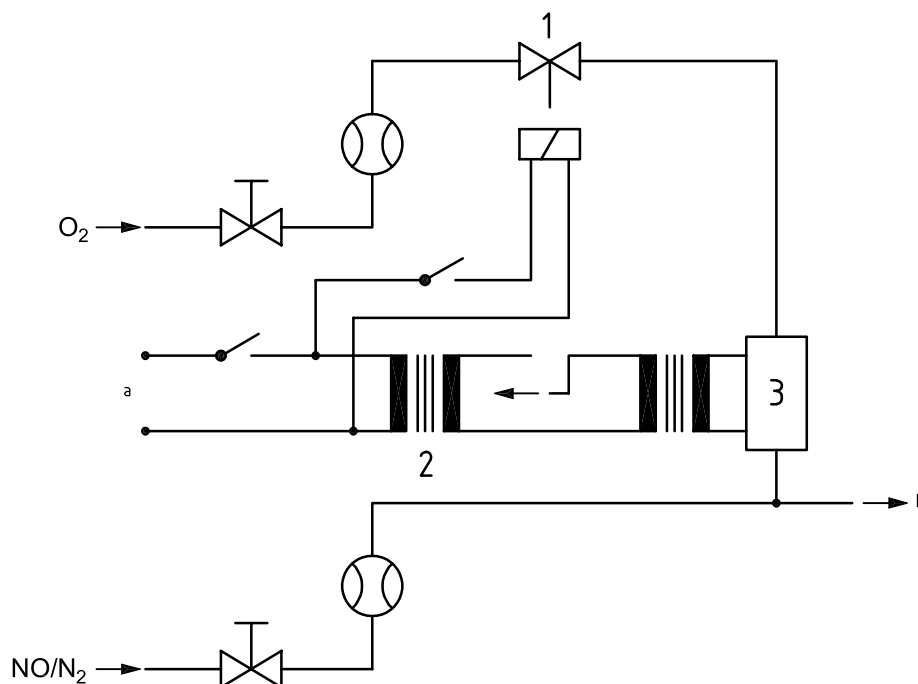
8.7 Efficiency test of the NO_x converter

8.7.1 Introduction

The efficiency of the converter used for the conversion of NO₂ into NO is tested as given in 8.7.2 to 8.7.9 (see Figure 1).

8.7.2 Test setup

Using the test setup as schematically shown in Figure 1 (see also 7.5.3.7) and the procedure below, the efficiency of converters can be tested by means of an ozonator.



Key

- 1 solenoid valve
- 2 variac
- 3 ozonator
- a Alternating current.
- b To analyser.

Figure 1 — Schematic representation of NO₂ converter efficiency device

8.7.3 Calibraton

The CLD and the HCLD shall be calibrated in the most common operating range, following the manufacturer's specifications, using zero and span gas (the NO content of which must amount to about 80 % of the operating range and the NO₂ concentration of the gas mixture to less than 5 % of the NO concentration). The NO_x analyser shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration shall be recorded.

8.7.4 Calculation

The efficiency of the NO_x converter is calculated as follows:

$$E_{\text{NO}_x} = \left(1 + \frac{a-b}{c-d} \right) \times 100 \quad (13)$$

where

a is the NO_x concentration according to 8.7.7;

b is the NO_x concentration according to 8.7.8;

c is the NO concentration according to 8.7.5;

d is the NO concentration according to 8.7.6.

8.7.5 Adding of oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 % less than the indicated calibration concentration given in 8.7.3. (The analyser is in the NO mode.)

The indicated concentration (*c*) shall be recorded. The ozonator is kept deactivated throughout the process.

8.7.6 Activation of the ozonator

The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20 % (minimum 10 %) of the calibration concentration given in 8.7.3. The indicated concentration (*d*) shall be recorded. (The analyser is in the NO mode.)

8.7.7 NO_x mode

The NO analyser is then switched to the NO_x mode so that the gas mixture (consisting of NO, NO₂, O₂ and N₂) now passes through the converter. The indicated concentration (*a*) shall be recorded. (The analyser is in the NO_x mode.)

8.7.8 Deactivation of the ozonator

The ozonator is now deactivated. The mixture of gases described in 8.7.7 passes through the converter into the detector. The indicated concentration (*b*) shall be recorded. (The analyser is in the NO_x mode.)

