INTERNATIONAL STANDARD

ISO 10054

First edition
1998-09-01

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

Reference number
ISO 10054:1998(E)

Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

Printed in Switzerland

Annexes

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 $\pm$ 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 $\pm$ 4 K (25 °C $\pm$ 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 $\pm$ 3) % when measured with a reflectometer with 45° incidence of standard illuminant A and viewed perpendicularly with an aperture angle of 2 × (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:

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

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:

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

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.

10.2.1 A temperature-measuring position at the point of volume determination (see 6.2.6) to determine the temperature of the gas within the suction volume during sampling. The sensor to be used shall be a shielded thermocouple class A according to IEC 584-1 and IEC 584-2 with an outer diameter of 0,5 mm. The active point of the thermocouple shall be at least 7,5 mm from the point of insertion into the sampling system.

10.2.2 A pressure-measuring point to measure the pressure at the point of volume determination (see 6.2.7). The response time of the pressure sensor shall be less than one-tenth of the suction time of the pump or the suction operation time.

10.2.3 A reference reflectometer with characteristics according to 6.3.1 for measurement of grey tones with a calibration known to 0,05 FSN traceable to national standards or specifications (e.g. DIN 5036-1, DIN 5036-3 or CIE 38) which are recognized generally in the country. The acceptance area ("evaluated" area) of the reference reflectometer shall cover about 80 % of the effective area of the filter to be verified.

10.2.4 A device for checking leak-tightness and actual suction volume of the filter-type smokemeter. To define the leakage of the smokemeter system, the actual suction volume is measured and compared with the (theoretical) nominal suction volume generally derived from the geometrical dimensions of the suction pump. For measuring the suction volume a membrane-type device is used. Details of this device and its methods of use are given in annex A.

10.2.5 The device specified in annex A should be used for the measurement of the nominal suction volume (in the case where it cannot be determined from the geometrical dimensions of the apparatus).

10.2.6 A photometric bench with standard illuminant A according to ISO/CIE 10526 and a **turbid medium with diffuse non-regular transmittance**. The system shall allow the measurement of the proportionality (linearity) with an uncertainty of 1 % and with a resolution of 0,5 % or better.

10.2.7 A dark room (photometric laboratory) with a relative absorptance of 99 % or better over the whole spectral range of the reflectometer which is to be tested.

10.3 Checking for verification

10.3.1 Check for compliance with the data indicated by the manufacturer (according to clauses 7 and 8.2).

10.3.2 Check instrumentation and measuring facilities supplied by the manufacturer for compliance with this International Standard.

10.3.3 Check the apparatus performance for compliance with the requirements of this International Standard.

10.3.4 Check the leak volume of the filter-type smokemeter sampling system.

Tests for leakage (see 6.2.5) shall be carried out using the device and the procedure referred to in 10.2.4 and 10.2.5 . These tests shall be carried out on a new smokemeter representative of the type and also on a used or especially prepared smokemeter which is at or just below the lower limit of acceptability according to the service check of the manufacturer's manual [see clause 7 k)].

10.4 Measurements and calculations for verification

10.4.1 Nominal suction volume, V_N

The nominal suction volume shall be calculated from measurements of the plunger stroke and the body internal diameter. It shall be determined to an accuracy of 1 %.

If the nominal suction volume cannot be calculated from geometrical dimensions, it shall be measured with the same accuracy (see 6.3.3 and 10.2.5), or be determined with the apparatus described in annex A.

10.4.2 Suction time, t

Suction time (see 6.2.4) shall be determined, if required, by measurement of pressure at the point of volume determination as a function of time using a time-measuring system having a resolution of at least 0,05 s and a pressure-measuring system as specified in 10.2.2. This test can be made at any temperature between 291 K and 303 K (18 °C and 30 °C).

10.4.3 Dead volume, V_D

The dead volume (see 6.2.1.2) shall be calculated from geometrical dimensions or from the volume of a suitable liquid needed to fill the space. It shall be determined to an accuracy of 0,25 % of the nominal suction volume.

10.4.4 Effective filter area, A_F

The effective filter area is calculated from the geometrical dimensions of the filter clamping device. It shall be determined to an accuracy of 0,5 % (see also 6.2.1.3).

