
**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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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 responsivity 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)
$\bar{V}$	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 than 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 $298 \text{ K} \pm 4 \text{ K}$ ($25 \text{ }^\circ\text{C} \pm 4 \text{ }^\circ\text{C}$), the manufacturer shall provide means for converting smokemeter readings to 298 K ($25 \text{ }^\circ\text{C}$).

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.

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.

6.2.7 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 $(92 \pm 3) \%$ when measured with a reflectometer with 45° incidence of standard illuminant A and viewed perpendicularly with an aperture angle of $2 \times (5' \pm 1')$.

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:

$$R_{45/0}(\text{BaSO}_4) \approx \beta_{45/0}(\text{BaSO}_4)$$

or

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

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.