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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions

Moteurs alternatifs à combustion interne — Mesurage des émissions de gaz d'échappement —

Partie 10: Cycles et procédures d'essai pour le mesurage sur site des émissions de fumées de gaz d'échappement des moteurs à allumage par compression fonctionnant en régime transitoire

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 part of ISO 8178 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-10 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: 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*

Annexes A, B and C form a normative part of this part of ISO 8178. Annex D is for information only.

Introduction

Throughout the world there currently exist many smoke measurement procedures in various forms. Some of these smoke measurement procedures are designed for test bed testing and may be used for certification or type-approval purposes. Others are designed for field testing and may be used in inspection and maintenance programmes. Different smoke measurement procedures exist to meet the needs of various regulatory agencies and industries. The two methods typically used are the filter smokemeter method and the opacimeter.

The objective of this part of ISO 8178 is to combine the key features of several existing smoke measurement procedures as much as is technically possible. This part of ISO 8178 is intended for the measurement of the emissions of smoke from compression ignition internal combustion engines under field conditions. It applies to engines operating under transient conditions – where the engine speed or load, or both, changes with time. It should be noted that the smoke emissions from typical well-maintained naturally-aspirated engines under transient conditions will generally be the same as the smoke emissions under steady state conditions.

Only opacimeter type smokemeters may be used for making the smoke measurements described in this part of ISO 8178. This part of ISO 8178 allows the use of either full-flow or partial-flow opacimeters. This part of ISO 8178 accounts for differences in response time between the two types of opacimeters, but does not account for any differences due to differences in temperatures at the sampling zone.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 10:
Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions

1 Scope

This part of ISO 8178 specifies the measurement procedures and test cycles for the evaluation of smoke emissions from compression ignition engines under field conditions. This part of ISO 8178 is intended for use primarily as a support for in-use smoke testing programmes on engines that have been "certified" or "type approved" in accordance with the provisions of ISO 8178-9. ISO 8178-9 provides test procedures and test cycles for measurement of smoke from different applications of engines operating on the test bed.

Likewise, ISO 8178-4 specifies a number of different test cycles to be used in order to characterize gaseous and particulate emissions from nonroad engines. The test cycles in ISO 8178-4 were developed in recognition of the differing operating characteristics of various categories of nonroad machines.

For transient smoke test cycles, smoke testing is conducted using smokemeters that operate on the light extinction principle. The purpose of this part of ISO 8178 is to define the smoke test cycles and the methods used to measure and analyse smoke. Specifications for measurement of smoke using the light extinction principle can be found in ISO 11614. The test procedures and measurement techniques described in clauses 5 to 11 of this part of ISO 8178 are applicable to reciprocating internal combustion (RIC) engines in general. However, an engine application can only be evaluated using this part of ISO 8178 once the appropriate test cycle has been developed. Annexes A to C to this part of ISO 8178 each contains a test cycle that is relevant only for those specific applications listed in the scope of that annex. Where possible, the smoke test cycle described in the annex utilizes the engine and machine categories developed in ISO 8178-4.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 8178. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 8178 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

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

ISO 8178-7, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 7: Engine family determination*

ISO 8178-8, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 8: Engine group determination*

ISO 8178-9:2000, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

ISO 11614:1999, *Reciprocating internal combustion compression-ignition engines — Apparatus for measurement of the opacity and for determination of the light absorption coefficient of exhaust gas*

3 Terms and definitions

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

3.1
exhaust gas smoke
visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis

NOTE Black smoke (soot) is mainly comprised of carbon particles. Blue smoke is usually due to droplets resulting from the incomplete combustion of fuel or lubricating oil. White smoke is usually due to condensed water and/or liquid fuel. Yellow smoke is caused by NO_2.

3.2
transmittance
τ
fraction of light, transmitted from a source through a smoke-obscured path, which reaches the observer or the instrument receiver

NOTE It is expressed as a percentage.

3.3
opacity
N
fraction of light, transmitted from a source through a smoke-obscured path, which is prevented from reaching the observer or the instrument receiver ($N = 100 - \tau$).

NOTE It is expressed as a percentage.