10.4.5 Effective filtered column length, L_F

The effective filtered column length shall be calculated according to 6.3.4. If it is other than in the range of 401 mm to 409 mm, the manufacturer's means for correcting results to 405 mm shall then be checked by comparison with practical tests with a filter-type smokemeter for which the effective length is 405 mm.

Such tests shall be made under the reference conditions of 6.1 , 6.2.6 and 6.2.7 with an unchanging smoke soot content of between 3,5 FSN and 4,5 FSN.

Smoke readings shall be taken simultaneously with the filter-type smokemeter under verification and the filter-type smokemeter with an effective length of 405 mm.

The total range of 10 measurements taken on either filter-type smokemeter shall not exceed 0,4 FSN.

The difference between the readings of the two filter-type smokemeters shall not exceed 0,3 FSN at any of the 10 measuring points.

The average difference between the readings of the two filter-type smokemeters over the 10 measuring points shall not exceed 0,1 FSN with a statistical confidence of at least 95 %.

These tests shall be repeated at a constant soot content of between 2 FSN and 3 FSN.

10.4.6 Minimum mean gas velocity, V_{min}

The minimum mean gas velocity shall be calculated from the nominal suction volume, the suction time and the largest cross-sectional area of the sampling system upstream of the filter. It shall be not less than 0,1 m/s as required by 6.2.4.

10.5 Cleanliness of gas in dead volume

The cleanliness of the gas in the dead volume shall be checked by operating the filter-type smokemeter in the normal way but sucking from the air rather than from exhaust gas. The sampling probe shall be fitted to an exhaust pipe and shall be quickly and easily removed by means provided by the manufacturer as specified in 6.2.1 if intended for use in vehicle measurement.

The filter-type smokemeter shall be used as normal, measuring exhaust smoke of 3,5 FSN to 4,5 FSN. The sampling probe shall then be removed from the exhaust pipe and a measurement taken sucking clean air after making provision for any cleaning of the dead volume as stated in the operating instructions. The cleanliness of the dead volume shall be considered to be verified if the reading does not exceed 0,1 FSN.

This sequence of measurements shall be repeated five times.

10.6 Temperature at end of sampling

Temperature measurements shall be taken when sampling over the whole range of exhaust temperatures and pressures specified by the manufacturer as being the operating range of the instrument; within this range the temperature during each sampling shall not vary be more than $\pm$ 2 K as indicated by the defined sensor (see 10.2.1). The mean temperature for each sampling shall correspond to that predicted directly or indirectly by the manufacturer within 2 K.

10.7 Representative sampling

10.7.1 As a partial check that the filter-type smokemeter takes a representative sample of the exhaust at a given cross-section, comparative measurements shall be made from two sections of an exhaust system, one of which is kept constant while the other is successively changed in diameter. The initial condition shall be one in which the exhaust diameter and exhaust velocity (controlled by engine size and speed) are about the centres of the ranges allowed by the manufacturer in the manual and the exhaust temperature is within the limits allowed by the manufacturer.

10.7.2 The initial condition and the conditions during change of the diameter of the variable section shall also meet the following requirements:

— exhaust velocity stays within the range allowed by the manufacturer [see clause 7 b)];

— exhaust temperature at the variable section is controlled (e.g. by heating or cooling) to remain constant (see 6.2.6);

— the proportion of straight length at the sampling points complies with 8.1;

— the length of exhaust pipe between the two sections is as short as possible.

10.7.3 Simultaneous or nearly simultaneous sampling shall be made at the "constant" section and each "variable" section. With smoke of 3,5 FSN to 4,5 FSN, the difference of reading between the "constant" and the "variable" sampling position shall not vary by more than 0,1 FSN. Sufficient repeated measurements shall be taken to establish this with a statistical confidence of 95 %.

10.8 Uniform blackening of filter area

Five filters blackened with soot and having a relative reflectometer value R_r, between 2 FSN and 6 FSN shall be tested with a reflectometer having a circular acceptance area of 4 mm diameter, a reproducibility of 0,05 FSN or better, and a resolution of the read-out equivalent to 0,01 FSN.

