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Internal combustion compression-ignition engines — Measurement apparatus for smoke from engines operating under steady-state conditions — Filter-type smokemeter

Moteurs à combustion interne à allumage par compression — Appareillage de mesure de la fumée des moteurs dans les conditions stabilisées — Fumimètres à filtre

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Contents

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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.

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 10054 was prepared jointly by Technical Committees ISO/TC 22, *Road vehicles*, Subcommittee SC 5, *Engine tests* and ISO/TC 70, *Internal combustion engines*, Subcommittee SC 5, *Special requirements*.

Annex A forms an integral part of this International Standard. Annex B is for information only.

Internal combustion compression-ignition engines — Measurement apparatus for smoke from engines operating under steady-state conditions — Filter-type smokemeter

1 Scope

This International Standard specifies the characteristics required for apparatus to measure the soot content from the exhaust gas of reciprocating internal combustion compression-ignition (diesel) engines operating under steady-state conditions according to the method of blackening a filter. These measuring apparatus are called "Filter-Type Smokemeters".

This International Standard does not deal with apparatus for measurement under transient conditions; if filter-type smokemeters are used under transient conditions, the results of different types of instruments cannot be compared unless sampling conditions are identical.

This International Standard does not apply to engines for aircraft.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard 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 534:1988, *Paper and board — Determination of thickness and apparent bulk density or apparent sheet density.*

ISO 2602:1980, *Statistical interpretation of test results — Estimation of the mean — Confidence interval.*

ISO 2758:—[1], *Paper — Determination of bursting strength.*

ISO/CIE 10526:1991, *CIE standard colorimetric illuminants.*

IEC 584-1:1995, *Thermocouples — Part 1: Reference tables.*

IEC 584-2:1982, *Thermocouples — Part 2: Tolerances.*

CIE 38:1977, *Radiometric and photometric characteristics of materials and their measurement.*

CIE 64:1984, *Determination of the spectral responsitivity of optical radiation detectors.*

CIE 69:1987, *Methods of characterizing illuminance meters and luminance meters: performance, characteristics and specifications.*

ANSI/ASTM D2156, *Method of test for smoke density in the flue gases from distillate fuels.*

DIN 5036-1:1978, *Radiometric and photometric properties of materials; definitions characteristics.*

DIN 5036-3:1979, *Radiometric and photometric properties of materials; methods of measurement for photometric and spectral radiometric characteristics.*

JIS D 8004:1986, *Reflection type smokemeters for automobile diesel engine* (an English translation exists of the 1971 edition).

1) To be published. (Revision of ISO 2758:1983)

3 Definition

For the purposes of this International Standard, the following definition applies.

3.1 soot: All components contained in the exhaust gas which blacken the filter.

4 Symbols

The following symbols are used in this International Standard.

A_F	is the effective filter area (see 6.2.1.3, 6.3.3 and 10.4.4)
A_S	is the cross-section of the sampling system at any point (see 6.2.4)
FSN	is the filter smoke number (see 6.3.2)
i	is the index of identification of single areas (see 10.8)
L_F	is the effective filtered column length, i.e. the length of the exhaust gas column passing through the filter (see 6.3.4)
R'_b	is the reflectometer value of the blackened filter (visual) (see 6.3.1 and 6.3.2)
R'_c	is the reflectometer value of the clean filter (visual) (see 6.3.1)
R'_r	is the relative reflectometer value of the blackened filter (see 6.3.1 and 6.3.2)
R'_{ri}	is the relative reflectometer value of part i of the blackened filter (see 10.8)
t	is the suction time (see 6.2.4 and 10.4)
$\overline{V}$	is the mean gas velocity (see 6.2.4)
V_D	is the dead volume of the sampling system (see 6.2.1.2 , 6.3.4 and 10.4.2)
V_E	is the effective suction volume (see 6.3.4)
V_L	is the leak volume (see 6.2.5, 6.3.4 and A.4)
V_N	is the nominal suction volume (see 6.2.4, 6.3.3 and 6.3.4 and 10.4.1)

5 Measurement principle

For smoke measurement with a filter-type smokemeter, a certain amount of exhaust gas is taken from the exhaust pipe through a sampling pipe and drawn through a filter with a certain area. Thus blackening of the filter is caused by the soot contained in a gas column of a certain length. The blackening of the filter is evaluated by calculation from the optical reflectance of the blackened filter relative to a clean filter.