3.4 Optical path length

3.4.1
effective optical path length
L_A
length of the smoke-obscured optical path between the opacimeter light source and the receiver, corrected as necessary for non-uniformity due to density gradients and fringe effect

NOTE 1 It is expressed in metres. 9.2 describes how to determine L_A and how to install measuring equipment, on exhaust systems that may be encountered in the field.

NOTE 2 Portions of the total light source to receiver path length which are not smoke obscured do not contribute to the effective optical path length.

3.4.2
standard effective optical path length
L_{AS}
measurement used to ensure meaningful comparisons of quoted opacity values

NOTE See 10.1.4.

3.5
light absorption coefficient
k
fundamental means of quantifying the ability of a smoke plume or smoke-containing gas sample to obscure light

NOTE By convention, the light absorption coefficient is expressed in reciprocal metres (m^{-1}). The light absorption coefficient is a function of the number of smoke particles per unit gas volume, the size distribution of the smoke particles, and the light absorption and scattering properties of the particles. In the absence of blue, white or yellow smoke or ash, the size distribution and the light absorption/scattering properties are similar for all diesel exhaust gas samples and the light absorption coefficient is primarily a function of the smoke particle density.

3.6
Beer-Lambert law
mathematical equation describing the physical relationships between the light absorption coefficient, k, the smoke parameters of transmittance, τ, and effective optical path length, L_A

NOTE Because the light absorption coefficient, k, cannot be measured directly, the Beer-Lambert law is used to calculate k, when opacity, N, or transmittance, τ, and effective optical path length, L_A, are known:

$$k = \frac{-1}{L_A} \ln \left(\frac{\tau}{100} \right) \quad (1)$$

$$k = \frac{-1}{L_A} \ln \left(1 - \frac{N}{100} \right) \quad (2)$$

3.7
opacimeter
instrument for the measurement of smoke characteristics using the optical method of transmittance

3.7.1
full-flow opacimeter
instrument in which all the exhaust gas flow passes through the smoke measuring chamber

3.7.1.1
full-flow end-of-line opacimeter
instrument that measures the opacity of the full exhaust plume as it exits the tailpipe

NOTE The light source and receiver for this type of opacimeter are located on opposite sides of the smoke plume and in close proximity to the open end of the tailpipe. When applying this type of opacimeter, the effective optical path length is a function of the tailpipe design.

3.7.1.2
full-flow in-line opacimeter
instrument that measures the opacity of the full exhaust plume within the tailpipe

NOTE The light source and receiver for this type of opacimeter are located on opposite sides of the smoke plume and in close proximity to the outer wall of the tailpipe. With this type of opacimeter the effective optical path length is dependent on the instrument.

3.7.2
partial flow opacimeter
instrument that samples a representative portion of the total exhaust flow and passes the sample through the measuring chamber.

NOTE With this type of opacimeter the effective optical path length is a function of the opacimeter design.

3.7.3 Opacimeter response time

3.7.3.1
opacimeter physical response time
t_p
difference between the times when the raw k-signal reaches 10 % and 90 % of the full deviation when the light absorption coefficient of the gas being measured is changed in less than 0,01 s

NOTE The physical response time of the partial flow opacimeter is defined by means of the sampling probe and transfer tube. Additional information on the physical response time can be found in 8.2.1 and 11.7.2 of ISO 11614:1999.

3.7.3.2
opacimeter electrical response time
t_e
difference between the times when the instrument recorder output signal or display goes from 10 % to 90 % of full scale when the opacity or light extinction coefficient is changed in less than 0,01 s

NOTE Additional information on the electrical response time can be found in 8.2.3 and 11.7.3 of ISO 11614:1999.

4 Symbols and units

For the purposes of this part of ISO 8178, the symbols and units listed in Table 1 apply.

Table 1 — Symbols and units

Symbol	Term	Unit
D	Bessel function constant	1
E	Bessel constant	1
f_a	Atmospheric factor	1
f_c	Bessel filter cut-off frequency	s^{-1}
k	Light absorption coefficient	m^{-1}
k_{corr}	Ambient condition corrected light absorption coefficient	m^{-1}
k_{obs}	Observed light absorption coefficient	m^{-1}
K	Bessel constant	1
K_S	Smoke ambient correction factor	1
L_A	Effective optical path length	m
L_{AS}	Standard effective optical path length	m
N	Opacity	%
N_A	Opacity at effective optical path length	%
N_{AS}	Opacity at standard effective optical path length	%