For each filter the relative reflectometer value R_{ri} on i single areas corresponding to the acceptance area shall be determined. The single areas shall be distributed symmetrically over the effective area: they may overlap and the outer ones shall approach the periphery of the effective area within 0,5 mm. A minimum of 80 % of the effective area (see 10.4.4) shall be checked by this method, with a statistical confidence of 95 %.

By calculating the mean value from those i values, the relative reflectometer value R_r of each filter is obtained.

The filter discs are regarded as uniformly sooted if the ratio R_{ri}/R_r is within the range 0,97 to 1,03 (relative reflectometer value) for any of the filter discs (see 6.2.2).

The area for normal evaluation (see 6.2.3) is regarded as acceptable if the average of the readings over this area is within 1 % of the average R_r with a statistical confidence of at least 95 % for each filter.

10.9 Reflectometer characteristics

10.9.1 Contact pressure

The pressure applied by the reflectometer shall be evaluated without application of an external force.

10.9.2 Uniformity of illumination

The uniformity of illumination of the evaluation area of the reflectometer shall be checked with an illuminance meter with a circular acceptance area of $d \leqslant 2$ mm for compliance with 6.3.1.2.

10.9.3 Spectral responsivity

For the proper procedure, see CIE 64.

10.9.4 Proportionality (linearity) of photo-electric detector

The proportionality (linearity) of the photo-electric detector shall be checked in a dark-room with all influences of stray light eliminated. For this purpose the photo-electric detector shall be removed from the reflectometer without disturbing the electrical circuit. The detector shall then be illuminated perpendicular with a variable illuminance E_x, on the photometer bench. The maximum illuminance E_{max} is that which gives an indicator reading of $A = 0$ FSN. The indicated reading A is then measured as a function of E_x by moving the illuminance source (kept at a constant setting) to different distances from the detector.

The proportionality error, in FSN, is then

$$\Delta A = A - \left(1 - \frac{E_x}{E_{max}}\right) \times 10$$

and the relative proportionality error, as a percentage, is

$$f = \left(\frac{\Delta A}{A}\right) \times 100$$

It shall be checked that f is less than 1 % (see 6.3.1.2).

See also note 3.

10.9.5 Reproducibility

In verifying the reproduceability according to 6.3.2.3, the test excluding the smokemeter indicator shall be made using a separate laboratory indicator which may have to have a greater sensitivity. It shall have equivalent electrical characteristics so as not to affect the performance of the smokemeter. If the reproducibility of the smokemeter with its own indicator is found to be no worse than 0,05 FSN over the whole range, then the test excluding the indicator need not be performed.

10.9.6 Influence of stray light

10.9.6.1 Stray light caused by reflectometer illumination

The measurement is made in a dark-room. The reflectometer is set to indicate 0 FSN on a stack of clean filters or as specified by the manufacturer. The indicator reading A is then recorded with the reflectometer pointing into the dark-room with no filter fitted. The influence of stray light is $(10 - A)$ in FSN and shall be less than 0,05 FSN.

10.9.6.2 Stray light caused by filter reflected light

Under these conditions the influence of stray light can only be measured together with the proportionality (linearity), in a dark-room on a photometric bench. A turbid medium with diffuse and nonregular transmittance is positioned in front of the reflectometer instead of a filter. This medium is illuminated from the outside with the lamp of the reflectometer switched off. The indicator reading A, in FSN, is then determined as a function of the outside illuminance E_x on the turbid medium. The reading of A, in FSN, and the illuminance E_x is

varied by varying the position of the outside light source as described in 10.9.4.

The influence of stray light is defined as the difference between the error measured according to this clause and the error measured according to 10.9.4. In determining all errors, indicator readings shall first be corrected according to the data provided as specified in clause 7 j).

NOTE 6 On a normal photometric bench it may not be possible to obtain a sufficient range E_x by movement of the constant source which gives E_{max}. Therefore when an illuminance E_{min} is reached at the largest practical distance of the lamp from the turbid medium or detector (see 10.9.6.1 or 10.9.4), the lamp may be moved back to the shortest distance ($\cong$ 1,5 m) and the voltage (current) to the lamp reduced to give the same indicator reading as that obtained with E_{min} at the largest distance. Lower illuminance values than E_{min} can then be obtained by moving the lamp (without change of voltage). This procedure can be repeated until a sufficient range of E_x has been obtained.

