

BS EN ISO 18854:2015



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Small craft — Reciprocating internal combustion engines exhaust emission measurement — Test-bed measurement of gaseous and particulate exhaust emissions

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee GME/33, Small craft.

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

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English Version

**Small craft - Reciprocating internal combustion engines exhaust
emission measurement - Test-bed measurement of gaseous and
particulate exhaust emissions (ISO 18854:2015)**

Petits navires - Moteurs alternatifs à combustion interne
mesurage des émissions de gaz d'échappement -
Mesurage des émissions de gaz et de particules au banc
(ISO 18854:2015)

Kleine Wasserfahrzeuge - Messung der Emission von
Hubkolben-Verbrennungsmotoren - Prüfstandsmessung der
gasförmigen Emission und der Partikelemission (ISO
18854:2015)

This European Standard was approved by CEN on 19 March 2015.

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Foreword

This document (EN ISO 18854:2015) has been prepared by Technical Committee ISO/TC 188 "Small craft".

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of an identical text or by endorsement, at the latest by October 2015, and conflicting national standards shall be withdrawn at the latest by October 2015.

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

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The text of ISO 18854:2015 has been approved by CEN as EN ISO 18854:2015 without any modification.

Annex ZA
(informative)
Relationship between this European Standard and the Essential Requirements of EU Directive 2013/53/EC

This European standard has been prepared under a mandate given to CEN by the European Commission to provide one means of conforming to Essential Requirements of the New Approach Directive 2013/53/EC.

Once this standard is cited in the Official Journal of the European Communities under that Directive and has been implemented as a national standard in at least one member state, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

Table ZA.1: Correspondence between this European Standard and Directive 2013/53/EC

Clauses/sub-clauses of this standard	Corresponding annexes/paragraphs of Directive 2013/53/EC	Comments
All Clauses of this Standard	Annex 1.B. 2. Exhaust emission requirements	In respect of measurement and evaluation methods for gaseous and particulate emissions
Clause 6	Annex 1.B. 2. Reference fuels	Fuels to be used for the emissions test for engines fuelled with petrol and diesel

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 188, *Small craft, SC 2, Engines and propulsion systems*.

Introduction

This International Standard is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of reciprocating internal combustion (RIC) engines for marine use in small craft. 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 International Standard is designed for marine 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 process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis (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.

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 [Figure 19](#)).

Many of the procedures described in this International Standard 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.

Small craft — Reciprocating internal combustion engines exhaust emission measurement — Test-bed measurement of gaseous and particulate exhaust emissions

1 Scope

This International Standard 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.

This International Standard is applicable to RIC marine engines intended to be installed in small craft up to 24 m length of hull.

2 Normative references

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

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

ISO 5725-2, *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 8178-1:2006, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

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

ISO 8666, *Small craft — Principal data*

ISO 14396, *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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8666 and the following apply.

3.1

particulates

material collected on a specified filter medium after diluting exhaust gases with clean, filtered air to a temperature 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 to entry: Particulates consist primarily of carbon, condensed hydrocarbons, and sulfates and associated water.

Note 2 to entry: Particulates defined in this International Standard are substantially different in composition and weight from particulates or dust sampled directly from the undiluted exhaust gas using a hot filter method. Particulates measurement as described in this International Standard is conclusively proven to be effective for fuel sulfur levels up to 0,8 %.

[SOURCE: ISO 8178-1:2006, 3.1, without Note 3 to entry]

3.2 partial-flow dilution system

system using a 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 1 to entry: See [18.2.1](#), [Figures 10](#) to [18](#).

3.3 full-flow dilution system

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

Note 1 to entry: 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 [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

[SOURCE: ISO 8178-1:2006, 3.4]

3.5 multiple-filter method

process of using one filter for each of the individual test cycle modes

Note 1 to entry: The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

[SOURCE: ISO 8178-1:2006, 3.6]

3.6 single-filter method

process of using one filter for all test cycle modes

Note 1 to entry: 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.

[SOURCE: ISO 8178-1:2006, 3.7]

3.7 specific emissions

mass emissions expressed in grams per kilowatt-hour

[SOURCE: ISO 8178-1:2006, 3.8—modified]

3.8 span gas

purified gas mixture used to span gas analyzers

Note 1 to entry: Calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analyzers and sample handling components might refer to either calibration gases or span gases.

