INTERNATIONAL STANDARD 3173

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Road vehicles — Apparatus for measurement of the opacity of exhaust gas from diesel engines operating under steady state conditions

Véhicules routiers — Dispositif pour le mesurage de l'opacité des gaz d'échappement des moteurs diesel fonctionnant en régime stabilisé

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FOREWORD

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Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 3173 was drawn up by Technical Committee ISO/TC 22, *Road vehicles*, and circulated to the Member Bodies in November 1973.

It has been approved by the Member Bodies of the following countries :

Australia	Iran	Switzerland
Austria	Ireland	Thailand
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The Member Bodies of the following countries expressed disapproval of the document on technical grounds :

Germany
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Road vehicles — Apparatus for measurement of the opacity of exhaust gas from diesel engines operating under steady state conditions

1 SCOPE

This International Standard specifies the general requirements and the installation of instruments for measuring the light obscuration of exhaust gas from diesel engines for driving road vehicles, operating under steady state conditions. These instruments are generally known as "opacimeters".[1)]

Clauses 7 and 8 detail the tests which must be made to verify that a particular design of opacimeter conforms to this International Standard and the checks which must be made in service to verify that an opacimeter continues to conform to this International Standard when in use. Clause 9 gives an example of the type of test report which shall be used to record the results of the verification tests.

2 FIELD OF APPLICATION

This International Standard covers opacimeters for diesel engines for driving road vehicles. It is not intended to cover :

- free piston engines
- stationary engines
- marine engines
- engines for rail traction
- engines for aircraft
- engines for agricultural tractors and special vehicles for use in civil engineering.

3 PRINCIPLE OF OPACIMETERS

The principle of measurement is that light is transmitted through a length of the medium to be measured and the proportion of incident light which reaches a receiver (for example a photo-electric cell) is used to assess the obscuration of the medium.

4 CHARACTERISTICS OF OPACIMETERS

4.1 Basic specification

The gas to be measured shall be confined in an enclosure having a non-reflective internal surface, or equivalent optical environment.

In determining the effective length of the light path through the gas, account shall be taken of the possible influence of devices protecting the light source and the photo-electric cell.

This effective length should be indicated on the apparatus.

The indicating dial of the opacimeter shall have two measuring scales, one in absolute units of light absorption from 0 to ∞ (m^{-1}) and the other in obscuration units from 0 to 100 % in relation to the light flux reaching the photo-electric cell; both scales shall range from 0 at total flux to full scale at complete obscuration.

The opacity of the gas shall be referred to ambient pressure and 100 °C.

4.2 Construction specification

4.2.1 *General*

The design shall be such that in steady state operating conditions the measuring chamber is filled with smoke of uniform opacity.

This condition shall be deemed to be met if :

a) the variation of opacimeter indicator output over a period of 10 s, with smoke of constant temperature having a constant density of about 1,7 m^{-1}, measured with a recorder with a response time of 1 s, is not more than 0,075 m^{-1};

b) where the smoke chamber is divided, the mean temperature in the different sections does not differ by more than 7 °C.

1) The specification of the instrument and its installation are based originally on the C.E.C. work embodied in C.E.C. Specifications No. A-01-T-70 and A-01-M-70 which were drawn up to meet the requirements of Working Party 29 of the Economic Commission for Europe of the United Nations.

4.2.2 *Smoke chamber and opacimeter casing*

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

The optical characteristics shall be such that the combined effect of diffusion and reflection does not exceed 0,1 m^{-1} on the opacity scale when the smoke chamber is filled with smoke having an absorption coefficient near to 1,7 m^{-1}.

4.2.3 *Light source*

The light source shall be an incandescent lamp with a colour temperature in the range from 2 800 to 3 250 K.

4.2.4 *Receiver*

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

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

4.2.5 *Measuring scales*

The light-absorption coefficient k is calculated by the formula

$$\phi = \phi_0 \times e^{-kL}$$

where

L is the effective length of the light path through the gas;

ϕ_0 is the light flux received by the photo-electric cell when the measuring chamber is filled with clean air;

ϕ is the light flux received by the photo-electric cell when the measuring chamber is full of smoke.

When the effective length L of a type of opacimeter cannot be assessed directly from its geometry, the effective length L shall be determined :

— either by the method described in 7.7.5 b)

— or by correlation with another type of opacimeter for which the effective length is known.

The relationship between the 0 to 100 obscuration scale and the absorption coefficient is given by the formula

$$k = -\frac{1}{L}\log_e\left(1 - \frac{N}{100}\right)$$

where

N is a reading on the obscuration scale;

k is the corresponding value of the absorption coefficient.

The indicating dial of the opacimeter shall enable an absorption coefficient of 1,7 m^{-1} to be read with an accuracy of 0,025 m^{-1}.

4.2.6 *Adjustment and calibration of the measuring apparatus*

The electric circuit of the photo-electric cell and of the indicator shall be adjustable so that the pointer can be reset at zero when the light flux passes through the smoke chamber filled with clean air or through a chamber having identical characteristics.