10.10 Filter characteristics

Compliance with the requirements of 6.2.8 shall be verified by reference to the filter manufacturer or by independent testing according to the standards quoted.

10.11 Calibration screen

The accuracy of the calibration screen shall be measured with a reflectometer with a calibration known to $\pm$ 0,05 FSN and traceable to national standards or specifications which are recognized generally in the country. The value given by the calibrated reflectometer shall not differ by more than 0,1 FSN from the value claimed for the calibration screen.

10.12 Accuracy of reflectometer system

The accuracy of the reflectometer system shall be determined by taking readings on blackened filters of about 2 FSN, 3 FSN, 5 FSN and 8 FSN blackness, first with the reflectometer supplied with the filter-type smokemeter and then with the reference reflectometer (see 6.2.3 and 10.2.3).

The difference between the two readings on any filter shall not exceed 0,05 FSN plus 3 % of the measured FSN. Sufficient measurements shall be made to establish this with a statistical confidence of 95 %.

10.13 Statistical methods

For calculating the accuracy in terms of the statistical significance of measurements, the methods of ISO 2602 shall be used.

Annex A
(normative)

Equipment for checking leakage and actual suction volume of filter-type smokemeter

A.1 General description

A.1.1 Diagram

A schematic diagram of the equipment is given in figure A.1.

A.1.2 Symbols

The following symbols are used in this annex — some are represented in figure A.1):

d_1 is the internal diameter of the measuring tube (see A.2.1)

d_2 is the internal diameter of the probe pipe (see A.2.3)

H is the level difference corresponding to actual suction volume

L_1 is the level of measuring membrane before suction stroke

L_2 is the level of measuring membrane after suction stroke

p_o is the ambient air pressure

s is the measuring tube wall thickness (see A.2.2)

T_o is the ambient air temperature

V_A is the actual suction volume (see A.4)

V_T is the measuring tube total volume (see A.2.5)

A.1.3 Measurement principle

In a measuring tube of known diameter, membranes are produced from a membrane-producing agent. After thoroughly wetting the measuring tube internally with several intermediate membranes, the level of the measuring membrane before suction is defined with the help of the aiming telescope and the digital measuring stand.

After performing the suction stroke, the level of the measuring membrane is measured again. The difference of the two levels corresponds directly to the effective suction volume of the tested filter-type smokemeter.

If the filter-type smokemeter is used under conditions where the static pressure at the probe inlet is other than atmospheric, then in deriving any correction for this fact the dynamic leakage test shall be made with the measuring tube under appropriate pressure or depression relative to the pump or smokemeter.

A.2 Specification of equipment necessary

A.2.1 Internal diameter of the measuring tube, d_1

To have similar conditions for smokemeters with different suction volumes, the internal diameter shall be within 15 % of that given by the equation:

$$d_1 = \sqrt[3]{\frac{V_N}{\pi}}$$

The effective inner diameter of the measuring tube shall be measured with an accuracy of 0,1 %.