The degree of blackening is expressed as the filter smoke number (FSN) and is calculated according to the formula given in 6.3.2 .

The filter-type smokemeter does not measure white or blue smoke.

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

6 Characteristics of filter-type smokemeters

6.1 Reference conditions

For practical engine testing, it is convenient to use a reference pressure of ambient and a reference temperature of 298 K (25 °C). This is because in current practice filter-type smokemeters measure at approximately ambient pressure and the effects of ambient conditions on the performance of an engine in producing smoke and the effects of the ambient conditions on the reading of the smokemeter are not separated. Such separation would also involve large corrections to meter readings when measurements are made at altitude, and the correction method for this is at present not firmly established.

However, if absolute comparison of two exhaust gases is required (ignoring any effects of conditions on engine performance), then a reference pressure of 100 kPa and a reference temperature of 298 K shall be used.

NOTE 1 At the reference conditions for engine performance in ISO 1585 and ISO 3046-1 (engine air inlet pressure of 100 kPa), the absolute and the practical units coincide.

The reference length of the exhaust gas column shall be 405 mm (for definition of the effective length of the exhaust gas column for a given apparatus, see 6.3.4).

6.2 General specifications

Deviations from the following specifications are allowed providing either equivalence can be proved or corrections provided. Claims for such corrections shall be validated in the verification including an assurance that their validity can be maintained in service.

6.2.1 Probe and sampling system

6.2.1.1 Probe design

The probe design shall be such that

a) it takes a representative sample of the exhaust gas (at about the centre of the cross-section of the exhaust system at the probe entrance; see 8.1.1) with a minimum increase of back pressure;

b) there is no net flow of exhaust gas into the probe opening(s) except when sampling;

c) the inner diameter within the whole length of the sampling system upstream of the filter is not smaller than 3 mm.

6.2.1.2 Dead volume, V_D

The dead volume is the total volume from the probe entrance to the filter surface; it shall not exceed 15 % of the nominal suction volume for the normal probe and sampling lines.

Where alternative probes and/or sampling lines are provided by the manufacturer (e.g. for large-engine application), the dead volume may exceed 15 % but shall not exceed 40 %; and the manufacturer shall provide data for correcting measured values to the reference effective length of 405 mm. In all cases the dead volume shall be filled with clean gas prior to sampling.

6.2.1.3 Clamping device design

The inner diameter of the upstream part of the filter clamping device is considered as defining the effective filter area. This diameter shall not be more than 35 mm and not less then 15 mm. The inner diameter of the downstream part shall be equal to or not more than 0,5 mm larger than the inner diameter of the upstream part and the coaxiality of the two inner diameters shall be within 0,2 mm or 0,7 % of the inner diameter of the upstream part, whichever is smaller.

To limit the influence of a chamfer on the inner edge of the filter clamping device, this chamfer shall not be larger than 0,2 mm or 0,7 % of the inner diameter, whichever is smaller.

6.2.2 Filter surface blackening

By appropriate design, it shall be ensured that homogeneous flow (uniform blackening) over the whole of the effective filter area is obtained. The variations of blackening over the filter area shall comply with the specifications given in 10.8.

6.2.3 Blackened filter evaluation

The reflectometer value (according to CIE 38 or DIN 5036-1) shall be determined over a representative area of the effective filter area, such that the value measured is within ± 0.05 FSN plus 3 % of the average of the central 80 % of the effective filter area.

6.2.4 Sampling system flow

In order to avoid undue deposition of soot, the mean gas velocity during sampling at any point of the sampling system upstream of the filter shall not be less than 0,1 m/s when the filter is clean.

