

Reciprocating internal combustion engines — Exhaust emission measurement —

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

The European Standard EN ISO 8178-1:1996 has the status of a
British Standard

ICS 13.040.40; 13.040.50; 27.020

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- Agricultural Engineers' Association
- British Industrial Truck Association
- Health and Safety Executive
- Ministry of Defence
- Society of Motor Manufacturers and Traders Limited

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- Association of Manufacturers of Power Generating Systems
- British Railways Board
- Department of Transport

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National foreword

This British Standard has been prepared by Technical Committee MCE/14 and is the English language version of EN ISO 8178-1:1996 *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test bed measurement of gaseous and particulate exhaust emissions*, published by the European Committee for Standardization (CEN). It is identical with ISO 8178-1:1996, published by the International Organization for Standardization (ISO). EN ISO 8178-1 was produced as a result of international discussions in which the UK took an active part.

Cross-references

Publication referred to	Corresponding British Standard
ISO 3046-3:1989	BS 2514 <i>Reciprocating internal combustion engines: performance</i> Part 3:1990 <i>Specification for test measurements</i>
EN ISO 5167-1:1995 (ISO 5167-1:1991)	BS 1042 <i>Measurement of fluid flow in closed conduits</i> Part 1 <i>Pressure differential devices</i> Section 1.1:1992 <i>Specification for square-edged orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full</i>

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 88, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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English version

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

(ISO 8178-1:1996)

Moteurs alternatifs à combustion interne —
Mesurage des émissions de gaz
d'échappement —
Partie 1: Mesurage des émissions de gaz et de
particules au banc d'essai
(ISO 8178-1:1996)

Hubkolben-Verbrennungsmotoren —
Abgasmessung — Teil 1: Messung der
gasförmigen Emission und der
Partikelemission auf dem Prüfstand
(ISO 8178-1:1996)

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Foreword

The text of the International Standard ISO 8178-1:1996 has been prepared by Technical Committee ISO/TC 70, Internal combustion engines, in collaboration with Technical Committee CEN/TC 270, Internal combustion engines, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 1997, and conflicting national standards shall be withdrawn at the latest by February 1997.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

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1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emission from reciprocating internal combustion engines (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 e.g. in 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 calibration methods specified in ISO 8178-2 are appropriate.

NOTE 1 This part of ISO 8178 is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of RIC engines for non-automotive use. Its purpose is to provide a map of an engine's emission 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 dilution method 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 below are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

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 shall be made at site or under appropriate conditions.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 8178. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 8178 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3046-3:1989, *Reciprocating internal combustion engines — Performance — Part 3: Test measurements*.

ISO 5167-1:1991, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*.

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 8178-2:—¹⁾, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 2: Measurement of gaseous and particulate exhaust emissions at site.*

ISO 8178-4:—¹⁾, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications.*

ISO 8178-5:—¹⁾, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels.*

ISO 8178-6:—¹⁾, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Test report.*

SAE J 1151:1988, *Methane measurement using gas chromatography.*

SAE J 1936:1989, *Chemical methods for the measurement of nonregulated diesel emissions.*

3 Definitions

For the purposes of this part of ISO 8178, the following definitions apply.

3.1

particulates

any material collected on a specified filter medium after diluting exhaust gases with clean, filtered air at a temperature of less than or equal to 325 K (52 °C), as measured at a point immediately upstream of the primary filter; this is primarily 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 sulfur levels up to 0,8 %.

3.2

partial flow dilution method

the process of separating a part of the raw exhaust gases from the total exhaust flow, then mixing with an appropriate amount of dilution air prior to passing through the particulate sampling filter (see 16.1.1, Figure 10 to Figure 18)

3.3

full flow dilution method

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

NOTE 3 It is common in many full-flow dilution systems to dilute this fraction of pre-diluted exhaust gases a second time to obtain appropriate sample temperatures at the particulate filter (see 16.1.2, Figure 19)

3.4

isokinetic sampling

the 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

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

3.6

multiple filter method

the process of using one pair of filters for each of the individual test cycle modes; the modal weighting factors are accounted for after sampling during the data evaluation phase of the test

3.7

single filter method

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

NOTE 4 This method dictates that particular attention be given to sampling duration and flow rates.

¹⁾ To be published.

3.8

specific emissions

emissions expressed on the basis of brake power as defined in 3.9

NOTE 5 For many engine types within the scope of this part of ISO 8178 the auxiliaries which will be fitted to the engine in service are not known at the time of manufacture or certification.