A.2.2 Wall thickness of measuring tube, s

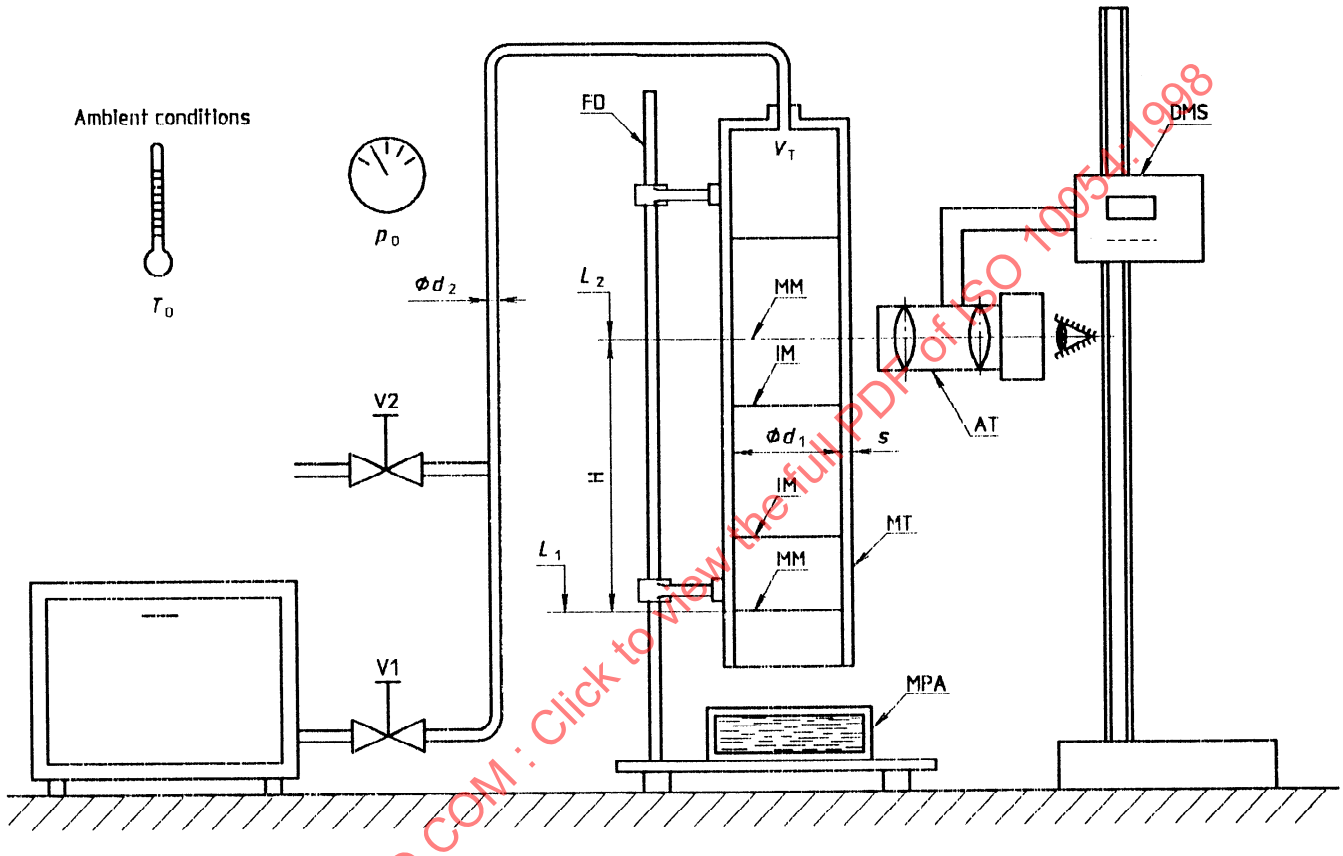
The measuring tube shall be made of transparent glass and the wall thickness of the measuring tube in the range where the membrane is travelling shall allow a clear sight of the membrane.

A.2.3 Probe pipe diameter, d_2

The active diameter of the probe pipe shall be according to the specifications of the smokemeter.

A.2.4 Aiming telescope, AT, and digital measuring stand, DMS

The aiming telescope and the digital measuring stand shall allow measurement of the membrane movement to an accuracy of at least 0,2 %.



Abbreviations:

AT:	aiming telescope	MT:	measuring tube
DMS:	digital measuring stand	V1, V2:	valves
IM:	intermediate membrane	FD:	fixing device
MM:	measuring membrane	MPA:	membrane-producing agent

Figure A.1

A.2.5 Total volume of measuring tube, V_T

To ensure similar conditions for the tests of smokemeters with different nominal suction volumes, V_N, the total volume, V_T, within the measuring tube shall be approximately twice the nominal suction volume, V_N.

A.2.6 Membrane-producing agent, MPA

The agent[4] allows the formation of membranes within the measuring tube of sufficient strength to withstand the travel during suction and with enough adhesion to the wall to keep the membranes in position even in a vertically arranged measuring tube.

A.3 Preparatory steps

To set up the equipment, the general rules for alignment and stability shall be observed.