Table 1 *(continued)*

Symbol	Term	Unit
p_{me}	Brake effective mean pressure	kPa
p_S	Dry atmospheric pressure	kPa
P	Engine Power	kW
S_i	Instantaneous smoke value	m^{-1} or %
Δt	Time between successive smoke data (= 1/sampling rate)	s
t_{Aver}	Overall response time	s
t_e	Opacimeter electrical reponse time	s
t_F	Filter response time for Bessel function	s
t_p	Opacimeter physical response time	s
T_a	Engine intake air temperature	K
X	Desired overall response time	s
Y_i	Bessel averaged smoke value	m^{-1} or %
ρ	Dry ambient density	kg/m^3
τ	Smoke Transmittance	%
Ω	Bessel Constant	1

5 Test conditions

5.1 Ambient 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 kPa, shall be measured, and the parameter, f_a, shall be determined according to the provisions evaluated by equations (3) to (5).

Naturally-aspirated and mechanically-supercharged compression ignition engines, and compression ignition engines with wastegates operating:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0,7} \quad (3)$$

NOTE This equation also applies if the wastegate is operating only during sections of the test cycle. If the wastegate is not operating during any section of the test cycle, equation (4) or (5) shall be used depending on the type of charge cooling, if any.

Turbocharged compression ignition engines without charge air cooling, or with charge air cooling by air/air cooler:

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,2} \quad (4)$$

Turbocharged compression ignition engines with charge air to liquid charge air cooler:

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

5.1.2 Test validation criteria — Test conditions

For a test to be recognized as valid, with respect to atmospheric conditions, the parameter f_a should be such that:

$$0,93 \leqslant f_a \leqslant 1,07 \quad (6)$$

Smoke values obtained within this range of f_a shall be corrected in accordance with the provisions given in 10.3. Results from tests conducted outside this range are not comparable to the results from ISO 8178-9.

Additional validation criteria are given in 7.3.4 (opacimeter zero drift) and annexes A to C (test cycle validation criteria).

5.2 Power

Auxiliaries necessary only for the operation of the machine shall be turned off. If they cannot be turned off, they shall be made to function at minimum power as much as is possible during the test. The following incomplete list of such auxiliaries is given as an example:

- air compressor;
- power steering pump;
- air conditioning compressor;
- pumps for hydraulic actuators;
- auxiliary electrical equipment (lights, blowers, etc.).

5.3 Engine air inlet system

The inlet air system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the air system, including whether or not the air cleaner is in need of service, shall be noted.

5.4 Engine exhaust system

The exhaust system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the exhaust system shall be noted.

5.5 Engines with charge air cooling

The charge air cooling system shall be inspected for leaks, loose or missing clamps or fittings, etc. The general condition of the charge air cooling system shall be noted.

6 Test fuels

Fuel characteristics influence engine smoke emissions. Smoke tests conducted in accordance with ISO 8178-9 are generally “certification” or “type approval” tests, utilizing a fuel specified in the regulation. Field tests are typically not conducted using the reference fuel. Therefore, especially for vehicles that fail the smoke test, the characteristics of the fuel used for the test shall be determined, recorded and presented with the results of the test.

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

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 2.

Table 2 — Selection of fuel

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

[a] Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily yield results that are comparable to those from testing with reference fuels.

The fuel used for acceptance tests should be within the range of fuel specifications allowed by the engine manufacturer, as specified in the engine manufacturer's technical literature. 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 accuracy

7.1 General

The equipment mentioned in 7.3 shall be used for smoke tests of engines in the field.

7.2 Test conditions

7.2.1 General

This part of ISO 8178 does not contain details of engine speed, pressure and temperature measuring equipment. Instead, only the accuracy requirements of such equipment are given in 7.4.

7.2.2 Engine speed

Measurement of engine speed is required in order to determine that the test is being run correctly. Measurement of engine speed is required to determine if the engine governor is operating correctly – in order to avoid possible damage to the engine. Incorrect low or high idle speeds may also cause the smoke to differ from those tests conducted according to the provisions of ISO 8178-9.

7.2.3 Ambient temperature

Ambient temperature (dry bulb temperature) is required in order to correct smoke for the ambient test conditions and determine if the engine complies with the standard to which it was certified according to the provisions of ISO 8178-9.