When it is not appropriate to test the engine in the conditions as defined in Annex B, 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 11.5. The auxiliary losses should not exceed 5 % of the maximum observed power. Losses exceeding 5 % must be approved, prior to the test, by the parties involved

3.9

brake power

the 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 (see 5.3 and Annex B)

3.10

auxiliaries

the equipment and devices listed in Annex B

4 Symbols and abbreviations

4.1 Symbols and subscripts

According to EEC regulations	Symbols		Unit
	SI ^a	Term	
A_p	A_p	Cross sectional area of the isokinetic sampling probe	m ²
A_T	A_x	Cross sectional area of the exhaust pipe	m ²
$conc_c$	c_{corr}	Background corrected concentration	ppm % (V/V)
$conc_d$	c_{dil}	Concentration of the dilution air	ppm % (V/V)
$conc_x$	c_x	Concentration (with suffix of the component nominating)	ppm % (V/V)
DF	D	Dilution factor	1
EAF	E	Excess air factor (kg dry air per kg fuel)	kg/kg
EAF_{Ref}	E_{ref}	Excess air factor (kg dry air per kg fuel) at reference conditions	kg/kg
f_a	f_a	Laboratory atmospheric factor	1
F_{FCB}	F_{cb}	Fuel specific factor for the carbon balance calculation	1
F_{FD}	F_d	Fuel specific factor for exhaust flow calculation on dry basis	1
F_{FH}	F_h	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	1
F_{FW}	F_w	Fuel specific factor for exhaust flow calculation on wet basis	1
G_{AIRD}	q_{mad}	Intake air mass flow rate on dry basis	kg/h
G_{AIRW}	q_{maw}	Intake air mass flow rate on wet basis	kg/h
G_{DILW}	q_{mdw}	Dilution air mass flow rate on wet basis	kg/h
G_{EDFW}	q_{mdx}^*	Equivalent diluted exhaust gas mass flow rate on wet basis	kg/h
G_{EXHW}	q_{mxw}	Exhaust gas mass flow rate on wet basis	kg/h
G_{FUEL}	q_{mf}	Fuel mass flow rate	kg/h
G_{TOTW}	q_{mdx}	Diluted exhaust gas mass flow rate on wet basis	kg/h

Symbols		Term	Unit
According to EEC regulations	SI ^a		
GAS_x	e_x	Gas emission (with subscript denoting compound)	kg/kW h
H_a	H_a	Absolute humidity of the intake air	g/kg
H_d	H_d	Absolute humidity of the dilution air	g/kg
H_{REF}	H_{ref}	Reference value of absolute humidity ^b	g/kg
$HTCRAT$	HC	Hydrogen-to-carbon ratio	mol/mol
i	i	Subscript denoting an individual mode	1
K_{HDIES}	K_{hd}	Humidity correction factor for NO_x for diesel engines	1
K_{HPET}	K_{hp}	Humidity correction factor for NO_x for gasoline (petrol) engines	1
K_p	K_p	Humidity correction factor for particulates	1
K_{Wa}	K_{wa}	Dry to wet correction factor for the intake air	1
K_{Wd}	K_{wd}	Dry to wet correction factor for the dilution air	1
K_{We}	K_{we}	Dry to wet correction factor for the diluted exhaust gas	1
K_{Wr}	K_{wr}	Dry to wet correction factor for the raw exhaust gas	1
L	M	Percent torque related to the maximum torque for the test engine speed	%
$mass$	q_{mPT}	Emissions mass flow rate	g/h
M_d	m_d	Particulate sample mass of the dilution air collected	mg
M_{DIL}	m_{dil}	Mass of the dilution air sample passed through the particulate sampling filters	kg
M_f	m_f	Particulate sample mass collected	mg
M_{GASi}	m_{gasi}	Mass of individual gas	kg
M_{SAM}	m_{sam}	Mass of the diluted exhaust sample passed through the particulate sampling filters	kg
p_a	p_a	Saturation vapour pressure of the engine intake air ^c	kPa
p_B	p_b	Total barometric pressure ^d	kPa
p_d	p_d	Saturation vapour pressure of the dilution air	kPa
p_s	p_s	Dry atmospheric pressure	kPa
P	P	Uncorrected brake power	kW
P_{AUX}	P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by Annex B	kW
P_m	P_m	Maximum measured or declared power at the test engine speed under test conditions (see 11.5)	kW
PT	e_{PT}	Particulate emission	g/kW h
PT_{mass}	q_{mPT}	Particle mass flow rate	kg/h
q	r_{dil}	Dilution ratio	1
r	r_a	Ratio of cross sectional areas of isokinetic probe and exhaust pipe	1
R_a	R_a	Relative humidity of the intake air	%