The test can be carried out at any temperature between 291 K and 303 K (18 °C and 30 °C) but it is important for the test that the temperature of the equipment used and the ambient temperature do not differ by more than 1 K. To achieve this, the equipment, including the filling with membrane-producing agent shall be set up well in advance of the actual test and the prepared equipment shall be kept at constant ambient temperature for at least 12 h prior to the tests.

When connecting the smokemeter to the test equipment, note the probe pipe volume and, if necessary, adapt the connecting hose supplied with the smokemeter to have the specified volume typical for the smokemeter to be tested from the probe entrance to the smokemeter inlet.

With the smokemeter connected to the equipment, the piston positioned ready for the suction stroke, and the valves V1 and V2 open, several intermediate membranes are produced by dipping the mouth of the measuring tube, MT, into the membrane-producing agent, MPA, and transported through the measuring tube by various actions of suction at the V2 outlet to wet the inside of the measuring tube for smooth travel of the measuring membrane.

Now with several membranes in position and V2 closed, perform a suction stroke.

Repeat this procedure until the membranes within the tube remain stable and are not destroyed by the suction stroke. The equipment is now ready for the measurement, which shall follow immediately.

Table A.1 presents the above preparatory steps.

Repeat the steps in table A.1 until at least five consecutive MM have survived the suction stroke of the FSM.

Table A.1 — Procedure for preparation

Action	V1	V2	Conditions
Form several membranes at distances of approximately d_1 by dipping mouth of MT into MPA. Transport membranes through MT by sucking at open end near V2 for wetting purposes.	Open	Open	System is open to ambient air, at ambient temperature ± 1 K
Perform a suction stroke with the FSM.	Open	Closed	

4) E.g. Shell Teepol diluted with water.

Teepol is a trade-name. 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.

A.4 Test procedure for checking leak-tightness and actual suction volume

Prepare the equipment for test as described in A.3 . Perform each of following tests with a new, clean filter. In the position as prepared with valves V1 and V2 open, and the inside of the measuring tube thoroughly wetted, form several intermediate membranes at a distance of approximately d_1. The last membrane near the mouth of the measuring tube is considered the measuring membrane and, after closing valve V2, measure its position with the help of the aiming telescope and the digital measuring stand, when the position of the membrane is stable. Then, with the valve V1 open, perform a suction stroke, raising the measuring membrane from level l_1 to level l_2, and 5 s after completion of the suction stroke, close valve V1.

Then measured the membrane position again with the help of the aiming telescope and the digital measuring stand, when the position of the membrane is stable.

Now with valves V1 and V2 open, perform a setting stroke and start a new measuring cycle.

Calculate the actual suction volume of each measurement according to the equation:

$$V_A = \frac{\pi}{4} d_1^2 (l_2 - l_1)$$

To determine the mean actual suction volume, at least 10 measurements shall be performed; for measurement evaluation, the laws of statistics shall be applied (see ISO 2602).

Calculate the leakage volume according to the equation:

$$V_L = V_N - V_A$$

Table A.2 presents the above procedure.

A.5 Test procedure for checking nominal suction volume

For checking the nominal suction volume (see 10.2.5), use the apparatus substantially as described in A.4, but replacing the filter with an impermeable gasket which has a central hole and which seals the clamping areas that normally hold the filter. Also in such tests the suction plunger shall — if necessary — be moved slowly so that no significant depression is caused in the suction pump.

Table A.2 — Procedure for checking leakage and actual suction volume

Action	V1	V2	Conditions
Prepare equipment for test.			Procedure given in table A.1.
Clamp new clean filter in FSM.	Open	Open	
Form a membrane and bring it to start level.	Open	Open	Approximate positioning of membrane by sucking at open end of V2.
Measure l_1 with AT and DMS.	Open	Closed	Membrane shall stay in position.
Perform a suction stroke with FSM.	Open	Closed	MM travels from l_1 to l_2
Close V1 5 s after completion of the suction stroke.	Open, then closed	Closed	
Measure l_2 with AT and DMS.	Closed	Closed	Membrane shall stay in position.
Calculate actual suction volume.			With known diameter of MT and $l_2 - l_1$
Perform a setting stroke.	Open	Open	To make system ready for a further measurement.
Start new measuring cycle.			