8.7.9 NO mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO_x reading of the analyser shall not deviate by more than ± 5 % from the value measured according to 8.7.3. (The analyser is in the NO mode.)

8.7.10 Test interval

The efficiency of the converter shall be tested prior to each calibration of the NO_x analyser.

8.7.11 Efficiency requirement

The efficiency of the converter shall not be less than 90 %, but a higher efficiency of 95 % is strongly recommended.

If, with the analyser in the most common range, the NO_x converter cannot give a reduction from 80 % to 20 % according to 8.7.3, then the highest range which will give the reduction shall be used.

8.8 Adjustment of the FID

8.8.1 Optimization of the detector response

The FID shall be adjusted as specified by the instrument manufacturer. A propane-in-air span gas should be used to optimize the response on the most common operating range.

With the fuel and air flow rates set at the manufacturer's recommendations, a 350 ± 75 ppmC span gas shall be introduced to the analyser. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to 8.8.2 and 8.8.3.

If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the air flow shall be incrementally adjusted above and below the manufacturer's specifications, 8.8.2 and 8.8.3 for each flow.

The optimization may optionally be conducted using the procedures outlined in SAE Technical Paper 770141 (see Bibliography).

8.8.2 Hydrocarbon response factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to 8.5.

Response factors shall be determined when introducing an analyser into service and after major service intervals. The response factor (r_h) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppmC1.

The concentration of the test gas shall be at a level to give a response of approximately 80 % of full scale. The concentration shall be known to an accuracy of ± 2 % in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 h at a temperature of $298 \text{ K} \pm 5 \text{ K}$ ($25 \text{ }^\circ\text{C} \pm 5 \text{ }^\circ\text{C}$).

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

- Methane and purified synthetic air: $1,00 \leq r_h \leq 1,15$.
- Propylene and purified synthetic air: $0,90 \leq r_h \leq 1,1$.
- Toluene and purified synthetic air: $0,90 \leq r_h \leq 1,1$.

These values are relative to a r_h of 1 for propane and purified synthetic air.

8.8.3 Oxygen interference check

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

A range shall be chosen where the oxygen interference check gases will fall in the upper 50 %. The test shall be conducted with the oven temperature set as required. The oxygen interference gases are specified in 8.2.5.

- a) The analyser shall be zeroed.
- b) The analyser shall be spanned with the 0 % oxygen blend for gasoline-fuelled engines. Diesel engine instruments shall be spanned with the 21 % oxygen blend.
- c) The zero response shall be rechecked. If it has changed by more than 0,5 % of full scale, steps a) and b) shall be repeated.
- d) The 5 % and 10 % oxygen interference check gases shall be introduced.
- e) The zero response shall be rechecked. If it has changed by more than ± 1 % of full scale, the test shall be repeated.
- f) The oxygen interference (%O₂int) shall be calculated for each mixture in step d) as follows:

$$\%O_{2int} = \frac{(B - \text{analyser response})}{B} \times 100 \quad (14)$$

where

$$\text{analyser response is } \frac{A}{\%FS \text{ at } A} \times \%FS \text{ at } B$$

where

A is the hydrocarbon concentration in parts per million C (microlitres per litre) of the span gas used in step b),

B is the hydrocarbon concentration (ppmC) of the oxygen interference check gases used in step d).

$$(\text{ppmC}) = \frac{A}{D} \quad (15)$$

where

D is the percentage of full scale analyser response due to *A*.

- g) The % of oxygen interference (%O₂int) shall be less than $\pm 3,0$ % for all required oxygen interference check gases prior to testing.
- h) If the oxygen interference is greater than $\pm 3,0$ %, the air flow above and below the manufacturer's specifications shall be incrementally adjusted, repeating 8.8.1 for each flow.
- i) If the oxygen interference is greater than $\pm 3,0$ % after adjusting the air flow, the fuel flow and thereafter the sample flow shall be varied, repeating 8.8.1 for each new setting.
- j) If the oxygen interference is still greater than $\pm 3,0$ %, the analyser, FID fuel, or burner air shall be repaired or replaced prior to testing. Steps a) to i) shall then be repeated with the repaired or replaced equipment or gases.