Symbols		Term	Unit
According to EEC regulations	SI ^a		
R_d	R_d	Relative humidity of the dilution air	%
R_f	r_f	FID response factor	1
R_{fM}	r_m	FID response factor for methanol	1
S	S	Dynamometer setting	kW
T_a	T_a	Absolute temperature of the intake air	K
T_{Dd}	T_d	Absolute dewpoint temperature	K
T_{ref}	T_{ref}	Absolute reference temperature (of combustion air: 298 K)	K
T_{SC}	T_c	Absolute temperature of the intercooled air	K
T_{SCRef}	T_{cref}	Absolute intercooled air reference temperature	K
V_{AIRD}	q_{Vad}	Intake air volume flow rate on dry basis	m ³ /h
V_{AIRW}	q_{Vaw}	Intake air volume flow rate on wet basis	m ³ /h
V_{DIL}	V_{dil}	Volume of the dilution air sample passed through the particulate sampling filters	m ³
V_{DILW}	q_{Vdw}	Dilution air volume flow rate on wet basis	m ³ /h
V_{EDFW}	q_{Vdx}^*	Equivalent diluted exhaust gas volume flow rate on wet basis	m ³ /h
V_{EXHD}	q_{Vxd}	Exhaust gas volume flow rate on dry basis	m ³ /h
V_{EXHW}	q_{Vxwi}	Exhaust gas volume flow rate on wet basis	m ³ /h
V_{SAM}	V_{sam}	Volume of the diluted exhaust sample passed through the particulate sampling filters	m ³
V_{TOTW}	q_{Vdx}	Diluted exhaust gas volume flow rate on wet basis	m ³ /h
W_F	W_f	Weighting factor	1
W_{FE}	W_{fe}	Effective weighting factor	1

^a According to ISO 31 on Quantities and units.

^b 10,71 g/kg; for calculation of NO_x and particulate humidity correction factors.

^c Correspond to p_{sy} or PSY (test ambient conditions) as defined in ISO 3046-1.

^d Corresponds to p_x or PX (site total pressure in ambient conditions); P_y or PY (test total pressure in ambient conditions) as defined in ISO 3046-1.

4.2 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	Diethyl 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	Sulfur dioxide
SO ₃	Sulfur trioxide

4.3 Abbreviations

CFV	Critical flow venturi
CLD	Chemiluminescent detector
CVS	Constant volume sampling
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 General requirements

All volumes and volumetric flow rates shall be related to 273 K (0° C) and 101,3 kPa.

5.2 Engine test conditions

5.2.1 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 kPa, shall be measured, and the parameter f_a shall be determined according to the following provisions:

Naturally aspirated and mechanically pressure charged compression ignition engines:

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

Turbocharged compression ignition engines with or without cooling of the intake air:

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

Formulae (1) and (2) are identical with the exhaust emission legislation from ECE, EEC and EPA.

For naturally aspirated and pressure charged spark ignition engines the parameter α_a shall be determined according to the following:

$$\alpha_a = \left(\frac{99}{p_s} \right)^{1,2} \times \left(\frac{T_a}{298} \right)^{0,6} \quad \dots(2 \text{ a})$$

and shall be between 0,93 and 1,07.

5.2.2 Test validity

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

$$0,98 \leq f_a \leq 1,02 \quad \dots(3)$$

If, for evident technical reasons, it is not possible to comply with this requirement, f_a shall be between 0,93 and 1,07. In this case the particulate emission, PT, shall be corrected according to **14.1.2**; f_a correction of the gaseous emissions shall not be applied.

5.2.3 Engines with charge air cooling

The temperature of the cooling medium and the temperature of the charge air shall be recorded.

The cooling system shall be set with the engine operating at the reference speed and load. The charge air temperature and cooler pressure drop shall be set to within ± 4 K and ± 2 kPa respectively, of the manufacturer's specification.

5.3 Power

The basis of specific emissions measurement is uncorrected brake 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 **3.8** and Annex B.

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 11.5.

5.4 Engine air inlet system

The test engine shall be equipped with an air inlet system presenting an air inlet restriction within $\pm 10\%$ of the upper limit specified by the manufacturer for a clean air filter for the engine operating conditions giving maximum air flow for respective engine applications.

For 2-stroke spark ignition engines, a system representative of the installed engine shall be used.

5.5 Engine exhaust system

The test engine shall be equipped with an exhaust system presenting an exhaust back pressure within $\pm 10\%$ of the upper limit specified by the manufacturer for the engine operating conditions giving maximum declared power for respective engine applications.

For 2-stroke spark ignition engines, a system representative of the installed engine shall be used.

5.6 Cooling system

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

5.7 Lubricating oil

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

6 Test fuels

Fuel characteristics influence 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 as reference fuels in ISO 8178-5 are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in ISO 8178-5.

The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded.

The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties the fuel shall be selected in accordance with Table 1.

Table 1 — Selection of fuel

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

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

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.

