INTERNATIONAL STANDARD

ISO 8178-1

Second edition
2006-09-15

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

Reference number
ISO 8178-1:2006(E)

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

Published in Switzerland

Contents

Page

Foreword

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

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

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

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

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

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

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

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

Introduction

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

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

Many of the procedures described in this part of ISO 8178 are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

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

Reciprocating internal combustion engines — Exhaust emission measurement —

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

1 Scope

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

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

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

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

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

2 Normative references

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

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

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

ISO 5167-1:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

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

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

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

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

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

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

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

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

ISO 15550:2002, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*

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

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

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

3 Terms and definitions

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

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

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

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

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

3.2
partial-flow dilution method
process of separating a part of the raw exhaust from the total exhaust flow, then mixing with an appropriate amount of dilution air prior to passing through the particulate sampling filter

NOTE See 17.2.1, Figures 10 to 18.

3.3
full-flow dilution method
process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis

NOTE It is common in many full-flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter (see 17.2.2, Figure 19).

3.4
isokinetic sampling
process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the probe equal to the exhaust stream mean velocity

3.5
non-isokinetic sampling
process of controlling the flow of the exhaust sample independently of the exhaust stream velocity

3.6
multiple-filter method
process of using one pair of filters for each of the individual test cycle modes

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

3.7
single-filter method
process of using one pair of filters for all test cycle modes

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

3.8
specific emissions
mass emissions expressed in grams per kilowatt-hour

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

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

3.9
brake power
observed power measured at the crankshaft or its equivalent, the engine being equipped only with the standard auxiliaries necessary for its operation on the test bed

NOTE See 5.3 and ISO 14396.

3.10
auxiliaries
equipment and devices listed in ISO 14396

4 Symbols and abbreviations

4.1 General symbols

Symbol	Term	Unit
A/F_{st}	Stoichiometric air-to-fuel ratio	1
A_p	Cross-sectional area of the isokinetic sampling probe	m^2
A_r	Atomic mass	g
A_x	Cross-sectional area of the exhaust pipe	m^2
c_c	Background corrected concentration	ppm % (V/V)
c_d	Concentration in the dilution air	ppm % (V/V)
c_x	Concentration in the exhaust (with suffix of the component nominating)	ppm % (V/V)
D	Dilution factor	1
E_{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}]))	1
λ_{Ref}	Excess air factor at reference conditions	1
f_a	Laboratory atmospheric factor	1
f_c	Carbon factor	1
f_{fd}	Fuel specific factor for exhaust flow calculation on dry basis	1
f_{fh}	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	1
f_{fw}	Fuel specific factor for exhaust flow calculation on wet basis	1
H_a	Absolute humidity of the intake air (g water / kg dry air)	g/kg
H_d	Absolute humidity of the dilution air (g water / kg dry air)	g/kg
i	Subscript denoting an individual mode	1
k_f	Fuel specific factor for the carbon balance calculation	1
k_{hd}	Humidity correction factor for NO_x for diesel engines	1
k_{hp}	Humidity correction factor for NO_x for gasoline (petrol) engines	1
k_p	Humidity correction factor for particulates	1
k_{wa}	Dry to wet correction factor for the intake air	1
k_{wd}	Dry to wet correction factor for the dilution air	1
k_{we}	Dry to wet correction factor for the diluted exhaust gas	1
k_{wr}	Dry to wet correction factor for the raw exhaust gas	1
M	Percent torque related to the maximum torque for the test engine speed	%
M_r	Molecular mass	g
m_d	Mass of the dilution air sample passed through the particulate sampling filters	kg
$m_{f,d}$	Particulate sample mass of the dilution air collected	mg
m_f	Particulate sample mass collected	mg
m_{sep}	Mass of the diluted exhaust sample passed through the particulate sampling filters	kg
P_A	Absolute outlet pressure at pump outlet	kPa

