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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions

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

Partie 3: Définitions et méthodes de mesure de la fumée des gaz d'échappement dans des conditions stabilisées

Reference number
ISO 8178-3:1994(E)

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 8178-3 was prepared jointly by Technical Committees ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement* and ISO/TC 22, *Road vehicles*, Subcommittee SC 5, *Engine tests*.

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 emissions*

— *Part 2: At-site measurement of gaseous and particulate exhaust emissions*

— *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: Determination of engine family and engine group*

Annex A of this part of ISO 8178 is for information only.

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Introduction

The International Standards listed below concerning the measurement of smoke emitted from reciprocating internal combustion (RIC) engines have been elaborated by ISO/TC 22 and ISO/TC 70 in smooth cooperation.

ISO 8178-3:—, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions.*

ISO 10054:—, *Internal combustion compression-ignition engines — Measurements apparatus for smoke from engines operating under steady-state conditions — Filter-type smokemeter.*

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

ISO 10054 and ISO 11614 define the measurement equipment for different smoke-measurement methods. This part of ISO 8178 defines their application to RIC engines on the basis of these International Standards.

The smoke-measurement methods are used for the measurement of visible emissions. The smoke-measurement results, evaluated in accordance with this part of ISO 8178, are different from the results obtained with the particulate-measurement methods described in ISO 8178-1 and ISO 8178-2 or in other standards and regulations.

Furthermore, the two smoke-measurement methods described in this part of ISO 8178 are different, which only allows a restricted correlation between them.

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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 3:
Definitions and methods of measurement of exhaust gas smoke under steady-state conditions

1 Scope

This part of ISO 8178 specifies two methods for the measurement of exhaust gas smoke characteristics of reciprocating internal combustion (RIC) engines operating under steady-state conditions. One method evaluates smoke opacity by measurement of the obscuration of a light beam; the other evaluates the soot content by measurement of the blackening of a filter. Where necessary, individual requirements may be specified for particular engine applications.

This part of ISO 8178 does not deal with measurement under transient conditions; if smokemeters are used under transient conditions, the results from different types of instrument cannot be compared unless the sampling conditions are identical and the instrument characteristics are compatible.

This part of ISO 8178 is applicable to RIC engines for land, rail-traction and marine use, including engines used to propel agricultural tractors and road vehicles.

It may be applied to engines used to propel road-construction and earth-moving machines, industrial trucks, and for other applications where no suitable International Standards for exhaust gas smoke measurement of these engines exist.

NOTE 1 If water is injected into the exhaust system, measurement or sampling can only be made upstream of the point of water injection.

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 2710-1:— ,[1] *Reciprocating internal combustion engines — Vocabulary — Part 1: Terms for engine design and operation.*

ISO 10054:—[2], *Internal combustion compression-ignition engines — Measurement apparatus for smoke from engines operating under steady-state conditions — Filter-type smokemeter.*

ISO 11614:—[2], *Reciprocating internal combustion compression-ignition engines — Apparatus for measurement of the opacity and for determination of the light absorption coefficient of exhaust gas.*

1) To be published. (Revision of ISO 2710:1978 and Add.1:1982)

2) To be published.

3 Definitions

For the purposes of this part of ISO 8178, the following definitions apply. (See also ISO 2710-1.)

3.1 exhaust gas smoke: Smoke is a visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis. [According to ISO/IEC Guide 52]

NOTE 2 Black smoke (soot) is mainly composed 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.

3.2 transmittance, τ: That fraction of light transmitted from a source, through a smoke-obscured path, which reaches the observer or the instrument receiver. It is expressed as a percentage.

3.3 opacity, N: That fraction of light transmitted from a source, through a smoke-obscured path, which is prevented from reaching the observer or the instrument receiver.

$$N = 100 - \tau$$

It is expressed as a percentage.

3.4 effective optical path length, L_A: The length of a light beam between the emitter and the receiver that is intersected by the exhaust gas stream, corrected for non-uniformity due to density gradients and fringe effects. It is expressed in metres.

3.5 light absorption coefficient, k: Coefficient defined by the Beer-Lambert law and given by the formula:

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

or

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

It is expressed in reciprocal metres.

NOTES

3 To obtain a proper comparison, the ambient temperature and the atmospheric pressure prevailing when taking the measurements should be stated because they influence the light absorption coefficient k. For comparison purposes it is also recommended that the exhaust gas temperature is reported or corrected to 373 K (see also 4.4.1.4).