With the lamp switched off, and the electric measuring circuit open or short-circuited, the absorption-coefficient scale reading shall be set to ∞, and it shall remain at ∞ with the measuring circuit reconnected.

An intermediate check shall be carried out with the lamp switched on, by placing in the measuring chamber a screen representing a gas, whose known absorption coefficient k, measured as in 4.2.5, is between 1,6 and 1,8 m^{-1}. The value of k should be known to within 0,025 m^{-1}. The check consists in verifying that this value corresponds to within 0,05 m^{-1} of the reading obtained on the indicator when the screen is introduced between the light source and the photo-electric cell.

4.2.7 *Pressure of the gas to be measured and of scavenging air*

The pressure of the exhaust gas in the smoke chamber shall not differ from the atmospheric pressure by more than 4 mbar. The pressure variation of the gas and the scavenging air in the smoke chamber shall not cause the absorption coefficient to vary by more than 0,05 m^{-1} in the case of a gas having an absorption coefficient of 1,7 m^{-1}.

The opacimeter shall be equipped with appropriate devices for assessing the pressure in the smoke chamber. It shall be possible to read these with an accuracy of 0,1 mbar.

The limits of pressure variation of the gas and the scavenging air shall be stated by the manufacturer of the apparatus.

4.2.8 *Temperature of the gas to be measured*

The opacimeter shall be equipped with appropriate devices for assessing the mean temperature of the gas in the smoke chamber and the manufacturer shall specify operating limits. The mean temperature must be indicated to ± 5 °C.

At every point in the smoke chamber the temperature of the test gas at the instant of measurement of opacity shall be not less than 60 °C and the mean temperature in the chamber shall be not more than 120 °C.

Where the mean operating temperature (t °C) is other than 100 °C the opacimeter reading shall be corrected to 100 °C by the formula

$$k_{\text{corrected}} = k_{\text{observed}} \frac{(t + 273)}{373}$$

This temperature range is one in which it is considered that all the water present is in vapour form and all other

uncondensed non-solid particles (i.e. the amount of uncondensed, unburnt fuel or lubricating oil) is insignificant in normal full-load exhaust smoke. Under these conditions the correction formula for the effect of temperature is valid. If the exhaust smoke contains an abnormal amount of non-solid constituents the correction formula may not be valid and a more restricted temperature range about the 100 °C reference condition is then advised.

4.3 Design details

Any pre-chamber and relief valve before the smoke chamber must not affect the opacity characteristics of the gas entering the smoke chamber by more than 0,05 m^{-1} for gas of 1,7 m^{-1} opacity.

Where an opacimeter is designed for intermittent operation a temperature sensor shall be provided upstream of the by-pass valve controlling entry of the gas into the smoke chamber. The by-pass system flow levels should be such that when set to the manufacturer's specification the change of sample temperature between the two by-pass positions is less than 5 °C.

5 DATA AND INSTRUMENTATION REQUIREMENTS

5.1 Data to be supplied by manufacturer

5.1.1 Effective length of the smoke column under sample conditions representing the recommended lower limits of temperature and pressure of exhaust gas and the higher limit of scavenge air pressure (where relevant) and normal test-bed ambient conditions.

5.1.2 Limits of sample pressure, at the inlet to the smoke chamber.

5.1.3 Limits on scavenge air delivery (where relevant). These should include setting instructions.

5.1.4 Limits of temperature (for example ambient air and exhaust sample) giving the position of measurement and their relation to mean temperature of the sample gas in the smoke chamber.

5.1.5 Limits on leakage of scavenge air from opacimeter casing and conditions of measurement (where relevant).

5.1.6 Instructions relating to dimensional limits on fittings which may be used, giving equivalent orifices.

5.1.7 Flow data :

a) Total sample flow to the opacimeter as a function of pressure at the inlet to the smoke chamber with exit conditions in accordance with 5.1.6 and at the limits of scavenge air pressure given in 5.1.3.

b) Sample flow through the smoke chamber as a function of pressure at the inlet to the smoke chamber with exit conditions in accordance with 5.1.6 and at the limits of scavenge air pressure given in 5.1.3. This information is only required when a pressure relief valve is fitted in the opacimeter upstream of the smoke chamber.

5.1.8 Limits of operation of light source, either :

a) limits of voltage at the contacts of the light source and instructions regarding bulb life; or

b) limits of reading with a coloured calibration filter.

5.1.9 Photo-electric cell surface temperature above which photo-electric cell output characteristics change significantly.

5.1.10 Photo-electric cell spectral characteristics, including its filter if one is used.

5.1.11 Limits of supply voltage within which the opacimeter will operate satisfactorily (separate limits for lamp and blower must be given if these have separate power supplies).

5.1.12 Technical description of opacimeter including electrical circuit diagram and dimensioned drawings of smoke chamber and adjacent areas (for example passages for air and smoke), with tolerances.

5.1.13 Information on servicing of opacimeter, including intervals between cleaning, and any special operating precautions particular to the given design including whether the opacimeter is designed for continuous or intermittent operation and, in the latter case, the time for which smoke must be passed through the opacimeter before a reading may be taken.