7 Measurement equipment and data to be measured

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in clauses 15 and 16. These clauses describe the recommended analytical systems for the gaseous emissions (clause 15) and the recommended particulate dilution and sampling systems (clause 16).

Other systems or analysers may be accepted if they yield equivalent results. The determination of system equivalency shall be based on a 7-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 and 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 criterion is defined as a $\pm 5\%$ agreement of the sample pair average with outliers excluded from the database as described in ISO 5725-2 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, 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 7.3.

7.1 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 must be such that the maximum tolerances of the figures given in 7.3 are not exceeded.

7.2 Exhaust gas flow

The exhaust gas flow shall be determined by one of the methods mentioned in 7.2.1 to 7.2.4.

7.2.1 Direct measurement method

Direct measurement of the exhaust flow is by flow nozzle or equivalent metering system. (Details are given in ISO 5167-1.)

NOTE 6 Direct exhaust gas flow measurement is a difficult task. Precautions must be taken to avoid measurement errors which may lead to emission value errors.

7.2.2 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow.

Air flowmeters and fuel flowmeters with an accuracy as defined in 7.3 shall be used.

The calculation of the exhaust gas flow is as follows:

$$G_{\text{EXHW}} = G_{\text{AIRW}} + G_{\text{FUEL}} \text{ (for wet exhaust mass)} \quad \dots(4)$$

or

$$V_{\text{EXHD}} = V_{\text{AIRD}} + F_{\text{FD}} \times G_{\text{FUEL}} \text{ (for dry exhaust volume)} \quad \dots(5)$$

or

$$V_{\text{EXHW}} = V_{\text{AIRW}} + F_{\text{FW}} \times G_{\text{FUEL}} \text{ (for wet exhaust volume)} \quad \dots(6)$$

Values F_{FD} and F_{FW} vary with the fuel type (see Annex A and ISO 8178-5).

7.2.3 Carbon balance method

This involves exhaust mass calculation from fuel consumption and exhaust gas concentrations using the carbon and oxygen balance method (see Annex A).

7.2.4 Total dilute exhaust gas flow

When using a full flow dilution system, the total flow of the exhaust (G_{TOTW} , V_{TOTW}) shall be measured with a PDP or CFV (see 16.1.2). The accuracy shall conform to the provisions of 9.2.

7.3 Accuracy

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

Table 2 — Permissible deviations of instruments for engine related parameters

No.	Item	Permissible deviation		Calibration intervals months
		based on engine's maximum values	based on engine's maximum values ^a	
1	Engine speed	± 2 %	± 2 %	3
2	Torque	± 2 %	± 2 %	3
3	Power	± 2 % ^b	± 3 %	not applicable
4	Fuel consumption	± 2 % ^b	± 3 %	6
5	Specific fuel consumption	not applicable	± 3 %	not applicable
6	Air consumption	± 2 % ^b	± 5 %	6
7	Exhaust gas flow	± 4 % ^b	not applicable	6

^a According to ISO 3046-3.

^b 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 3046-3.

Table 3 — Permissible deviations of instruments for other essential parameters

No.	Item	Permissible deviation		Calibration intervals months
		absolute	^a	
1	Coolant temperature	± 2 K	± 2 K	3
2	Lubricating oil temperature	± 2 K	± 2 K	3
3	Exhaust gas pressure	± 5 % of max.	± 5 %	3
4	Inlet manifold depressions	± 5 % of max.	± 5 %	3
5	Exhaust gas temperature	± 15 K	± 15 K	3
6	Air inlet temperature (combustion)	± 2 K	± 2 K	3
7	Atmospheric pressure	± 0,5 % of reading	± 0,5 %	3
8	Intake air humidity (relative)	± 3 %	not applicable	1
9	Fuel temperature	± 2 K	± 5 K	3
10	Dilution tunnel temperatures	± 1,5 K	not applicable	3
11	Dilution air humidity (relative)	± 3 %	not applicable	1
12	Diluted exhaust gas flow	± 2 % of reading	not applicable	24 (partial flow) (full flow) ^b

^a According to ISO 3046-3.

^b Full flow systems: the CVS positive displacement pump or CFV shall be calibrated following initial installation, major maintenance or as necessary when indicated by the CVS system verification described in 11.4.

7.4 Determination of the gaseous components

7.4.1 General analyser specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (7.4.1.1). It is recommended that the analysers be operated such that the measured concentration falls between 15 % and 100 % of full scale.

If the full scale value is 115 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 (8.5.6.2).

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

7.4.1.1 Measurement error

The total measurement error, including the cross sensitivity to other gases (see 8.9), shall not exceed ± 5 % of the reading or $\pm 3,5$ % of full scale, whichever is smaller. For concentrations of less than 100 ppm the measurement error shall not exceed ± 4 ppm.

