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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

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

Partie 9: Cycles et procédures d'essai pour le mesurage au banc d'essai des émissions de fumées de gaz d'échappement des moteurs alternatifs à combustion interne 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.

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.

International Standard ISO 8178-9 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 transitory conditions*

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

Introduction

Throughout the world there currently exists 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 purpose of ISO 8178 is to combine the key features of several existing smoke measurement procedures as much as technically possible. Part 4 of ISO 8178 specifies a number of different test cycles to be used to characterize gaseous and particulate emissions from nonroad engines. The test cycles in 8178-4 were developed in recognition of the differing operating characteristics of various categories of nonroad machines. Likewise, different smoke test cycles may be appropriate for different categories of nonroad engines and machines. Within ISO 8178-4 it was possible to characterize and control gaseous and particulate emissions from nonroad engines using a variety of steady-state operating points. To properly characterize and control smoke emissions from many engine applications a transient smoke test cycle is needed.

This part of ISO 8178 is intended for the measurement of the emissions of smoke from compression ignition internal combustion engines. 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 which allows the use of either full-flow or partial-flow opacimeters and corrects 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 9:
Test cycles and test procedures for test-bed 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 on the test bed.

For transient smoke test cycles, smoke testing is conducted using smokemeters which 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 1 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 and B to this part of ISO 8178 each contain 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 part 4 of ISO 8178.

For certain categories of non-road engines "at site" rather than "test bed" smoke test procedures may prove to be necessary. For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations), additional test conditions and special evaluation methods may apply.

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

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

ISO 8178-4, *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 8528-1, *Reciprocating internal combustion engine driven alternating current generating sets — Part 1: Application, ratings and performance*.

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 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, expressed as a percentage, transmitted from a source through a smoke-obscured path and which reaches the observer or the instrument receiver

3.3
opacity
N
fraction of light, expressed as a percentage, transmitted from a source through a smoke-obscured path and which is prevented from reaching the observer or the instrument receiver

NOTE $N = 100 - \tau$

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, expressed in metres and corrected, as necessary, for non-uniformity due to density gradients and fringe effect

NOTE 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 L_{AS} values are defined in 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:

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

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

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

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

3.7.1.1
full-flow end-of-line opacimeter
instrument which 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 which 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 which 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 with 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 reaches 10 % and 90 % of full scale when the light source is interrupted or completely extinguished in less than 0,01 s

NOTE Additional information on the electrical response time can be found in 6.2.6.2 of ISO 11614:1999.

4 Symbols and units

See Table 1.

Table 1 — Symbols and units for terms used in this part of ISO 8178

Symbol	Term	Unit
B	Bessel function constant	1
C	Bessel function constant	1
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	%
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 %
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
Δt	Time between successive smoke data (=1/sampling rate)	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 atmospheric factor f_a, shall be determined using equations (3) to (5).

For naturally aspirated and mechanically supercharged compression-ignition engines and compression-ignition engines with wastegates operating:

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

NOTE This formula 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, formula (4) or (5) shall be used depending on the type of charge cooling, if any.

For turbocharged compression-ignition engines without charge air cooling, or with charge air cooling by air/air cooler:

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

For turbocharged compression-ignition engines with charge air to liquid charge air cooler:

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

5.1.2 Test validation criteria — test conditions

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

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

NOTE It is recommended that tests be with the parameter f_a between 0,96 and 1,06.

Additional validation criteria are given in 7.3.2.3 and A.3.2.2.

5.2 Power

Those auxiliaries which are 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:

— air compressor for brakes;

— power steering pump;

— air conditioning compressor;

— pumps for hydraulic actuators.

For further details see 3.8 and Table B.1 of ISO 8178-1:1996.

5.3 Engine air inlet system

The test engine shall be equipped with an air inlet system presenting an air inlet restriction within ± 10 % of the manufacturer's specified upper limit for a clean air-cleaner. The upper limit shall be at the engine operating condition, as specified by the manufacturer, that results in the maximum air flow for the respective engine application.