4 The term "light absorption coefficient" is in common use and is, therefore, used in this part of ISO 8178. However, "light extinction coefficient" would be a more accurate term. As used, the two terms mean exactly the same.

3.6 soot: All components contained in the exhaust gas and blackening a filter.

3.7 filter smoke number, (FSN)**:** A measurement of the smoke characteristics of an exhaust gas, represented by the degree of blackening of a clean filter caused by the soot in a given column of exhaust gas passing through this filter.

3.8 effective filtered column length, L_F: The length of the gas column actually passing through the filter, taking into account dead volume and leakage in the sampling system. It is expressed in millimetres.

3.9 opacimeter: An instrument for the measurement of smoke characteristics, using the optical method of transmittance. (See ISO 11614.)

3.9.1 partial-flow opacimeter: An instrument in which only a part of the exhaust gas flow passes through its measuring chamber.

3.9.2 full-flow opacimeter: An instrument in which all the exhaust gas flow passes through its measuring chamber.

3.10 filter-type smokemeter: An instrument in which a given exhaust gas volume is passed through a clean filter of a certain area and the blackness condition of this filter is subsequently used to define the filter smoke number. (See ISO 10054.)

4 Method 1: Smoke measurement by an opacimeter

4.1 Application

This method measures all three types of smoke as described in 3.1, but is most suitable for measuring black and blue smoke.

NOTE 5 The measured values will be influenced by the effective optical path length (3.4) and gas flow temperature.

4.2 Principle

Passage of a beam of light through the exhaust gases in the instrument measuring chamber, measurement of its intensity and comparison with its original intensity.

NOTE 6 The opacimeter may be constructed to take the full flow of exhaust gas or only a part of it (see also 3.9.1 and 3.9.2).

4.3 Procedure

4.3.1 Partial-flow opacimeter

Direct an exhaust gas sample through a probe and a sampling pipe to the measuring chamber as a flow, allowing continuous measurement. Measure the intensity of the received light.

4.3.2 Full-flow opacimeter

Place the measuring chamber in the engine exhaust system, or at a specified distance downstream from the exhaust line end. Measure the intensity of the received light.

4.4 General requirements

The measuring apparatus shall comply with ISO 11614. Relevant parts of the measuring apparatus shall be able to withstand the temperatures applied.

4.4.1 Partial-flow opacimeter

4.4.1.1 Sampling probe

The sampling probe shall be placed in the exhaust gas flow to obtain a representative sample of the exhaust gas. The gas sample shall be introduced into and passed through the chamber in such a manner as to remain representative.

The overall installation shall be such that the sampling pipe from the probe to the opacimeter is as short as possible and inclined upwards. The pipe shall be gas-tight with no sharp bends or constrictions which might cause avoidable local resistance to the gas flow.

In order to provide the required temperature conditions at the chamber inlet, a heat exchanger may be fitted in the sampling pipe, but this must not unduly modify the gas characteristics.

4.4.1.2 Measuring chamber

The impingement of stray light on the receiver due to internal reflections or diffusion effects in the measuring chamber shall be reduced to a minimum (for example, by finishing internal surfaces in matt black and by suitable general layout).

4.4.1.3 Gas flow rate

Transmission of light through the exhaust gas shall be independent of the gas flow rate within the limits specified by the manufacturer of the opacimeter.

4.4.1.4 Gas temperature

When the mean operating temperature, T, is other than 373 K, the opacimeter reading, k_{obs}, should be converted to 373 K by the formula

$$k_{corr} = k_{obs} \times \frac{T}{373}$$

NOTE 7 k at a given temperature may be written, for example, k_{500}.

For use of the above formula, at all points in the measuring chamber the temperature of the exhaust gas shall be no lower than 343 K and no higher than 553 K. If temperatures are outside this range, the readings shall be recorded without conversion and the temperature shall be noted. This temperature range is that in which it is considered that all the water present is in the vapour form and all other uncondensed non-solid particles (i.e. the amount of uncondensed, unburnt fuel or lubricating oil) are insignificant in normal full-load exhaust smoke. Under these conditions the conversion formula for the effect of temperature is valid.

If the exhaust gas contains an abnormal proportion of non-solid constituents, the conversion formula may not be valid. For example, the formula will not apply to exhaust gases from engines operating on heavy fuel oil having a high sulfur content, as the exhaust gas at 373 K may include condensed acidic sulfur droplets. In these cases, it is necessary for comparative purposes to measure with a more restrictive temperature range about 373 K or, if measuring these droplets is to be avoided, the exhaust gas of these engines shall be kept above 413 K and, if required, converted to 373 K to give a nominal reference value for comparative purposes.