5.2 Instrumentation requirements

5.2.1 Instruments shall be fitted to measure the following :

a) Pressure of exhaust gas at inlet to the smoke chamber.

b) Temperature at point specified by manufacturer for measurement of sample temperature.

c) Pressure of scavenge air (if used).

d) Temperature of exhaust gas upstream of by-pass (if fitted).

e) Voltage at the lamp (unless a separate method using a coloured filter is provided for checking colour temperature).

f) Output of photo-electric cell circuit (i.e. for indicating the opacity of the exhaust gas).

5.2.2 Controls shall be fitted for the following :

a) Sensitivity of photo-electric cell circuit.

b) Flow of scavenge air.

5.2.3 Separate items for checking purposes must be provided as follows :

a) Filter for checking accuracy of the photo-electric cell and its circuit.

b) Orifice (or equivalent) for checking leakage (when scavenge air is used).

c) Orifice (or equivalent) for checking pressure drop characteristics of waste pipes.

6 INSTALLATION OF OPACIMETERS

6.1 Sampling opacimeter

The ratio of the cross-sectional area of the probe to that of the exhaust pipe shall not be less than 0,05. Insertion of the sampling probe into the exhaust pipe shall not affect the engine performance.

The probe shall be a tube with an open end facing upstream on the axis of the exhaust pipe, or of the extension pipe if one is required. It shall be situated in a section where the distribution of smoke is approximately uniform. To achieve this, the probe shall be placed as far downstream in the exhaust pipe as possible (or, if necessary, in an extension pipe) so that, if D is the diameter of the exhaust pipe at the probe, the end of the probe is situated in a straight portion at least $6\,D$ in length upstream of the sampling point and $3\,D$ in length downstream. If an extension pipe is used, no air shall be allowed to enter at the joint.

The pressure in the exhaust pipe and the characteristics of the pressure drop in the sampling line shall be such that the probe collects a sample equivalent to that which would be obtained by isokinetic sampling. If necessary, an expansion tank of sufficient capacity to damp the pulsations, and of compact design, may be incorporated in the sampling line as near to the probe as possible. A cooler may also be fitted. The design of the expansion tank and cooler shall not unduly disturb the composition of the exhaust gases.

A butterfly valve or other means of increasing the sampling pressure may be placed in the exhaust pipe at least $3\,D$ downstream from the sampling probe, on condition that this does not affect the engine performance.

The connecting pipes between the probe, the cooling device, the expansion tank (if required) and the opacimeter shall be as short as possible while satisfying the pressure and temperature requirements prescribed in 4.2.7 and 4.2.8. The pipe shall be inclined upwards from the sampling point to the opacimeter, and sharp bends where soot might accumulate shall be avoided. Where the opacimeter is fitted with a water trap the sample pipe need not rise continuously providing that there are no bends where soot and water might accumulate.

A check shall be carried out during the test to ensure that the requirements of 4.2.7. concerning pressure and those of 4.2.8, concerning the temperature in the smoke chamber are observed.

6.2 Full flow opacimeter

The only general precautions to be observed are the following :

– Joints in the connecting pipes between the exhaust pipe and the opacimeter shall not allow air to enter from outside.

– Pipes connecting the exhaust with the opacimeter shall be as short as possible. The pipe system shall be inclined upwards from the exhaust pipe to the opacimeter, and sharp bends where soot might accumulate shall be avoided. Where the opacimeter is fitted with a water trap the sample pipe need not rise continuously providing that there are no bends where soot and water might accumulate.

– A check shall be carried out during the test to ensure that the requirements of 4.2.7, concerning pressure, and those of 4.2.8, concerning the temperature in the smoke chamber, are observed.

– A cooling system may also be required upstream from the opacimeter.

7 VERIFICATION OF OPACIMETER TYPES

7.1 Scope and field of application

This clause specifies the procedures which shall be adopted in order to verify that a given opacimeter type complies with clauses 4 and 5. It covers full flow and sampling type opacimeters, and designs with and without scavenge air. All parts do not apply to all opacimeters and the applicability of any given clause will depend on the details of the opacimeter design, including whether it is for use with continuous or intermittent operation of the instrument. Where possible each heading includes a reference to the particular sub-clause in clauses 4 and 5 to which the test refers.

7.2 General considerations

In order to verify that an opacimeter type complies with the specification it is necessary first to check that certain instruments and controls required by the specification are fitted to the opacimeter and that certain operational limits and data are specified by the manufacturer. The verification test then consists of checking that the characteristics of the instruments are as required by the specification and that, within the limits claimed by the manufacturer, the opacimeter does in fact satisfy the performance requirements of the specification. For the verification tests certain instruments may be needed in addition to those normally fitted to the opacimeter.

In areas where well-known experimental techniques already exist (for example, optical and electrical) the tests are not described in detail, but in other cases detailed instructions are given. These instructions may not, however, cover all possible designs of opacimeters 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 described method. Wherever recorders are used it is essential that any effect of the recorder on the response or sensitivity of the circuit should be taken into account.