3.9**zero gas**

gas that yields a zero response in an analyzer

Note 1 to entry: This may either be purified nitrogen, purified air, or a combination of purified air and purified nitrogen.

3.10**calibration**

process of setting a measurement system's response so that its output agrees with a range of reference signals

3.11**verification**

means to evaluate whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance

4 Symbols and abbreviations**4.1 General symbols**

Symbol	Term	Unit
A/F_{st}	Stoichiometric air-to-fuel ratio	—
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	—
E_{CO2}	CO ₂ quench of NO _x analyser	%
E_E	Ethane efficiency	%
E_{H2O}	Water quench of NO _x analyser	%
E_M	Methane efficiency	%
E_{NOx}	Efficiency of NO _x converter	%
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] * $[A/F_{st}]$))	—
λ_{Ref}	Excess air factor at reference conditions	—
f_a	Laboratory atmospheric factor	—
f_c	Carbon factor	—
f_{fd}	Fuel specific factor for exhaust flow calculation on dry basis	—
f_{fh}	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	—
f_{fw}	Fuel specific factor for exhaust flow calculation on wet basis	—
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

Symbol	Term	Unit
i	Subscript denoting an individual mode	—
k_f	Fuel specific factor for the carbon balance calculation	—
k_{hd}	Humidity correction factor for NO _x for diesel engines	—
k_{hp}	Humidity correction factor for NO _x for gasoline (petrol) engines	—
k_p	Humidity correction factor for particulates	—
k_{wa}	Dry to wet correction factor for the intake air	—
k_{wd}	Dry to wet correction factor for the dilution air	—
k_{we}	Dry to wet correction factor for the diluted exhaust gas	—
k_{wr}	Dry to wet correction factor for the raw exhaust gas	—
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
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 13.5)	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	—
r_a	Ratio of cross-sectional areas of isokinetic probe and exhaust pipe	—
R_a	Relative humidity of the intake air	%
R_d	Relative humidity of the dilution air	%
r_h	FID response factor	—
r_m	FID response factor for methanol	—
r_x	Ratio of the SSV throat to inlet absolute, static pressure	—

Symbol	Term	Unit
r_y	Ratio of the SSV throat diameter, d , to the inlet pipe inner diameter	—
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	—
W_{fe}	Effective weighting factor	—

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 ISO 8178-1:2006, Formulae A.3 to A.12.

4.3 Symbols and abbreviations for the chemical components

ACN acetonitrile

C1 carbon 1 equivalent hydrocarbon

CH₄ methane

C₂H₆ ethane

C₃H₈ propane

CH₃OH methanol

CO carbon monoxide

CO₂ 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	sulfur dioxide
SO ₃	sulfur trioxide

4.4 Abbreviations

CFV	critical flow venturi
CLD	chemiluminescent detector
CVS	constant volume sample
EP	exhaust pipe
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
RH	relative humidity
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:

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

Tests should preferably 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.

5.3 Power

The basis of specific emissions measurement is uncorrected, 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 (brake power) as defined in ISO 14396. The engine shall be submitted with auxiliaries needed for operating the engine. If it is impossible or inappropriate to install the auxiliaries on the test bench, the power absorbed by them shall be determined and subtracted from the measured engine power.

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

- power steering;
- air conditioning compressor;
- pumps for hydraulic systems.

For further details, see 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 [13.5](#), 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 80 % to 100 % 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 [8.5.4](#), [18.2.1](#), and [18.2.2](#).

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 craft 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

Adjustable carburettors shall be set at the manufacturer's recommendation.

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 shall be determined, recorded, and presented with the results of the test. For reference fuels designated in ISO 8178-5, the reference code and the analysis of the fuel shall be provided. The reference fuels in ISO 8178-5 or equivalent fuels apply.

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. Fuel temperature measurement shall be optional in case of use of a mass flow meter.

7 Application of the engine family concept and choice of parent engine

The engine manufacturer is responsible for defining those engines from his range which are to be included in a family. In order that engines be considered to belong to the same engine family, the following list of basic characteristics (but not specification) must be common:

- combustion cycle;
- cooling medium;
- individual cylinder displacement: engines to be within a total spread of 15 %;
- number of cylinders and cylinder configuration (applicable to spark ignition engines only);
- method of aspiration;
- fuel type;
- combustion chamber type;
- valve and porting (configuration, size and number);
- fuel system type;
- other features such as exhaust gas recirculation, air injection, exhaust after treatment, dual fuel, etc.