8.8.4 Efficiency of the Non-Methane Cutter (NMC)

8.8.4.1 General

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 %, and for the other hydrocarbons represented by ethane is 100 %. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate (see 14.4).

8.8.4.2 Methane efficiency

Methane calibration gas shall be flowed through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$E_M = 1 - \frac{c_{wCutter}}{c_{w/oCutter}} \quad (16)$$

where

$c_{wCutter}$ is the HC concentration with CH_4 flowing through the NMC,

$c_{w/oCutter}$ is the HC concentration with CH_4 bypassing the NMC.

8.8.4.3 Ethane efficiency

Ethane calibration gas shall be flowed through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$E_E = 1 - \frac{c_{wCutter}}{c_{w/oCutter}} \quad (17)$$

where

$c_{wCutter}$ is the HC concentration with C_2H_6 flowing through the NMC,

$c_{w/oCutter}$ is the HC concentration with C_2H_6 bypassing the NMC.

8.8.5 Methanol response factor

When the FID analyser is to be used for the analysis of hydrocarbons containing methanol, the methanol response factor (r_m) of the analyser shall be established.

A known volume of methanol (a , in millilitres) is injected, using a microlitre syringe, into the heated mixing zone [395 K (122 °C)] of a septum injector, vapourized and swept into a tedlar bag with a known volume of zero-grade air (b , in cubic metres). The air volume(s) shall be such that the methanol concentration in the bag is representative of the range of concentrations found in the exhaust sample.

The bag sample is analysed using the FID, and the response factor is calculated as follows:

$$r_m = \frac{x_{FID}}{c_{SAM}} \quad (18)$$

where

x_{FID} is the FID reading, in parts per million (microlitres per litre) of C,

c_{SAM} is the methanol concentration in the sample bag in ppmC, as calculated from a and b :
 $c_{SAM} = 594 \times a/b$.

8.9 Interference effects with CO, CO₂, NO_x, O₂, NH₃ and N₂O analysers

8.9.1 General

Gases other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in 8.9.2 and 8.9.3 shall be performed prior to an analyser's initial use and after major service intervals, but at least once per year.

8.9.2 CO analyser interference check

Water and CO₂ can interfere with the CO analyser performance. Therefore, a CO₂ span gas having a concentration of 80 % to 100 % of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response shall not be more than 1 % of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

8.9.3 NO_x analyser quench checks

The two gases of concern for CLD (and HCLD) analysers are CO₂ and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

8.9.3.1 CO₂ quench check

A CO₂ span gas having a concentration of 80 % to 100 % of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO₂ value recorded as *A*. It shall then be diluted approximately 50 % with NO span gas and passed through the NDIR and (H)CLD, with the CO₂ and NO values recorded as *B* and *C*, respectively. The CO₂ shall then be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as *D*.

The quench shall be calculated as follows:

$$E_{\text{CO}_2} = \left[1 - \left(\frac{(C \times A)}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad (19)$$

where

- A* is the undiluted CO₂ concentration measured with NDIR [%],
- B* is the diluted CO₂ concentration measured with NDIR [%],
- C* is the diluted NO concentration measured with (H)CLD [ppm],
- D* is the undiluted NO concentration measured with (H)CLD [ppm].

Alternative methods of diluting and quantifying CO₂ and NO span gas values, such as dynamic mixing/blending, can be used.

8.9.3.2 Water quench check

This check applies to wet gas concentration measurements only. Calculation of water quench shall consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing.

A NO span gas having a concentration of 80 % to 100 % of full scale of the normal operating range shall be passed through the (H)CLD and the NO value recorded as D . The NO span gas shall then be bubbled through water at a temperature of 298 ± 5 K (25 ± 5 °C), passed through the (H)CLD and the NO value recorded as C . The water temperature shall be determined and recorded. The mixture's saturation vapour pressure that corresponds to the bubbler water temperature (F) shall be determined and recorded as G . The water vapour concentration (H , in %) of the mixture shall be calculated as follows:

$$H = 100 \times \left(\frac{G}{p_b} \right) \quad (20)$$

The expected diluted NO span gas (in water vapour) concentration (D_e) shall be calculated as follows:

$$D_e = D \times \left(1 - \frac{H}{100} \right) \quad (21)$$

For diesel exhaust, the maximum exhaust water concentration (in %) expected during testing shall be estimated, under the assumption of a fuel atom H:C ratio of 1,8:1, from the maximum CO₂ concentration A in the exhaust gas as follows:

$$H_m = 0,9 \times A \quad (22)$$

Record H , D_e and H_m .