Symbol	Term	Unit
p_a	Saturation vapour pressure of the engine intake air	kPa
p_b	Total barometric pressure	kPa
p_d	Saturation vapour pressure of the dilution air	kPa
p_r	Water vapour pressure after cooler	kPa
p_s	Dry atmospheric pressure	kPa
P	Uncorrected brake power	kW
P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by ISO 14396	kW
P_m	Maximum measured or declared power at the test engine speed under test conditions (see 12.5)	kW
q_{mad}	Intake air mass flow rate on dry basis	kg/h
q_{maw}	Intake air mass flow rate on wet basis	kg/h
q_{mdw}	Dilution air mass flow rate on wet basis	kg/h
q_{medf}	Equivalent diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mew}	Exhaust gas mass flow rate on wet basis	kg/h
q_{mf}	Fuel mass flow rate	kg/h
q_{mdew}	Diluted exhaust gas mass flow rate on wet basis	kg/h
q_{mgas}	Emission mass flow rate of individual gas	g/h
q_{mPT}	Particle mass flow rate	g/h
r_d	Dilution ratio	1
r_a	Ratio of cross-sectional areas of isokinetic probe and exhaust pipe	1
R_a	Relative humidity of the intake air	%
R_d	Relative humidity of the dilution air	%
r_h	FID response factor	1
r_m	FID response factor for methanol	1
r_x	Ratio of the SSV throat to inlet absolute, static pressure	1
r_y	Ratio of the SSV throat diameter, d, to the inlet pipe inner diameter	1
ρ	Density	kg/m³
S	Dynamometer setting	kW
T_a	Absolute temperature of the intake air	K
T_d	Absolute dewpoint temperature	K
T_{ref}	Absolute reference temperature (of combustion air: 298 K)	K
T_c	Absolute temperature of the intercooled air	K
T_{cref}	Absolute intercooled air reference temperature	K
V_m	Molar volume	l
W_f	Weighting factor	1
W_{fe}	Effective weighting factor	1

4.2 Symbols for fuel composition

w_{ALF} H content of fuel, % mass

w_{BET} C content of fuel, % mass

w_{GAM} S content of fuel, % mass

w_{DEL} N content of fuel, % mass

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

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

4.3 Symbols and abbreviations for the chemical components

ACN	acetonitrile
C1	carbon 1 equivalent hydrocarbon
CH_4	methane
C_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	sulphur dioxide
SO_3	sulphur trioxide

4.4 Abbreviations

CFV	critical flow venturi
CLD	chemiluminescent detector
CVS	constant volume sample
ECS	electrochemical sensor
FID	flame ionization detector
FTIR	Fourier transform infrared analyser
GC	gas chromatograph
HCLD	heated chemiluminescent detector
HFID	heated flame ionization detector
HPLC	high-pressure liquid chromatograph
NDIR	non-dispersive infrared analyser
NMC	non-methane cutter
PDP	positive displacement pump
PMD	paramagnetic detector
PT	particulates
UVD	ultraviolet detector
ZRDO	zirconium dioxide sensor

5 Test conditions

5.1 Engine test conditions

5.1.1 Test condition parameter

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

a) Compression-ignition engines

Naturally aspirated and mechanically pressure-charged engines:

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

Turbocharged engines with or without cooling of the intake air:

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

b) Spark-ignition engines

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

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

5.1.2 Test validity

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

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

Tests should be conducted with the parameter f_a between 0,96 and 1,06.

5.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared rated power and full load, within ± 5 K of the maximum charge air temperature specified by the manufacturer. The temperature of the cooling medium shall be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature shall be set to within ± 5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared rated power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle. The charge air cooler volume shall be based upon good engineering practice and typical vehicle/machinery applications.

5.3 Power

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

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

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

For further details, see 3.9 and ISO 14396.

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

5.4 Specific test conditions

5.4.1 Engine air inlet system

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

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

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

5.4.2 Engine exhaust system

An engine exhaust system or a test shop system shall be used, presenting an exhaust backpressure within ± 650 Pa of the maximum value specified by the manufacturer at the speed of rated power and full load. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in 7.5.5, 17.2.1, EP and 17.2.2, EP.

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

If the engine is equipped with an exhaust aftertreatment device, the exhaust pipe shall have the same diameter as found in use for at least four pipe diameters upstream to the inlet of the beginning of the expansion section containing the aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above, and may be set with a valve. The aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

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

5.4.3 Cooling system

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

5.4.4 Lubricating oil

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

5.4.5 Adjustable carburettors

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

5.4.6 Crankcase breather

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