A parent engine shall be selected from an engine family in such a way that its emissions characteristics are representative for all engines in that engine family. The engine incorporating those features that are expected to result in the highest specific emissions (expressed in grams per kilowatt hour), when measured on the applicable test cycle, shall be selected as the parent engine of the family.

8 Measurement equipment and data to be measured

8.1 General

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in [Clauses 17](#) and [18](#). These clauses describe the recommended analytical systems for the gaseous emissions ([Clause 17](#)) and the recommended particulate dilution and sampling systems ([Clause 18](#)).

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 in this International Standard. "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 shall be run concurrently. The test cycle to be used shall be the appropriate cycle. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics (see ISO 8178-1:2006, Annex D), with outliers excluded, and 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 the introduction of a new system into the document, 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 International Standard 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 [8.4](#).

8.2 Dynamometer specification

An engine dynamometer with adequate characteristics to perform the appropriate test cycle 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 [8.4](#) are not exceeded.

8.3 Exhaust gas flow

8.3.1 General

The exhaust gas flow shall be determined by one of the methods given in [8.3.2](#) to [8.3.6](#).

8.3.2 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 series);
- 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 [8.4](#).

8.3.3 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 8.4 shall be used. The calculation of the exhaust gas flow is as follows:

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

8.3.4 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 ISO 8178-1:2006, A.3.2.3.1):

$$q_{mew} = q_{mf} \times \left(\frac{\left(\frac{w_{BET} \times w_{BET} \times 1,4}{f_c} + w_{ALF} \times 0,08936 - 1 \right) \times \frac{1}{1,293} + f_{fd}}{f_c \times f_c} + w_{ALF} \times 0,08936 - 1 \right) \times \left(1 + \frac{H_a}{1\,000} \right) + 1 \quad (6)$$

where

f_{fd} is according to ISO 8178-1:2006, Formulae A.20 to A.23;

H_a is the g water per kg dry air;

f_c is according to ISO 8178-1:2006, Formula A.64:

$$f_c = (c_{CO2d} - c_{CO2ad}) \times 0,5441 + \frac{c_{COd}}{18\,522} + \frac{c_{HCw}}{17\,355} \quad (7)$$

where

c_{CO2d} is the dry CO₂ concentration in the raw exhaust [%];

c_{CO2ad} is the dry CO₂ 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 ISO 8178-1:2006, A.3.3.

8.3.5 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 [cm³/min];
- c_{mix} is the concentration of the tracer gas after mixing [ppm];
- ρ_{ew} is the density of the exhaust gas [kg/m³];
- 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 [9.6](#).

8.3.6 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), Formulae (10) and (11) cannot be used.

The air flowmeter shall meet the accuracy specifications of [8.4](#), the CO_2 analyser used shall meet the specifications of [8.5.3.3](#), 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 [8.5.3.13](#) may be used for the measurement of the excess air ratio.

8.3.7 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 [18.2.2](#)). The accuracy shall conform to the provisions of [10.2](#).

8.4 Accuracy

The calibration of all measuring instruments shall be traceable to national or international standards and comply with the requirements given in [Tables 1](#) and [2](#).

NOTE Calibration requirements for analysers are given in [9.5](#).

The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer. The deviations given in [Tables 1](#) and [2](#) refer to the final recorded value, which includes the data acquisition system.

Table 1 — Permissible deviations of instruments for engine-related parameters

No.	Measurement instrument	Permissible deviation
1	Engine speed	± 2 % of reading or ± 1 % of engine's max. value, whichever is larger
2	Torque	± 2 % of reading or ± 1 % of engine's max. value, whichever is larger
3	Fuel consumption ^a	± 2 % of engine's max. value

^a The calculations of the exhaust emissions as described in this International Standard 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, shall be smaller than the allowed tolerances given in ISO 15550:2002, Table 4.

Table 1 (continued)

No.	Measurement instrument	Permissible deviation
4	Air consumption ^a	±2 % of reading or ±1 % of engine's max. value, whichever is larger
5	Exhaust gas flow ^a	±2,5 % of reading or ±1,5 % of engine max. value, whichever is larger
^a The calculations of the exhaust emissions as described in this International Standard 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, shall be smaller than the allowed tolerances given in ISO 15550:2002, Table 4.		