The mean gas velocity at any point is determined with the equation:

$$\bar{V} = \frac{V_N}{A_S \times t}$$

The suction time, t, for apparatus with piston pumps is the time from the first movement of the piston until the pressure in the sampling chamber has returned to within ± 1 kPa (10 mbar) of the mean static pressure at the inlet of the probe when sampling smoke of between 3 FSN and 4 FSN. If the pressure returns to within ± 1 kPa of this pressure before the end of the stroke, then the suction time shall be taken as the time of movement of the piston.

The suction time, t, for apparatus with pumps having constant delivery or any other suction device is the time from starting the pumping action until the pressure in the sampling system downstream of the filter has returned to within ± 1 kPa (10 mbar) of the mean static pressure at the inlet of the probe when sampling smoke of between 3 FSN and 4 FSN. If the pressure returns to within ± 1 kPa of this pressure before stopping the pumping action, then the suction time shall be taken as the time between start and stop of the pumping action.

At the end of the sampling, at least 95 % of the gas mass corresponding to the actual effective length shall have passed through the filter. The end of sampling is defined as a point in time when the flow of exhaust gas through the filter has stopped. This may be either when the probe is removed from the exhaust line or disconnected or closed off from the pump, or the pump action has been stopped.

6.2.5 Leak volume, V_L

In general leakage should be avoided, but in some cases this will not be possible (e.g. leakage across the piston sealings while the piston is moving or across the edges of the clamped filter while a pressure difference is acting).

To minimize influences on the effective length, the leak volume of ambient air entering the sampling

system, from the probe up to the point of volume determination, shall not exceed 10 % and the difference between the leak volumes of any two different sampling cycles performed under the same conditions shall not exceed 1 % of the nominal suction volume.

The allowable change of leakage in-service due, for example, to deterioration of seals shall not cause the leakage to differ by more than 1 % of the nominal suction volume from the norm established by the manufacturer for his design of instrument.

The above requirements apply to filter-type smokemeters of current design in which low pressures in the suction chamber only occur when the smokemeter is sucking gas through the filter.

If by design, the suction chamber is brought to a low pressure before sampling of the exhaust gas takes place, then it shall be checked that no significant leakage occurs while the suction chamber is at this depression. Such leakage is termed static leakage, and it shall be less than 1 % of the nominal suction volume when the smokemeter is subjected to a depression equal to that which can occur in normal operation of the smokemeter for a time equal to the maximum time the smokemeter is subjected to such a depression in normal operation.

6.2.6 Temperature

The design of the apparatus and sampling system shall be such that the gas temperature at the point of volume determination (e.g. sampling chamber of the piston-type apparatus or volume-measuring device for some other types) shall be constant within ± 4 K during a given sampling, and independent of exhaust gas temperature within the limits specified by the manufacturer (see 6.2.7). The manufacturer shall provide means for identifying this temperature by monitoring or controlling the gas temperature directly or indirectly.

The design shall ensure that the filter remains unwetted during the sampling procedure.

Where the temperature is outside the range 298 K ± 4 K (25 °C ± 4 °C), the manufacturer shall provide means for converting smokemeter readings to 298 K (25 °C).

NOTE 2 With a sample pipe of more than 1 m length and a mean gas velocity between 10 m/s and 50 m/s in the pipe, it has been found possible to ensure ambient temperature of the sample at the point of volume determination. In this case, the gas temperature is indirectly obtained by measuring ambient temperature.

6.2.7 Pressure and temperature limits

The manufacturer shall state the operating conditions at which the instrument sucks a smoke sample of a mass within 5 % of that at the reference conditions (see 6.1) — for example, exhaust temperature and pressure at specified points.

The manufacturer shall also indicate how to correct measured values to reference conditions.

6.2.8 Filter specifications

The filter shall be made of natural cellulose fibre with no blinder or resin. The filter surface shall be smooth, as for example the filters Schleicher & Schüll No. 604 LB or Whatmann No. 4.[2)]

The unexposed filter shall comply with the requirements in 6.2.8.1 to 6.2.8.4.

