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Reciprocating internal combustion engines — Exhaust emission measurement —

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

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

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Contents

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Annexes

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.

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

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

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

- *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*
- *Part 2: Measurement of gaseous and particulate exhaust emissions at site*
- *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*
- *Part 4: Test cycles for different engine applications*
- *Part 5: Test fuels*
- *Part 6: Test report*
- *Part 7: Engine family determination*
- *Part 8: Engine group determination*
- *Part 9: Test bed measurement of exhaust gas smoke emissions from engines used in non-road mobile machinery*

Annexes A, B, C and D form an integral part of this part of ISO 8178. Annexes E and F are for information only.

Reciprocating internal combustion engines — Exhaust emission measurement —

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

1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust 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 polluant. 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.*

1) To be published.

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, figures 10 to 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.

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

Symbols: According to EEC regulations	Symbols: SI[1]	Term	Unit
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
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[2]	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

Symbols According to EEC regulations	Symbols SI[1)]	Term	Unit
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[3)]	kPa
p_B	p_b	Total barometric pressure[4)]	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	%
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

Symbols According to EEC regulations	SI 1)	Term	Unit
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

1) According to ISO 31 on Quantities and units.

2) 10,71 g/kg; for calculation of NO_x and particulate humidity correction factors.

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

4) 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_2H_6	Ethane
C_3H_8	Propane
CH_3OH	Methanol
CO	Carbon monoxide
CO_2	Carbon dioxide
DNPH	Dinitrophenyl hydrazine
DOP	Dioctyl phthalate
HC	Hydrocarbons
HCHO	Formaldehyde
H_2O	Water
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
N_2O	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:

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

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

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

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:

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

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

$$0{,}98 \leqslant f_a \leqslant 1{,}02 \quad \ldots (3)$$

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 ± 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 ± 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 2. Manufacturer or supplier	Reference fuel, if one is defined Commercial fuel if no reference fuel is defined
Acceptance test	1. Manufacturer or supplier 2. Customer or inspector	Commercial fuel as specified by the manufacturer[1)]
Research/development	One or more of: manufacturer, research organization, fuel and lubricant supplier, etc.	To suit the purpose of the test

1) 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 ± 5 % agreement of the sample pair average with outliers excluded from the database as described in ISO 5725-2 obtained under the laboratory