The water quench shall be calculated as follows:

$$E_{H_2O} = 100 \times \left(\frac{D_e - C}{D_e} \right) \times \left(\frac{H_m}{H} \right) \quad (23)$$

where

D_e is the expected diluted NO concentration [ppm];

C is the diluted NO concentration [ppm];

H_m is the maximum water vapour concentration [%];

H is the actual water vapour concentration [%].

NOTE It is important that the NO span gas contains minimal NO₂ concentration for this check, since absorption of NO₂ in water has not been accounted for in the quench calculations.

8.9.3.3 Maximum allowable quench

The maximum allowable quench shall be as follows.

- For all dry CLD analysers, it shall be demonstrated that for the highest expected water vapour concentration (i.e. “%H₂Oexp” as calculated later in this section), the water removal technique maintains CLD humidity at less than or equal to 5 g water per kg dry air (or about 0,008 % H₂O), which is 100 % RH at 3,9 °C and 101,3 kPa. This humidity specification is also equivalent to about 25 % RH at 25 °C and 101,3 kPa. This can be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow of the dehumidifier.
- For raw measurement CO₂-quench according to 8.9.3.1: 2 % of full scale.
- Water quench according to 8.9.3.2: 3 % of full scale.
- For dilute measurement: 2 % combined CO₂ and water quench.

8.9.4 O₂ analyser interference

Instrument response of a PMD analyser caused by gases other than oxygen is comparatively slight. The oxygen equivalents of the common exhaust gas constituents are shown in Table 6.

Table 6 — Oxygen equivalents

Gas	O ₂ equivalent %
Carbon dioxide (CO ₂)	– 0,623
Carbon monoxide (CO)	– 0,354
Nitric oxide (NO)	+ 44,4
Nitrogen dioxide (NO ₂)	+ 28,7
Water (H ₂ O)	– 0,381

The observed oxygen concentration shall be corrected by the following formula if high-precision measurements are to be done:

$$\text{Interference} = \frac{(\text{Equivalent \% O}_2 \times \text{Observed concentration})}{100} \quad (24)$$

For ZRDO and ECS analysers, instrument interference caused by gases other than oxygen shall be compensated for in accordance with the instrument supplier's instruction and with good engineering practice.

8.9.5 Cross-interference check compensation for NH₃ and N₂O measurement channels using IR and UV measurement techniques

8.9.5.1 Procedure for establishing the cross-interference correction for NH₃ analysers (NDUVR method)

There are cross-interferences to nitrogen oxide (NO) and nitrogen dioxide (NO₂). Both components shall be measured with the measurement equipment and a compensation shall be applied to the analyser readings, if the cross-interference exceeds 2 % full scale.

8.9.5.2 Check of the cross-interferences

NO and NO₂ calibration gases are fed into the analyser with cross-interference compensation activated. For each component, at least five different calibration gas concentrations with equidistant spacing between zero and the maximum expected interference gas concentration shall be used for the compensation check. The maximum deviation of the NH₃ reading from the zero reading shall be less than ± 2 % full scale of the commonly used range. If the deviation is higher, a new correction curve for the corresponding interference component shall be established and applied to the analyser readings. The use of single-blend gases is possible, as well as the use of gas mixtures containing two or more interference gases.

8.9.5.3 Procedure for the generation of cross-interference correction curves

8.9.5.3.1 NO cross-interference

Calibration gases with at least five different NO concentrations that have to be spread equidistantly over the used NO analyser range during measurement shall be fed into the NH₃ analyser.

The nominal NO values and the measured NH₃ concentrations have to be recorded. Using a least-squares fit for a suitable fit function (e.g. polynomial fit function) $f(\text{NO})$, a correction curve to compensate for the NO cross-interference is calculated. The number of fit points has to be higher by at least two than the number of fit

parameters (e.g. polynomial of fourth order needs at least seven fit points). The correction values $NH_3_{\text{compensated}} = NH_3_{\text{not compensated}} - f(NO)$ should be within ± 1 % full scale of the analyser zero reading.