6.2.8.1 An opaque stack having at least 20 layers shall have a reflectometer value of (92 ± 3) % when measured with a reflectometer with 45° incidence of standard illuminant A and viewed perpendicularly with an aperture angle of 2 × (5° ± 1°).

As reference, a reflectance standard with known reflectometer value (e.g. a barium sulfate tablet according to ANSI/ASTM D 2156-80, CIE 38, DIN 5036-1 or DIN 5036-3, or a magnesium oxide tablet according to JIS D 8004) shall be used.

As the reflectometer value of a pressed barium sulfate ($BaSO_4$) or magnesium oxide (MgO) tablet is nearly identical to its luminance factor β, for the purposes of this International Standard, the luminance factor β of the tablet is taken as the reference reflectometer value:

$$R_{45/0}\ (BaSO_4) \approx \beta_{45/0}\ (BaSO_4)$$

or

$$R_{45/0}\ (MgO) \approx \beta_{45/0}\ (MgO)$$

NOTE 3 The luminance factors of the pressed barium sulfate tablets and magnesium oxide tablets differ from batch to batch; they will need to be determined according to national standards and stated by the manufacturer of the powder.

6.2.8.2 The air resistance of the paper shall be between 2 s and 5 s per 100 ml using the "Gurley" method with a 142 g cylinder and 28,66 mm clamping diameter.

2) These are trade-names. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

6.2.8.3 The mean thickness shall be 0,17 mm to 0,23 mm [according to ISO 534, measured with 50 kPa (0,5 bar)].

6.2.8.4 The burst pressure shall not be less than 40 kPa (0,4 bar) for an apparatus with a maximum clamping diameter of 35 mm (according to ISO 2758).

If other filters are specified by the manufacturer of the filter-type smokemeter, follow the requirement in clause 7 f).

6.3 Parameters

6.3.1 Relative reflectometer value, R_r'

6.3.1.1 Measured the reflectometer values of the clean filter R_c' and of the blackened filter R_b'. When measuring these values, a background material shall be used consisting of a nominally opaque stack of clean filters having at least 20 layers, or any other material which has the same reflectivity of (92 ± 3) % as defined in 6.2.8.1. The background material shall be as flat as possible.

For the measurement, place the reflectometer head onto the filter so that the applied pressure does not cause any undue displacement of the filter surface out of the ideal plane of observation and the contact between the reflectometer head and the filter does not change the reflectivity of the filter. This is deemed to be the case when the applied contact pressure of the reflectometer head on the contact area is between 150 kPa and 300 kPa. The relative reflectometer value, as a percentage, is determined by calculation using the equation:

$$R_r' = \left(\frac{R_b'}{R_c'} \right) \times 100$$

R_r' shall be determined in the scale from 0 to 100 %, where 100 % refers to a clean filter and 0 to zero reflection.

6.3.1.2 The reflectometer values R_b' and R_c' shall be be determined by an opto-electrical reflectometer which shall comply with the following requirements:

a) The evaluated area of the filter shall be illuminated with diffuse light equivalent to Standard Illuminant A according to ISO/CIE 10526.

   The uniformity of the illuminance shall be determined with a diameter of the evaluation area $d \leqslant 2$ mm, and the ratio of the reflectometer value of the darkest to the brightest evaluation area shall not be less than 0,85.

b) The relative spectral responsivity of the reflectometer head shall be similar to the luminous efficiency $V(\lambda)$ of the human eye with an error of less than 3 % (as defined in CIE 69).

   The design of the electric circuit, including the indicator, shall be such that the relationship between the output of the photo-electric detector in the reflectometer head and the intensity of the light received by the reflectometer head does not change over the range of adjustment of the circuit and over the operating temperature range of the photo-electric detector.

c) The direction of viewing shall be perpendicular to the surface of the specimen.

d) The directional responsivity of the reflectometer head shall be as uniform as possible with a maximum aperture angle of 2 × 5°.

e) The influence of stray light by reflections within the illumination/detection system shall not exeed 1,5 % of the measured value or 0,05 FSN, whichever is smaller (see 10.9.6).

f) The proportionality (linearity) of the reflectometer system with respect to luminance shall be better than 1 % of the value measured according to CIE 69.