7.3 Definitions

The following symbols are used :

k = light absorption coefficient (opacity) of the gas in units metre^{-1} (m^{-1});

L = effective length of the opacimeter smoke column in metres (m);

N = reading on opacimeter obscuration scale in per-cent (%);

t = temperature in degrees Celsius (°C).

7.4 Data supplied by manufacturer (5.1)

Check that the data supplied by the manufacturer covers all the items required by 5.1 of the specification.

7.5 Instrumentation requirements (5.2)

Check that the instrumentation requirements of 5.2 of the specification are met by standard instruments supplied by the manufacturer.

7.6 Verification of instrumentation

7.6.1 *Colour temperature* (4.2.3)

Check that over the indicated conditions (for example by voltage at the contacts of the bulb or reading with a coloured checking filter) the colour temperature of the light source is between 2 800 and 3 250 K.

7.6.2 *Photo-electric cell response to different wavelengths and temperatures* (4.2.4)

Check that the combined photo-electric cell and filter characteristic has a maximum response in the range 550 to 570 nm, and less than 4 % of that maximum response below 430 nm and above 680 nm.

Check that the response of the photo-electric cell is not changed by operation at the maximum temperature specified by the manufacturer.

7.6.3 *Accuracy of measuring circuit and calibration* (4.1 and 4.2.6)

a) Check that the zero of the instrument can be satisfactorily adjusted over the range of supply voltages indicated by the manufacturer and that with the lamp switched off, the scale reading is infinity irrespective of whether the measuring circuit is connected or not.

b) Check the accuracy of the obscuration scale at at least six points between 10 % and 95 % obscuration. This check may be done on an optical bench or by using screens of neutral density, known to an accuracy of ± 0,5 %, or by other suitable equivalent methods. The obscuration scale should be accepted as satisfactory if the error of the scale is always less than 1 %. This test should be made with the normal and the maximum photo-electric cell temperature, given by the manufacturer.

NOTE — Using screens with a known density, account should be taken of the fact that the light passing through the screen is not exactly proportional to its density, since it is also influenced by reflection on the two borders of the screen between glass and air.

c) Check that the absorption of the calibrating screen supplied with the opacimeter, integrated over the range 430 to 680 nm in accordance with the photo-electric cell and filter characteristics, is within ± 0,025 m^{-1} of the value marked on it.

d) Check that the calibration filter supplied with the opacimeter gives an indicator reading within ± 0,05 m^{-1} of the value marked on it.

7.7 Verification of flow characteristics in relation to internal design

7.7.1 *Temperature distribution* (4.2.1 and 4.2.8)

7.7.1.1 Object

In order to determine the opacity of gas at 100 °C it is necessary to show that the temperature indicator provided by the manufacturer does in fact assess the mean temperature of the gas in the measuring chamber. This can be shown by comparing the reading of the temperature indicator with the results of measurements of temperature distribution within the smoke chamber. This test also permits verification that the minimum and maximum temperatures of the gas meet those specified in 4.2.8 and, where a central entry divides the smoke chamber into two, that the temperature difference between the two halves is acceptable.

7.7.1.2 Preparation of test

For measurement of temperature distribution, arrange-ments must be made for measurement of tempera-ture at different points along the centre line of the smoke chamber. Any temperature sensor must be held in a holder which provides good heat insulation and does not unduly affect the flow of gases. An example of a satisfactory method is to traverse the centre line of the smoke chamber with a thermocouple where the wires, of about 0,1 mm diameter, are joined end to end; with this system, however, it may be necessary to use a dummy bulb and photo-electric cell with holes drilled to allow passage of the wire. A thermocouple must also be provided for measuring the temperature of any scavenge air near where it mixes with the smoke.

7.7.1.3 Test procedure

With the opacimeter supplied with exhaust gas or heated air, measure the temperature distribution, point by point,

along the centre line of the smoke chamber and the scavenge air temperature near the mixing zone under the following stabilised conditions :

a) minimum sample temperature and minimum sample flow recommended by the manufacturer (minimum sample pressure and maximum scavenge air pressure);

b) maximum sample temperature and minimum sample flow recommended by the manufacturer (minimum sample pressure and maximum scavenge air pressure);

c) maximum sample temperature and maximum sample flow recommended by the manufacturer (maximum sample pressure and minimum scavenge air pressure).

7.7.1.4 Evaluation

Plot the temperature distribution along the centre line of the smoke chamber and, for opacimeters which use scavenge air, adjust the temperature distribution for the presence of air mixing with smoke, by the method of annex A and assess as follows :

a) Calculate the mean temperature t_a, t_b and t_c under the three test conditions and verify that when expressed as absolute temperature (K) they agree within 5 °C with the temperature derived from the indicator provided by the manufacturer.

b) Verify that under test condition (7.7.1.3 a)) the temperature of the test gas before mixing with scavenge air is not less than 60 °C.

c) Calculate the mean temperature t_a and t_b under test conditions 7.7.1.3 a) and b) and verify that

$$\frac{t_b + 273}{t_a + 273} \leqslant 1{,}06$$

Verify that under test condition 7.7.1.3 c) the maximum mean temperature does not exceed 120 °C.