4.4.2 Full-flow opacimeter

NOTE 8 When a full-flow opacimeter is used to determine the light absorption coefficient, the remarks on gas temperature in 4.4.1.4 also apply.

4.4.2.1 Arrangement of measuring equipment

The measuring equipment shall be arranged in one of the following two ways.

a) **In-line method:** the measuring chamber is placed in the engine exhaust system.

b) **End-of-line (plume) method:** the instrument measures smoke in the atmosphere at a specified distance downstream from the exhaust line end.

4.5 Requirements for the light system

The light system shall be made up of two components: a light source and a light receiver. A system of reflecting elements may be used.

4.5.1 Light source

The light source shall be an incandescent lamp with a colour temperature in the range 2 800 K to 3 250 K (see ISO/CIE 10526) or a green light-emitting diode (LED) with a spectral peak between 550 nm and 570 nm.

4.5.2 Light receiver

The light receiver shall consist of a photo-electric cell with a spectral response curve similar to the photopic curve of the human eye (maximum response in the range 550 nm to 570 nm, to less than 4 % of that maximum response below 430 nm and above 680 nm) or a photodiode when used with a green LED.

4.5.3 Reflecting and protecting elements

If reflecting or protecting elements are used, the response of the light source/receiver system shall not be taken outside the required frequency limits defined in 4.5.2 and they shall not cause significant deviations of the measured value during the time of measurement.

4.5.4 Effective optical path length

The value of the effective optical path length (3.4) is required to allow calculation of the light absorption coefficient k. When using clean air to protect the optical elements from sooting, the influence on the effective optical path length shall be taken into account. The effective optical path length, L_A, is usually stated by the manufacturer of the instrument.

NOTE 9 Not all instruments which measure opacity are suitable for measurement of the light absorption coefficient, since the effective optical path length is not always readily determined and, with end-of-line (plume-type) instruments, the exhaust gas being measured is not in a non-reflective enclosure.

4.6 Calibration

Neutral density filters of known transmittance shall be used to calibrate the instrument.

4.7 Parameters to be measured

The instrument shall measure the transmittance τ from which the opacity N and the light absorption coefficient k can be calculated. The instrument may also indicate the light absorption coefficient k directly.

5 Method 2: Smoke measurement by a filter-type smokemeter

5.1 Application

This method is suitable for evaluating the content of soot in exhaust gas. It does not measure blue or white smoke (see note to 3.1).

NOTE 10 A long column length for measuring low soot content may be made by multiple operation of the instrument without changing the filter paper.

5.2 Principle

Extraction of a sample of exhaust gas from the exhaust pipe through a sampling pipe and passage through a filter of known area. Blackening of the filter is caused by soot contained in a gas column with an effective length L_F. This blackening is a measure of the content of soot in the exhaust gas. The blackening of the filter is evaluated by calculation from the optical reflectance of the blackened filter relative to a clean filter.

5.3 Procedure

Draw the exhaust gas sample into a probe and a sampling pipe and pass it through the filter with a homogeneous flow per unit area (for instance, using a piston pump). From the ratio of the effective suction volume to the blackened area of the filter paper, calculate the effective gas column length. This length is indicated by the manufacturer of the instrument.

5.4 General requirements

The measuring apparatus shall comply with ISO 10054.

5.5 Gas temperature and pressure

The reference conditions for the measured gas are 298 K and 100 kPa. Where the density of the measured gas is more than 5 % different from that under reference conditions, means shall be provided for converting the measured values to those for standard reference conditions.

6 Test report

If required, the test report shall contain, as a minimum, the following:

a) description of the engine:

- manufacturer,
- type and designation,
- declared power,
- declared speed;

b) description of the smokemeter or opacimeter:

- manufacturer,
- type and model of instrument used;

c) ambient conditions at the engine and at the smokemeter or opacimeter:

- temperature,
- pressure,
- humidity;

d) engine operating conditions during test:

- power,
- speed,
- exhaust temperature at probe entrance, where applicable,
- exhaust pressure at probe entrance, where applicable;

e) test results.

The opacimeter shall display, as a minimum, the opacity N and the filter-type smokemeter shall provide the filter smoke number, FSN. The light absorption coefficient k should be calculated, where possible.

The temperature of the smoke in opacimeters shall be recorded or the opacity N shall be converted to 373 K.