7.4.1.2 Repeatability

The repeatability, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, must be no greater than ± 1 % of full scale concentration for each range used above 155 ppm (or ppmC) or ± 2 % of each range used below 155 ppm (or ppmC).

7.4.1.3 Noise

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

7.4.1.4 Zero drift

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

7.4.1.5 Span drift

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

7.4.2 Gas drying

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

7.4.3 Analysers

7.4.3.1 to 7.4.3.11 describe the measurement principles to be used. A detailed description of the measurement systems is given in clause 15. The gases to be measured shall be analysed using the instruments given below. For non-linear analysers, the use of linearizing circuits is permitted.

7.4.3.1 Carbon monoxide (CO) analysis

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

7.4.3.2 Carbon dioxide (CO₂) analysis

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

7.4.3.3 Oxygen (O₂) analysis

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

NOTE 7 Zirconium dioxide sensors are not recommended when HC and CO concentrations are high such as for lean burn ignited engines. Electrochemical sensors shall be compensated for CO₂ and NO_x interference.

7.4.3.4 Hydrocarbon (HC) analysis

The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ °C} \pm 10\text{ °C}$). For methanol fueled engines the temperature requirements of 7.4.3.11.2 apply.

7.4.3.5 Non-methane hydrocarbon (NMHC) analysis

Depending on the methane (CH_4) concentration this method is more relevant for gaseous than for liquid fuels.

7.4.3.5.1 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 7.4.3.4.

7.4.3.5.2 Non-methane cutter (NMC) method

The determination of the non-methane fraction shall be performed with a heated NMC operated in line with a heated HFID as per 7.4.3.4. The calculation formulae are given in Annex C.

7.4.3.6 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 a NO_2/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 333 K (60 °C) shall be used, provided the water quench check (see 8.9.2.2) is satisfied.

7.4.3.7 Sulfur dioxide (SO_2) analysis

The SO_2 concentration shall be calculated from the sulfur content of the fuel used, since experience has shown that using the direct measurement method for SO_2 does not give more precise results.

NOTE 8 The application of the calculation method for SO_2 is limited to engines without aftertreatment systems. In this case SO_2 may be measured in accordance with the instrument supplier's instructions. Since SO_2 measurement is a difficult task and has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.4.3.8 Ammonia (NH_3) analysis

Ammonia shall be determined with a CLD, as described in 7.4.3.6, by using two different converters. For the total amount of NO_x and NH_3 , 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, a FTIR (fourier transform 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. The response time of this method is considerably shorter than with the double converter method.

7.4.3.9 Dinitrogen oxide (N_2O) analysis

A 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.

7.4.3.10 Formaldehyde (HCHO) analysis

Formaldehyde shall be determined by passing an exhaust sample 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 .

7.4.3.11 Methanol (CH_3OH) analysis

A 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.

7.4.3.11.1 Gas chromatographic (GC) method

Methanol shall be determined by passing an exhaust sample through an impinger containing deionized

water. The sample shall be analysed by a GC with FID.

7.4.3.11.2 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 must be determined at several concentrations in the range of concentrations in the sample, according to 8.8.4.

7.4.4 Sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or 3 times the diameter of the exhaust pipe — whichever is the larger — upstream of the exit of the exhaust gas system, as far as is applicable, and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a “V” engine con-figuration, 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 determination of the particulates, the gaseous emissions in the diluted exhaust gas may also be determined. The sampling probes shall be close to the particulate sampling probe in the dilution tunnel (16.1.2, Figure 19, DT and PSP). CO and CO₂ may also be determined by sampling into a bag with subsequent measurement of the concentration in the sampling bag.

7.5 Particulate determination

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

For a partial flow dilution system, the particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in 7.4.4 and in accordance with 16.1.1, Figure 10 to Figure 18, exhaust pipe and sampling probe (EP and SP).

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. From that it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (see 16.1.1).

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

For particulate sampling, two methods may be applied.

The multiple filter method dictates that one pair of filters (see 7.5.1.3) 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 7.5.1.3) for all modes of the 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.

7.5.1 Particulate sampling filters

7.5.1.1 Filter specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required for certification tests. For special applications different filter materials may be used. All filter types shall have a 0,3 µm DOP (dioctyl phthalate) collection efficiency of at least 95 % at a gas face velocity between 35 cm/s and 80 cm/s. When performing correlation tests between laboratories or between a manufacturer and a regulatory agency, filters of identical quality shall be used.

7.5.1.2 Filter size

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter). Larger filters are acceptable (see 7.5.1.5).

7.5.1.3 Primary and back-up filters

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

7.5.1.4 Filter face velocity

A gas face velocity through the filter of 35 cm/s to 80 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.