Table 2 — Permissible deviations of instruments for other essential parameters

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

8.5 Determination of the gaseous components

8.5.1 General analyser specifications

8.5.1.1 General specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (see [8.5.1.2](#)). The analysers shall 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.

8.5.1.2 Accuracy

The analyser shall not deviate from the nominal calibration point by more than ±2 % of the reading over the whole measurement range (except zero) or ±0,3 % of full scale, whichever is larger. The accuracy shall be determined according to the calibration requirements laid down in [9.5.5](#).

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

8.5.1.3 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 ± 1 % of full-scale concentration for each range used above 100 ppm (or ppmC) or ± 2 % of full-scale concentration for each range used below 100 ppm (or ppmC).

8.5.1.4 Noise

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

8.5.1.5 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.

8.5.1.6 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.

8.5.2 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.

8.5.3 Analysers

8.5.3.1 General

The measurement principles to be used are defined in [8.5.3.2](#) to [8.5.3.12](#). 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 nonlinear analysers, the use of linearizing circuits is permitted.

8.5.3.2 Carbon monoxide (CO) analysis

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

8.5.3.3 Carbon dioxide (CO₂) analysis

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

8.5.3.4 Oxygen (O₂) analysis

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

Zirconium dioxide sensors shall 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.

8.5.3.5 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 $463 \text{ K} \pm 10 \text{ K}$ ($190 \text{ }^{\circ}\text{C} \pm 10 \text{ }^{\circ}\text{C}$). For methanol-fuelled engines, the temperature requirements of [8.5.3.12.3](#) 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.

8.5.3.6 Non-methane hydrocarbon (NMHC) analysis

8.5.3.6.1 General

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

8.5.3.6.2 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 [8.5.3.5](#).

8.5.3.6.3 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 [8.5.3.5](#) by subtraction of the methane from the hydrocarbons.

8.5.3.7 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 NO_2/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 is satisfied (see [9.9.3.2](#)). 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.

8.5.3.8 Sulfur dioxide (SO_2) analysis

The SO_2 emission 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:

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

NOTE The application of the calculation method for SO_2 assumes a 100 % sulfur conversion and is limited to engines without aftertreatment systems. In this case, SO_2 may be measured in accordance with the instructions of the instrument suppliers. 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.

8.5.3.9 Ammonia (NH_3) analysis

Ammonia shall be determined with a CLD, as described in [8.5.3.7](#), 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 Fourier transform infrared (FTIR) analyser or non-dispersive ultraviolet resonance (NDUVR) 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.

8.5.3.10 Dinitrogen oxide (N₂O) analysis

An FTIR analyser or a non-dispersive infrared (NDIR) 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.

8.5.3.11 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.

8.5.3.12 Methanol (CH₃OH) analysis

8.5.3.12.1 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.

8.5.3.12.2 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.

8.5.3.12.3 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 [9.8.5](#).

8.5.3.13 Air-to-fuel measurement

The air-to-fuel measurement equipment used to determine the exhaust gas flow as specified in [8.3.6](#) 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 $\lambda \leq 2$
- $\pm 5\%$ of reading for $2 < \lambda \leq 5$
- $\pm 10\%$ of reading for $\lambda > 5$

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

8.5.4 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 shall 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 shall be roughly equal dimensions in height, width, and depth. The mixing chamber size shall be kept as small as practicable and shall be coupled as close as possible to the engine. The exhaust line leaving the mixing chamber shall 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 [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.

8.6 Particulate determination

8.6.1 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 at or below 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.

For a partial-flow dilution system, the particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in [8.5.4](#) and in accordance with [18.2.1](#), [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 [18.2.1](#)).

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 8.6.2.3) 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 8.6.2.3) 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.

8.6.2 Particulate sampling filters

8.6.2.1 Filter specification

Fluorocarbon coated glass-fibre filters or fluorocarbon membrane filters are required. All filter types shall have a 0,3 µm DOP (dioctyl phthalate) 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.

8.6.2.2 Filter size

Particulate filters shall have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (see 8.6.2.5).

8.6.2.3 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 8.6.2.1), 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.

8.6.2.4 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.

8.6.2.5 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 3.

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 3 — Minimum filter loading

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