6.3.2 Filter Smoke Number FSN

6.3.2.1 The relation between the relative reflectometer value according to 6.3.1 and the filter smoke number of the exhaust gas sample (value when the filter is blackened by soot) is given, as a percentage, by the equation:

$$\text{FSN} = \left(1 - \frac{R_r'}{100} \right) \times 10$$

This equation may be applied only if the effective length calculated according to the formula given in 6.3.4 is 405 mm and the temperature and pressure of the gas in the system are according to 6.1, 6.2.6 and 6.2.7 respectively.[3)]

6.3.2.2 The indicator (display) shall have a resolution of at least 1 % of full scale.

6.3.2.3 Means shall be provided for checking and/or setting of full scale or near full scale value and for intermediate checks (see clause 9).

3) For the measurement of low or high smoke numbers, filter-type smokemeters whose effective lengths are greater or smaller, respectively, than 405 mm may be used. The measured values, however, need to be corrected as specified in clause 7 i), and the indicator range in filter smoke units may be reduced.

6.3.2.4 The reproducibility error of measurements on a calibrating screen shall be no worse than 0,05 FSN excluding the indicator and no worse than 0,05 FSN plus 1 % of full scale including the indicator (see 6.3.2.2).

6.3.3 Nominal suction volume, V_N, and effective filter area, A_F

The nominal suction volume and the effective filter area are normally determined from the design of the apparatus. If the nominal suction volume and the effective filter area (see 6.2.1.3), cannot be determined from the design data, they shall be measured.

The leak volume V_L shall be measured according to 10.2.4.

6.3.4 Effective suction volume, V_E, and effective filtered column length, l_F

The effective suction volume, V_E, is calculated according to the equation:

$$V_E = V_N - V_D - V_L$$

The effective filtered column length, l_F, is calculated according to the equation:

$$l_F = \frac{V_E}{A_F}$$

The actual effective length shall be determined to an accuracy of $\pm$ 1 %.

7 Information required from manufacturer

The manufacturer of the smokemeter shall provide a manual including the following items:

a) data on the dead volume and provisions necessary to ensure that this volume is filled with clean gas prior to sampling (see 6.2.1.2 and 8.2);

b) probe limitations with respect to temperature, pressure, velocity of exhaust gas, and exhaust pipe diameter (see 6.2.1.1 and 6.2.2);

c) data on the leakage (see 6.2.5);

d) data on the temperature of gas and, if applicable, correction means (see 6.2.6);

e) data on the nominal suction volume and reference/operating conditions (see 6.3.3);

f) means to correct the measured value if filters with properties other than those specified in 6.2.8 are used by the manufacturer of the filter-type smokemeter;

g) data on the characteristics of the smokemeter's reflectometer system and means for checking and/or setting (see 6.3.1);

h) data on the effective filter area (see 6.2.1.3 and 6.3.3);

i) data on the effective length (see 6.3.4): if the effective length is not within the range of 401 mm to 409 mm calculated according to 6.3.4, the manufacturer of the filter-type smokemeter shall provide the user with means to correct the measured values;

j) means to correct the measured values if the reflectometer characteristics differ from those specified in 6.3.1;

k) data on maintenance and/or checking schedule (see clause 9);

l) service test for ensuring and checking the performance of the apparatus (leak-tightness: see 6.2.5 and annex A ; calibration means for linearity check: see clause 9);

m) tolerances for operational voltages;

n) stabilizing time from switch-on for reflectometer;

o) any other information necessary to maintain the characteristics required in this International Standard.

8 Operating conditions of filter-type smokemeter

8.1 Installation of filter-type smokemeter

8.1.1 General

Only the probe(s) and sampling system provided by the manufacturer of the smokemeter shall be used.

The insertion of the sampling probe into the exhaust pipe shall not affect the engine performance; this shall be deemed to be achieved if the increase of back-pressure by the probe is less than 1 kPa (10 mbar). Should this not be the case, a sufficient length of a larger diameter exhaust pipe shall be provided for installation.