d) Find the distance l_m (from the point of smoke entry) on the temperature traverse for test condition 7.7.1.3 b) at which the indicated temperature equals the mean temperature. For purposes of other parts of the verification test the temperature at this point will be deemed to be equal to the mean temperature of the sample gas in the smoke chamber. But for opacimeters with a central entry to the smoke chamber determine l_{m1} and l_{m2} for the two halves of the smoke chamber separately. For purposes of other parts of the verification test the mean temperature in the smoke chamber will be deemed to be the mean reading of two thermocouples, one in each half, mounted at a distance $0{,}5\,(l_{m1} + l_{m2})$ from the centre. A suitable design of thermocouple is given in figure 1.

e) For opacimeters with central entry to the smoke chamber verify that the mean temperature in the two halves does not differ by more than 7 °C under either of the test conditions.

7.7.2 *Steadiness of reading* (4.2.1)

7.7.2.1 Object

In opacimeters using scavenge air there may be a relatively large region of mixing of air and exhaust gas at the ends of the smoke chamber; this mixing may cause vorticity and a variation of effective length, leading to an unsteadiness and possible error of reading. Similarly where flow in the smoke chamber is divided, for example by a central entry, there is a possibility of a variation of flow between the two halves of the chamber which will also lead to variations of opacimeter readings. The extent of these effects shall be checked. Other designs of opacimeter, for example full flow designs, may also exhibit unsteadiness of reading and unsteadiness must, therefore, be checked on all designs.

7.7.2.2 Preparation of test

The output from the photo-electric cell shall be connected to a recorder with a frequency response of about 1 s to 90 % of full scale and with a chart speed of at least 10 mm/s. The sensitivity shall be such that 4 mm corresponds to not more than 0,05 m^{-1} at 1,7 m^{-1}. To ensure constancy of opacity, the exhaust sample shall be passed through a damping chamber with a volume of at least 20 times the flow through the sample line in 1 s and shall be drawn from an engine which has a firing frequency of at least 5 000 per minute.

7.7.2.3 Test procedure

Record the output from the photo-electric cell for about 10 s while a constant smoke of about 1,7 m^{-1} is passed through the opacimeter at the upper and lower sample pressures.

7.7.2.4 Evaluation

The steadiness shall be deemed satisfactory if the difference between the lowest and highest recorded values is less than 0,075 m^{-1} for each test condition.

7.7.3 *Internal reflectivity and diffusion* (4.2.2)

7.7.3.1 Object

If the internal surfaces of the smoke chamber are reflective or not sufficiently closed to external light, then unwanted reflected or diffused light will be received by the photo-electric cell. The extent of this effect must be checked.

7.7.3.2 Preparation of test

The principle of the method is to differentiate between reflected/diffused light and direct light by focusing the direct light from the lamp with a lens. Light from diffusion and reflection effects may then be defined as the light which crosses the plane of focus outside the area covered by the focused image of the lamp filament, for example if the image is a 10 mm diameter circle, any light crossing the focal plane outside of the 10 mm diameter circle, must be

reflected or diffused light. A screen, placed at the plane of focus, with a central hole slightly larger than the lamp filament image, will allow the light forming the image to pass but will stop most of the reflected and diffused light. Measurement of the light with and without the screen gives, by difference, the reflected and diffused light.[1] Preparation of test requires replacement of the photo-electric cell by a lens of focal length and diameter about equal to the diameter of the sensitive part of the photo-electric cell, provision of a matt black screen with a central hole slightly larger than the image of the lamp formed by the lens, and provision to move the photo-electric cell to collect light which comes through the hole in the screen.

Arrangements shall be made to allow measurement in two conditions :

a) The lamp, lens, screen and photo-electric cell shall be fitted in the opacimeter (for example as in figure 3) with the smoke chamber in normal condition (this should not be a "new" condition but the inside surfaces of the smoke chamber should be "conditioned" by passing smoke through the opacimeter in normal operation). Arrangements should be made for easy removal of the screen from the light path, and it may be necessary to modify the opacimeter casing so that the screen and photo-electric cell can be accommodated inside the opacimeter casing and the opacimeter can be operated normally in terms of passage of smoke and (where relevant) scavenge air.

b) The lamp, lens, screen and photo-electric cell shall be set up in the same relative positions as in arrangements a) but in a non-reflecting environment. In a sampling type opacimeter this may be achieved by removing the smoke tube and part of the casing, painting the inside of the remainder of the casing matt black and carrying out the test in a room with matt black walls.

7.7.3.3 Test procedure

a) With the lamp, lens etc., arranged as in 7.7.3.2 b) above, set the electrical circuit sensitivity to give an indicator reading of 1,7 m^{-1} when the lamp is switched on. Remove the screen and note the new reading. Repeat to give at least four pairs of readings.

b) With the opacimeter arranged as in 7.7.3.2 a) above and screen in position, set the electrical circuit sensitivity to give an indicator reading of 1,7 m^{-1} units; remove the screen and note the new reading. Repeat to give at least four pairs of readings.

c) With the opacimeter arranged as in 7.7.3.2 a) above and screen in position, set the sensitivity to give an indicator reading of zero when the smoke chamber is filled with clean air. Pass smoke of about 1,7 m^{-1} through the instrument and note the indicator reading; remove the screen and note the new readings. Repeat to give at least four pairs of readings. (For this test a large damping volume may be required in the sample line to smooth out effects of engine variations; recording of the photo-electric cell output is also recommended.)