7.5.1.5 Filter loading

The recommended minimum filter loading shall be 465 µg/mm² (0,5 mg/1 075 mm²) stain area for the single filter method. For the most common filter sizes the values are given in Table 4.

For the multiple filter method, the recommended minimum filter loading for the sum of all filters is the product of the appropriate value in Table 4 and the square root of the total number of modes.

Table 4 — Recommended minimum filter loading

Filter diameter mm	Recommended stain diameter mm	Recommended minimum loading mg
47	37	0,5
70	60	1,3
90	80	2,3
110	100	3,6

7.5.2 Weighing chamber and analytical balance specifications

7.5.2.1 Weighing chamber conditions

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

7.5.2.2 Reference filter weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilization. Disturbances to weighing room specifications as outlined in 7.5.2.1 will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to entry of personnel into the weighing room. At least two unused reference filters or reference filter pairs shall be weighed within 4 hours of, but preferably at the same time as the sample filter (pair) weighings. They shall be of 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 $\pm 5\%$ ($\pm 7,5\%$ for the filter pair) of the recommended minimum filter loading (see 7.5.1.5), then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in 7.5.2.1 are not met, but the reference filter (or pair) weighings meet the above criteria, the engine manufacturer has the option of accepting the sample filter masses or, if not, voiding the tests, fixing the weighing room control system and rerunning the test.

7.5.2.3 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 diameter, the precision and resolution shall be $2\text{ }\mu\text{g}$ and $1\text{ }\mu\text{g}$, respectively.

7.5.2.4 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.

7.5.3 Additional specifications for particulate measurement

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

8 Calibration of the analytical instruments

8.1 Introduction

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 7.4.3.

8.2 Calibration gases

The shelf life of all calibration gases shall be respected.

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

8.2.1 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 $\leq 1\text{ ppmC}$, $\leq 1\text{ ppmCO}$, $\leq 400\text{ ppmCO}_2$, $\leq 0,1\text{ ppmNO}$)

Purified oxygen: (purity $> 99,5\%$ vol. O_2)

Hydrogen-helium mixture: ($40\% \pm 2\%$ hydrogen, balance helium)
(contamination $\leq 1\text{ ppmC}$, $\leq 400\text{ ppmCO}$)

Purified synthetic air: (contamination $\leq 1\text{ ppmC}$, $\leq 1\text{ ppmCO}$, $\leq 400\text{ ppmCO}_2$, $\leq 0,1\text{ ppmNO}$
(oxygen content $18\% - 21\%$ vol.)

8.2.2 Calibration and span gases

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

C_3H_8 and purified synthetic air (see 8.2.1);

CO and purified nitrogen;

NO_x and purified nitrogen the amount of NO_2 contained in this calibration gas must not exceed 5% of the NO content);

O ₂	and purified nitrogen;
CO ₂	and purified nitrogen;
CH ₄	and purified synthetic air;
C ₂ H ₆	and purified synthetic air.

NOTE 9 Other gas combinations are allowed provided the gases do not react with one another.

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

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N₂ or with purified synthetic air. The accuracy of the mixing device must be such that the concentration of the diluted calibration gases may be determined to within $\pm 2\%$.

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 8.7 and 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. Disconnect the probe from the exhaust system and plug the end. Switch on analyser pump. After an initial stabilization period all flow meters should read zero. If not, check the sampling lines and correct the fault.

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 calibration 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 shall be according to the recommendations of the manufacturer. If not specified, a minimum of two hours 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 (8.8.1).

8.5.4 GC and HPLC

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

8.5.5 Calibration

Calibrate each normally used operating range.

Using purified synthetic air (or nitrogen), set the CO, CO₂, NO_x, HC and O₂ analysers at zero.

Introduce the appropriate calibration gases into the analysers, record the values and establish the calibration curve according to 8.5.6.

Recheck the zero setting and repeat the calibration procedure, if necessary.

8.5.6 Establishment of the calibration curve

8.5.6.1 General guidelines

The analyser calibration curve is established by at least five calibration points (excluding zero) spaced as uniformly as possible. 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. If the resulting polynomial degree is greater than 3, the number of calibration points (zero included) shall be at least equal to this polynomial degree plus 2.

The calibration curve must not differ by more than $\pm 2\%$ from the nominal value of each calibration point and by more than $\pm 1\%$ of full scale zero.

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

- the measuring range;
- the sensitivity;
- the date on which the calibration was carried out.

8.5.6.2 Calibration below 15 % of full scale

The analyser calibration curve shall be established by at least 10 calibration points (excluding zero) spaced so that 50 % of the calibration points are below 10 % of full scale.

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

The calibration curve must not differ by more than $\pm 4\%$ from the nominal value of each calibration point and by more than $\pm 1\%$ of full scale at zero.