5.4 Engine exhaust system

The test engine shall be equipped with an exhaust system presenting an exhaust back pressure within ± 10 % of the manufacturer's specified upper limit. The upper limit shall be at the engine operating condition, as specified by the manufacturer, that results in the maximum declared power for the respective engine application. Tests may be conducted with a muffler, as this will tend to reduced exhaust pulsations which may interfere with measurement of smoke. Further, the use of a muffler should provide better correlation between test-bed smoke measurement and any in-field smoke tests that may occur. The design of the muffler (i.e. volume) should be typical of that used in actual field applications of the engine being tested.

5.5 Cooling system

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

5.6 Lubricating oil

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

5.7 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 speed and load specified by the manufacturer. The charge air temperature and cooler pressure drop shall be set to within ± 4 K and ± 2 kPa respectively of the manufacturer's specification.

5.8 Test fuel temperature

The test fuel temperature shall be in accordance with the manufacturer's recommendations. In the event that the manufacturer does not specify the temperature, it shall be 311 K ± 5 K. Except for cases where “heavy” fuel is used, the temperature specified by the manufacturer shall not be greater than 316 K. The fuel temperature shall be measured at the inlet to the fuel injection pump unless otherwise specified by the manufacturer, and the location of measurement shall be recorded.

6 Test fuels

Fuel characteristics influence the engine smoke emissions. Therefore, 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 are used as reference fuels, 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 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. 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.

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
Acceptance 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 comply with limits specified when using 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.

7 Measurement equipment and accuracy

7.1 General

The following equipment shall be used for smoke tests on engines using dynamometers. This part of ISO 8178 does not contain details of pressure and temperature measuring equipment. Instead, only the accuracy requirements of such equipment necessary for conducting a smoke test are given in 7.4.

7.2 Dynamometer specification

An engine dynamometer with adequate characteristics to perform the test cycle as described in annexes A and B shall be used. Test cycle linearity requirements apply only when tests have been conducted using an electric dynamometer. The instrumentation for torque and speed measurement shall allow the measurement accuracy required for running the test cycle within the limits given in annexes A and B. Speed and torque shall be sampled at a frequency of at least 1 Hz. The accuracy of the measuring equipment shall be such that the maximum tolerances of the figures given in Table 3 are not exceeded. Engine driven equipment that meets these requirements may be used instead of dynamometers.

7.3 Determination of smoke

7.3.1 General

Transient smoke tests must be conducted using opacimeter-type smokemeters. Three different types of opacimeters are allowed: in-line and end-of-line full-flow opacimeters and the partial-flow opacimeter. Specifications for the three types of opacimeters can be found in clause 11 of this part of ISO 8178 and in clauses 6 and 7 of ISO 11614:1999. Temperature correction has not been validated for transient tests, therefore, temperature correction of smoke results has not been included in this part of ISO 8178.

Table 3 — Permissible deviations of instruments for engine-related parameters

Item	**Permissible deviation** (% based on engine maximum values) in accordance with ISO 3046-3	**Calibration intervals** months
Engine speed	± 2 %	3
Torque	± 2 % or ± 5 Nm [a]	3
Power	± 3 %	not applicable

[a] Whichever is greater.

7.3.2 Specifications — opacimeters

7.3.2.1 General

Smoke tests require the use of a smoke measurement and data processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

— a full-flow or a partial-flow opacimeter meeting the specifications of this clause. Detailed specifications for opacimeters can be found in clause 11 and in ISO 11614;

— a data processing unit capable of performing the functions described in 10.2 and 10.3 and in annex D;

— a printer and/or electronic storage medium to record and output the required smoke values specified in annexes A and B.

7.3.2.2 Linearity

Linearity is defined as the difference between the value measured by the opacimeter and the reference value of the calibrating device. The linearity shall not exceed 2 % opacity.

7.3.2.3 Zero drift

The zero drift over either a one hour period or the duration of the test – whichever is the lesser – shall not exceed 1 % opacity.

7.3.2.4 Opacimeter display and range

For display in both opacity and light absorption coefficient the opacimeter shall have a measuring range appropriate for accurately measuring the smoke of the engine being tested. The resolution shall be at least 0,1 % of full scale.

The optical path length selected for the smoke instrument shall be suitable for the smoke levels being measured in order to minimize errors in calibrations, measurements and calculations.

7.3.2.5 Instrument response time

The physical response time of the opacimeter shall not exceed 0,2 s, and the electrical response time of the opacimeter shall not exceed 0,05 s.