7.7.3.4 Evaluation

If the change of readings under the three conditions are Δ_a, Δ_b and Δ_c (each an average of at least four values) then the test set-up is satisfactory if :

$\Delta_a < 0{,}1\ m^{-1}$ (this will mainly be light scattered from the lens surface)

and the opacimeter reflection and diffusion characteristics are satisfactory if :

$$\Delta_b - \Delta_a < 0{,}65\ m^{-1}$$

and

$$\Delta_c - \Delta_a < 0{,}1\ m^{-1}$$

7.7.4 *Photo-electric cell temperature* (4.2.4)

7.7.4.1 Object

Above a certain temperature the sensitivity of the photo-electric cell is changed; this temperature is given by the manufacturer and the object of the test is to verify that this is not exceeded under the most severe operating conditions of the opacimeter. For this test a thermocouple resting on the surface of the cell/filter assembly shall be deemed to indicate photo-electric cell temperature.

7.7.4.2 Preparation of test

A thermocouple shall be placed on the surface of the photo-electric cell/filter assembly on the axis and facing the light beam. Arrangements shall be made to supply the opacimeter with exhaust gas or air at the highest temperature and pressure recommended by the manufacturer. Arrangements shall be made to heat the scavenge air supply to the maximum recommended by the manufacturer.

7.7.4.3 Test procedure

The exhaust gas or hot air shall be passed through the opacimeter, otherwise operating normally, until the temperature of the photo-electric cell has stabilised. This temperature shall be measured together with the temperature and pressure of the gas and the temperature of the scavenge air.

7.7.4.4 Evaluation

The specification is deemed to be met if the temperature of the photo-electric cell is below the maximum recommended by the manufacturer.

1) It should be noted that this light does not only come from reflection and diffusion effects in the opacimeter but may also come from light scattering at the surface of the lens. This scattered light may be reduced by use of a bloomed lens but some remains as a baseline which has to be taken into account during calculation.

7.7.5 *Effective length* (4.2.5)

7.7.5.1 OBJECT

The effective length, given by the manufacturer, must be checked to verify the absolute calibration of the opacimeter; it can be obtained either by comparison with an opacimeter for which the effective length is known or by comparison of readings taken with the opacimeter operating normally and when modified so that the smoke fills a known length. In both cases it is necessary also to know the average temperature of the gas in the smoke chamber in order to permit corrections for the difference in temperature between the opacimeter operating normally and the reference or modified opacimeter.

7.7.5.2 COMPARISON WITH A KNOWN OPACIMETER

7.7.5.2.1 Preparation of test

The test opacimeter and known opacimeter shall be connected for simultaneous sampling. The sample to each opacimeter shall be controlled to the lower limits of temperature and minimum sample flow recommended by the manufacturer (minimum sample pressure and maximum scavenge air pressure). Provision shall be made for measuring the mean temperature, t, in the smoke chamber of the opacimeter under test in accordance with 7.7.1.

7.7.5.2.2 Test procedure

Simultaneous readings shall be taken on the two opacimeters with smoke at between 40 and 60 obscuration units. At least ten readings shall be made.

7.7.5.2.3 Evaluation

For each obscuration reading calculate the effective length by the formula :

$$L = L_0 \times \frac{t + 273}{t_0 + 273} \times \frac{\log\left(1 - \frac{N}{100}\right)}{\log\left(1 - \frac{N_0}{100}\right)}$$

where L, N and t, refer to the opacimeter under test and L_0, N_0 and t_0 refer to the known opacimeter. The average of the readings shall be taken as the effective length. Verify that the average effective length is statistically valid to an accuracy of ± 1 %[1] with 95 % confidence[2]; if this degree of confidence is not attained then further tests shall be made until the statistical requirement is satisfied. In calculating the confidence limits account must be taken of the known accuracy of the reference opacimeter. The latter must clearly be much better than ± 1 %.

7.7.5.2.4 Alternative

When it is not possible to control the sample temperature to the desired values, measurements should be made separately of the average temperature in the smoke chamber of both opacimeters; the opacimeter readings should then be corrected for the difference between the measured temperature and the average temperature in the smoke chamber corresponding to the minimum sample temperature specified by the manufacturer.

7.7.5.3 COMPARISON OF RESULTS FROM ONE OPACIMETER WITH AND WITHOUT MODIFICATION OF OPERATION

7.7.5.3.1 Preparation of test

Provision must be made for rapid modification of the opacimeter from its normal operating condition (geometric effective length L) to a condition where the test gas fills a well-defined length L_0. With an opacimeter using scavenge air to contain the smoke column a convenient method of modification is merely to block the scavenge air inlet so that the test gas fills the space between the bulb and photo-electric cell. The surfaces defining the length L_0 will depend on the design of the opacimeter, they may for example be glass screens or the surface of the bulb and the surface of the photo-electric cell/filter combination. In the latter case the measurement shall be made from the surface of the bulb nearest to the photo-electric cell.