8.5.6.3 Alternative methods

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

8.6 Verification of the calibration

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

Check the calibration 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 $\pm 4\%$ of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with 8.5.5.

8.7 Efficiency test of the NO_x converter

The efficiency of the converter used for the conversion of NO₂ into NO is tested as given in 8.7.1 to 8.7.8 (see Figure 1).

8.7.1 Test setup

Using the test set-up as shown in Figure 1 (see also 7.4.3.6) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

8.7.2 Calibrator

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 the span gas shall 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 analyser shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration shall be recorded.

8.7.3 Calculation

The efficiency of the NO_x converter is calculated as follows:

$$\text{Efficiency (\%)} = \left(1 + \frac{a-b}{c-d} \right) \times 100 \quad \dots(7)$$

where

- a* is the NO_x concentration according to 8.7.6;
- b* is the NO_x concentration according to 8.7.7;
- c* is the NO concentration according to 8.7.4;
- d* is the NO concentration according to 8.7.5.

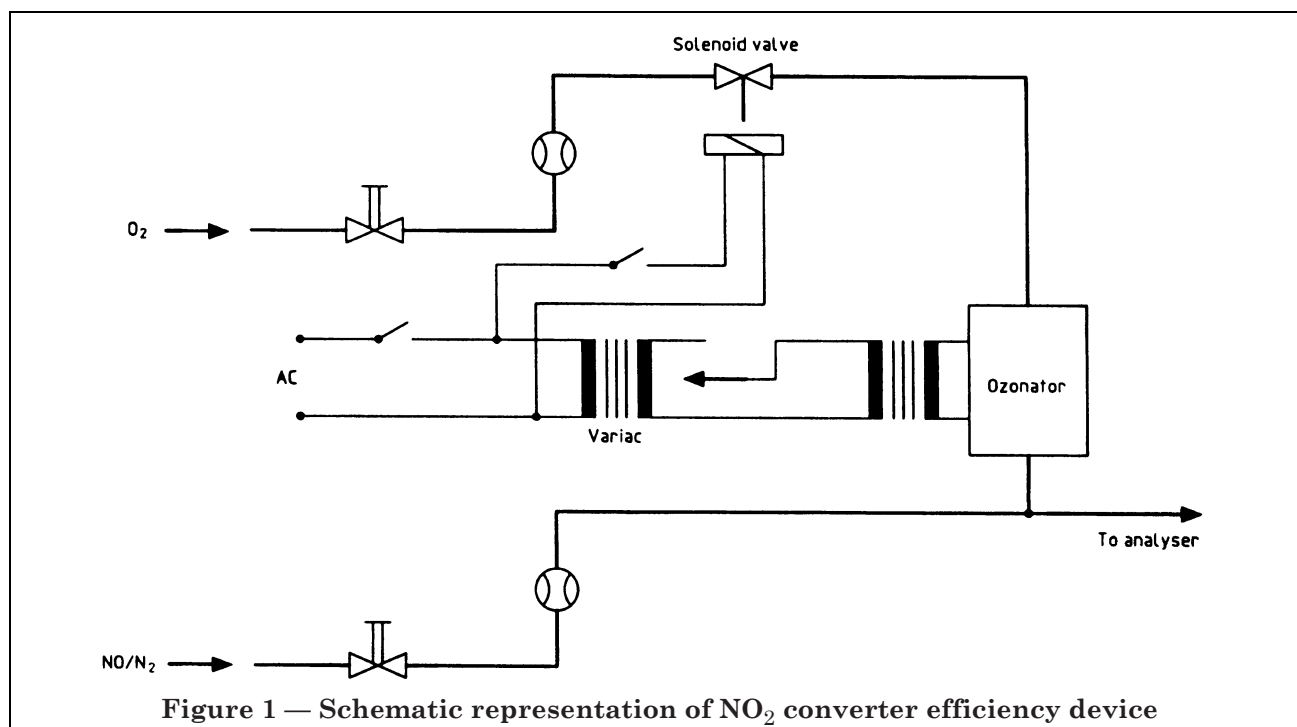


Figure 1 — Schematic representation of NO₂ converter efficiency device

8.7.4 Adding of oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 % less than the indicated calibration concentration given in 8.7.2. (The analyser is in the NO mode.)

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

8.7.5 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 8.7.2. The indicated concentration (d) shall be recorded. (The analyser is in the NO mode.)

8.7.6 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.)

8.7.7 Deactivation of the ozonator

The ozonator is now deactivated. The mixture of gases described in 8.7.6 passes through the converter into the detector. The indicated concentration (b) shall be recorded. (The analyser is in the NO_x mode.)

8.7.8 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 8.7.2. (The analyser is in the NO mode.)