The temperature at the entrance of the probe shall be above the dew point of the exhaust gas.

NOTE 4 The exhaust gas temperature will usually be above the dew point but caution may be necessary when the ambient temperature is low, the engine is not fully warmed up, or the sulfur content of the fuel is high.

The overall installation shall be such that the sampling pipe from the probe to the smokemeter rises steadily and does not contain any sharp bends.

The probe shall be installed in the centre of the exhaust pipe; the straight part of the exhaust pipe upstream of the probe entrance shall be at least six times the diameter, and downstream at least three times the diameter of the exhaust pipe.

In cases where, for example because of high temperature conditions, it is not possible to install the filter-type smokemeter with the manufacturer's normal sampling pipe, an extension supplied by the manufacturer may be used (see 6.2.1.2). In these cases, however, a valve shall be fitted near to the smokemeter (see 8.2 for use of this probe in the sampling procedure).

In the case of large exhaust pipes, for example of more than about 250 mm diameter, it may be difficult to respect the requirements concerning the length of straight pipe. In such cases an alternative sampling arrangement may be used provided it has been established that the alternative ensures a representative sample.

8.1.2 Vehicle tail-pipe

For smoke measurement on vehicles with tail-pipe diameters of less than about 250 mm, the probe shall be installed — as precisely as possible — in the centre of the tail-pipe and a minimum of 300 mm from the end. The straight part of the exhaust pipe upstream of the probe entrance shall be at least six times the diameter and downstream at least three times the diameter of the exhaust pipe. If necessary, the tail-pipe shall be extended; however, if an extension pipe is used, no air shall be allowed to enter.

8.2 Sampling procedure

Sampling shall be carried out according to the operation instructions of the manufacturer of the smokemeter. Provisions shall be made to ensure that the dead volume is filled with clean gas immediately prior to sampling. If the sampling pipe has had to be extended, the valve in the sampling pipe shall only be open during the sampling period.

A sample shall then be taken with a filter inserted in the smokemeter. This filter shall be discarded and a new sample taken through a new filter. At least one more sample shall to be taken subsequently to cross-check the reading and to record the average.

Filters wetted by condensate or non-uniformly sooted shall be rejected.

9 Maintenance of filter-type smokemeter functional ability

Maintenance and/or checking shall be carried out according to the manufacturer's manual (see clause 7). Such maintenance shall ensure functioning of the filter-type smokemeter according to the requirements of this International Standard.

As an aid for checking apparatus in service, the manufacturer shall provide sufficient calibration screens or equivalent to ensure that linearity is checked. At least one calibration screen corresponding to about 3 FSN or 5 FSN known to an accuracy of 0,1 FSN shall be provided.

10 Verification of types of filter-type smokemeters

10.1 Applicable procedures

The procedures to be applied for verification of compliance of types of filter-type smokemeters with this International Standard (clauses 6 and 7) are specified below. This verification shall also include the test methods and limits for in-service tests, e.g. leak-tightness.

It shall first be checked that the required operational limits and data have been specified by the manufacturer. The verification test then consists of checking that, within the limits claimed by the manufacturer, the filter-type smokemeter does in fact satisfy the performance requirements of this International Standard.

Guidance is given as appropriate in 10.2 to 10.13 as to techniques to be used in the verification; they do not represent a complete list of tests, since guidance is not necessary where well-known experimental techniques already exist (e.g. dimensional, electrical, pressure, temperature, gas volume and mean velocity measurements).

These instructions may not, however, cover all possible designs of filter-type smokemeters and test set-up; alternative methods will, therefore, be accepted provided that they are equivalent in accuracy and comply with the response requirements of the methods described. Wherever recorders are used, it is essential that any effect of the recorder on the response or sensitivity of the circuit is taken into account.

10.2 Instrumentation and checking facilities for verification

For the verification of compliance of filter-type smokemeters with this International Standard, additional measuring and checking facilities are required, as follows.