For the actual test the opacimeter should be supplied with exhaust gas of constant opacity at the lower limit of temperature and sample flow (lowest sample pressure and highest scavenge air pressure) specified by the manufacturer. The output from the photo-electric cell shall be connected to a recorder with a response time of less than 1,0 s and sensitivity such that 4 mm corresponds to not more than 0,05 m^{-1} for a smoke at 1,7 m^{-1}. The relation of recorder deflection to obscuration units shall be determined.

To ensure satisfactory constancy of opacity, exhaust samples shall be passed through a damping chamber of at least 20 times the flow through the sample line in 1 s. This sampling system may require a heater to ensure satisfactory sample temperature. If not already provided, a by-pass shall be fitted to the opacimeter with the outlet adjusted so that the temperature of the sample at the by-pass is not changed by more than 5 °C between the two by-pass positions.

Provision shall be made for measuring the mean temperature in the smoke chamber as described in 7.7.1. Where the modification to fill a known length involves any modification of scavenge air flow, a check should be made to ensure that this modification does not affect the bulb

1) For the present this may be increased to 2 %.

2) Annex B gives some notes on statistical tests.

performance (i.e. the modification does not affect zero reading) or a separate power supply to the bulb must be provided. Where the ratio $L_0/L \leqslant 1{,}25$ the mean temperature sensor position derived from 7.7.1 can also be taken as indicating the mean temperature of the smoke in both the modified and unmodified opacimeter conditions. But, when $L_0/L > 1{,}25$ the temperature indicated by the above sensor must be converted to true mean temperature over the length L_0 by use of separately obtained data. Such data can, for example, be obtained by comparing the sensor temperature with the temperature indicated by a resistance wire cage spanning the full length L_0; it is essential, however, that the comparative data be obtained under the same sequence of test conditions as used in the measurement of effective length, for example scavenge air blanked for 10 to 15 s following a stabilised period of normal operation.

7.7.5.3.2 Test procedure

Calibration lines should be recorded corresponding to two convenient points. Recordings should then be made while test gases of different opacities are passed through the opacimeter and the opacimeter is switched from working normally to working as modified with the effective length L_0. For each test the modified conditions should be held for at least 10 s or for a time greater than the response time of the mean temperature indicator, whichever is the longer. At the end of each period of modification check the "zero" setting with clean air.

In order to protect the photo-electric cell surface from excessive temperatures a shield may be placed in front of it during the initial period of each modification; this shield should not be more than 1 mm from the surface of the photo-electric cell and should be completely removed during all periods of measurement. If the "zero" recorded between tests increases to more than 0,4 m^{-1} the bulb and photo-electric cell should be cleaned before further tests are made. Readings should be made with exhaust opacities corresponding to levels of between 40 and 60 obscuration units and at least ten readings (each reading comprising a comparison of modified and unmodified conditions) made.

7.7.5.3.3 Evaluation

For each recording determine :

N = reading with unmodified opacimeter referred to the "zero" immediately before admitting the smoke sample;

t = average temperature in smoke chamber corresponding to opacimeter reading N;

N_0 = reading with opacimeter modified, taken immediately after the modification, and referred to the zero obtained immediately before admitting the smoke sample;

t_0 = average temperature in the smoke chamber corresponding to opacimeter reading N_0.

The effective length is then given by :

$$L = L_0 \times \frac{t + 273}{t_0 + 273} \times \frac{\log\left(1 - \frac{N}{100}\right)}{\log\left(1 - \frac{N_0}{100}\right)}$$

Verify that the average effective length is statistically valid to an accuracy of ± 1 %[1] with 95 % confidence; if this degree of confidence is not attained then further tests shall be made until the statistical requirement is satisfied.

7.7.6 *Effect of sample and scavenge air pressures* (4.2.7)

7.7.6.1 Object

The effective length of the opacimeter may be changed by changes of sample pressure and scavenge air (where used); the operating limits claimed by the manufacturer should be verified. This test also enables a check to be made on the pressure in the measuring chamber.

7.7.6.2 Preparation of test

The same test method should be used as for the measurement of effective length, 7.7.5, but additionally arrangements should be made to measure the maximum pressure/depression in the smoke chamber. This latter provision may be omitted if it can be shown from consideration of sample and scavenge air pressures that the pressure in the smoke chamber does not differ from atmospheric pressure by more than 4 mbar.

7.7.6.3 Test procedure

The effective length shall be determined by the method given in 7.7.5 with the opacimeter supplied with exhaust gas of about 1,7 m^{-1} opacity and at the maximum flow (maximum sample pressure and minimum scavenge air pressure) and minimum temperature specified by the manufacturer. At least ten readings shall be made. Note the pressure of gas in the measuring chamber unless such measurement is excepted under 7.7.6.2.