8.7.9 Test interval

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

8.7.10 Efficiency requirement

The efficiency of the converter shall not be less than 90 %, but an efficiency higher than 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 8.7.2, 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 $350 \text{ ppmC} \pm 75 \text{ ppmC}$ span gas shall be introduced into 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.

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_f) 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 sufficient to give a response of approximately 80 % of full scale. The concentration must be known to an accuracy of $\pm 2 \%$ in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 hours 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	$1 \leq R_f \leq 1,15$
Propylene and purified synthetic air	$0,94 \leq R_f \leq 1,1$
Toluene and purified synthetic air	$0,94 \leq R_f \leq 1,1$

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

8.8.3 Oxygen interference check

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

The response factor is defined and shall be determined as described in 8.8.2. The test gas to be used and the recommended relative response factor range are as follows:

Propane and nitrogen	$0,95 \leq R_f \leq 1,05$
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This value is relative to a R_f of 1 for propane and purified synthetic air.

The oxygen concentration of the FID burner air shall be within ± 1 mole % of the oxygen concentration of the burner air used in the latest oxygen interference check. If the difference is greater, the oxygen interference shall be checked and, if necessary, the analyser adjusted.

8.8.4 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 ($122 \text{ }^\circ\text{C}$)] of a septum injector. It is then vaporized 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:

$$R_{\text{FM}} = \text{FID} / \text{SAM} \quad \dots(8)$$

where

R_{FM}	is the FID response factor for methanol;
FID	is the FID reading in ppmC;
SAM	is the methanol concentration in the sample bag in ppmC, as calculated from a and b : $\text{SAM} = 594 \times a/b$

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

Other than the one being analysed, gases present in the exhaust can interfere with the reading in several ways. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives rise to the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments due to the interfering gas broadening the absorption band of the measured gas, and in CLD instruments due to the interfering gas quenching the radiation. The interference checks in 8.9.1 and 8.9.2 shall be performed prior to an analyser's initial use and after major service intervals.

8.9.1 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.

8.9.2 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.

8.9.2.1 CO₂ quench check

Pass a CO₂ span gas having a concentration of 80 % to 100 % of full scale of the maximum operating range through the NDIR analyser and record the CO₂ value as *A*. Then dilute it approximately 50 % with NO span gas and pass through the NDIR and (H)CLD, with the CO₂ and NO values recorded as *B* and *C*, respectively. Shut off the CO₂ and pass only the NO span gas through the (H)CLD with the NO value recorded as *D*.

The quench, which shall not be greater than 3 % full scale, shall be calculated as follows:

$$\% \text{ quench} = \left[1 - \left(\frac{(C \times A)}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad \dots(9)$$

where

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

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

8.9.2.2 Water quench check

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

For a NO span gas having a concentration of 80 % to 100 %, pass 0 % of full scale of the normal operating range through the (H)CLD and record the NO value as *D*. Then bubble the NO span gas through water at room temperature and pass through the (H)CLD and record the NO value as *C*. Determine the analyser's absolute operating pressure and the water temperature and record as *E* and *F*, respectively. Determine the mixture's saturation vapour pressure that corresponds to the bubbler water temperature (*F*) and record as *G*. Calculate the water vapour concentration (*H*, in %) of the mixture as follows:

$$H = 100 \times (G/E) \quad \dots(10)$$

Calculate the expected diluted NO span gas (in water vapour) concentration (*D_e*) as follows:

$$D_e = D \times (1 - H/100) \quad \dots(11)$$

For diesel exhaust, the maximum exhaust water concentration (H_m , in %) expected during testing shall be estimated, under the assumption of a fuel atom H : C ratio of 1,8 : 1, from the undiluted CO₂ span gas concentration (A, as measured in 8.9.2.1) as follows:

$$H_m = 0,9 \times A \quad \dots(12)$$

Record the D_e and H_m .

The water quench, which shall not be greater than 3 %, shall be calculated as follows:

$$\% \text{ quench} = 100 \times [(D_e - C)/D_e] \times (H_m/H) \quad \dots(13)$$

where

D_e is the expected diluted NO concentration in ppm;

C is the diluted NO concentration in ppm;

H_m is the maximum water vapour concentration in %;

H is the actual water vapour concentration in %.

NOTE 10 It is important that the NO span gas contain minimal NO₂ concentration for this check, since absorption of NO₂ in water has not been accounted for in the quench calculations.

8.9.3 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 5.

Table 5 — 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:

$$\text{Interference} = (\text{Equivalent \% O}_2 \times \text{Obs. conc.}) / 100 \quad \dots(14)$$

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

8.10 Calibration intervals

The analysers shall be calibrated to 8.5 at least every 3 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 fulfill the accuracy requirements of this part of ISO 8178. The calibration method to be used is described below for the components indicated in 7.5 and clause 16.

9.2 Flow measurement

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