8.9.5.3.2 NO₂ cross-interference

The procedure for NO₂ is equivalent to that for NO₂ span gases. The result is the correction curve $f(NO_2)$.

The calibration gases used for establishing the cross-interference compensation curves shall be single-blend mixtures. The use of gas mixtures with two or more interference gases is not allowed for generating the cross-interference compensation curves.

The following compensation calculation should be done by the measurement system:

$$NH_3_{\text{compensated}} = NH_3_{\text{not compensated}} - f(N) - f(NO_2)$$

After the compensation curves have been established, the cross-interference compensation shall be checked by the procedures given in 8.9.5.2.

8.9.5.4 Procedure for establishing the cross-interference correction for N₂O analysers (NDIR method)

There are cross-interferences for CO₂, CO and NO and small interferences for some hydrocarbons.

8.9.5.5 Check the cross-interferences

Calibration gases for CO, CO₂, NO and C₃H₈ are fed into the analyser with cross-interference compensation activated. For each component at least five different calibration gas concentrations with equidistant spacing between zero and the maximum expected interference gas concentration shall be used for the compensation check. The maximum deviation of the NO₂ reading from the zero reading shall be less than ± 2 % full scale of the commonly used range. If the deviation is higher, a new correction curve for the corresponding interference component shall be established and applied to the analyser readings. The use of single-blend gases is allowed, as well as the use of gas mixtures containing two or more interference gases.

8.9.5.6 Procedure for the generation of cross-interference correction curves

8.9.5.6.1 CO cross-interference

Calibration gases with at least five different CO concentrations that have to be spread equidistantly over the used CO analyser range during measurement shall be fed into the N₂O analyser.

The nominal CO values and the measured N₂O concentrations shall be recorded. Using a least-squares fit for a suitable fit function (e.g. polynomial fit function) $f(CO)$, a correction curve to compensate for the CO cross-interference is calculated. The number of fit points shall be higher by at least two than the number of fit parameters (e.g. polynomial of fourth order needs at least seven fit points).

The corrected values $N_2O_{\text{compensated}} = N_2O_{\text{not compensated}} - f(CO)$ should be within ± 1 % full scale of the analyser zero reading.

8.9.5.6.2 CO₂, NO and C₃H₈ cross-interference

The same procedure is done for CO₂, NO and C₃H₈. The result is the correction functions $f(CO_2)$, $f(NO)$, and $f(C_3H_8)$, respectively.

The calibration gases used for establishing the cross-interference compensation curves shall be single-blend mixtures. The use of gas mixtures with two or more interference gases is not allowed for generating the cross-interference compensation curves.

The following compensation calculation should be done by the measurement system:

$$N_2O_{\text{compensated}} = N_2O_{\text{not compensated}} - f(CO_2) - f(CO) - f(NO) - f(C_3H_8)$$

After the compensation curves have been established, the cross-interference compensation shall be checked by the procedure given in 8.9.5.5.

8.10 Calibration intervals

The analysers shall be calibrated according to 8.5 at least every three months or whenever a system repair or change is made that could influence calibration

9 Calibration of the particulate measuring system

9.1 General

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this part of ISO 8178. The calibration method to be used is described in this clause for the components indicated in 7.6 and 17.

9.2 Calibration procedure

9.2.1 Flow measurement

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

If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of q_{medf} is within $\pm 4\%$ (see also 17.2.1, exhaust gas analyser explanations given below Figures 10 to 18). It can be calculated by taking the root-mean-square of the errors of each instrument.

9.2.2 Exhaust gas analysers

If CO_2 or NO_x concentration measurement is used for the determination of the dilution ratio, the exhaust gas analysers shall be calibrated in accordance with 8.5.5.

9.2.3 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 F shall be applied. The carbon flow rates shall be calculated according to Equations F.1, F.2 and F.3. All carbon flow rates should agree to within 6 %.

9.3 Checking the partial-flow conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of 17.2.1, exhaust pipe explanations given below Figures 10 to 18, if applicable.