7.7.6.4 Evaluation

The sample pressure and scavenge air limits claimed by the manufacturer are satisfactory if :

$$\frac{\text{Effective length at maximum sample flow}}{\text{Effective length at minimum sample flow}} \leqslant 1{,}03 \text{ and } > 1{,}00$$

The above relation shall be satisfied to a statistical confidence limit of 95 %[2]. If this degree of confidence is not attained then further tests shall be made until the statistical requirement is satisfied. The pressure in the smoke chamber is satisfactory if it does not differ from atmospheric by more than 4 mbar.

1) For the present this may be increased to 2 %.

2) Annex B gives some notes on statistical tests.

7.7.7 *Gas tightness of opacimeter* (5.1.5)

7.7.7.1 GAS TIGHTNESS OF BY-PASS VALVE

7.7.7.1.1 Object

If the by-pass valve leaks, then, depending on the design of the opacimeter, the zero of the instrument will be affected and incorrect opacimeter readings obtained. The efficiency of the by-pass valve must, therefore, be checked.

7.7.7.1.2 Preparation of test

Arrangements must be provided for reducing the smoke pressure at the by-pass to below the pressure in the opacimeter; for engines connected to an exhaust main operating at ambient pressure or a slight depression it will be sufficient to stop the engine. In other cases it may be necessary to disconnect the sample line from the probe or opacimeter, or fit (for this test only) a valve in the sample line which can be positively closed.

7.7.7.1.3 Test procedure

The by-pass should be set in the position so that the exhaust gas by-passes the smoke chamber. Reduce the pressure on the sample side of the by-pass until it is below the pressure on the smoke chamber side and set the opacimeter "zero". Then allow the pressure on the sample side of the valve to return to normal and pass smoke of about 1,7 m^{-1} opacity through the sample system and by-pass at a rate corresponding to the maximum sample pressure when the opacimeter is operating normally; note the opacimeter reading.

7.7.7.1.4 Evaluation

The by-pass valve is satisfactory if the change of reading between the two conditions is less than 0,01 m^{-1}.

7.7.7.2 GAS TIGHTNESS OF CASING

7.7.7.2.1 Object

In opacimeters using scavenge air, leakage of the air through joints and clearances around controls may alter the effective length. The manufacturer specifies a limit for this leakage and it must be verified that this amount of leakage does not alter the effective length.

7.7.7.2.2 Preparation of test

An opacimeter must be prepared in which all joints and clearances are sealed. An adjustable "leak" must then be provided in the casing near the waste outlet of the housing. With the leak valve shut find the scavenge air system setting (S_1) to give the maximum allowable scavenge air flow.

Then, find the scavenge air setting (S_2) and leak valve setting (L) such that the maximum leakage allowed by the manufacturer is obtained with a scavenge air setting corresponding to the maximum scavenge air flow allowed by the manufacturer.

7.7.7.2.3 Test procedure

Pass smoke of about 1,7 m^{-1} opacity at minimum sample pressure through the opacimeter and note the reading with leakage valve shut and scavenge air setting S_1, and then with leakage valve setting L and scavenge air setting S_2. Repeat at least four times. For ease of reading the opacimeter the sample system shall include a damping chamber of at least five times the flow through the sample line in 1 s.

7.7.7.2.4 Evaluation

Average the readings with and without the leak; the difference should not be greater than 0,025 m^{-1} with a statistical confidence of 95 %. If this degree of confidence is not attained then further tests shall be made until the statistical requirement is satisfied.

7.7.8 *Waste exit conditions* (5.1.6)

7.7.8.1 OBJECT

The manufacturer has to state limits on the waste exit conditions, for example length of pipe(s), pressure characteristics of pipes, limitation of back pressure or extraction pressure permissible on any standard pipes provided. The effect of these limits must be tested.

7.7.8.2 PREPARATION OF TEST

Arrangements shall be made so that the waste exit conditions can be rapidly varied between the limits specified by the manufacturer.

7.7.8.3 TEST PROCEDURE

Pass smoke of about 1,7 m^{-1} opacity through the opacimeter and note the readings with the waste exit conditions alternated between the limits. For ease of reading the opacimeter, the sample system shall include a damping volume of at least five times the flow through the sample line in 1 s.

7.7.8.4 EVALUATION

No measurable change of opacimeter reading should occur between operation with the two exit conditions.

7.7.9 *Effect of pre-chamber and pressure relief valve design* (4.3)

7.7.9.1 OBJECT

Certain opacimeters may have a pressure relief valve in a pre-chamber just upstream of the smoke chamber. This item, if incorrectly designed, could result in a modification of the exhaust gas sample by unequal division of soot by the valve. The possible occurrence of this must be checked.

7.7.9.2 Preparation of test

The test set up shall be as shown in figure 2, and, to ensure satisfactory constancy of opacity of exhaust samples, the damping chamber shall have a volume of at least 20 times the flow through the sample line in 1 s. The need for the heater will depend on the temperature and insulation of the sampling system. Means shall be provided so that the relief valve can quickly be shut or opened. The butterfly valve in the exhaust system shall be adjusted so that with the relief valve operating normally, the maximum sample pressure is obtained at the opacimeter with valve A closed and valve B fully open. With the relief valve shut, find positions of valves A and B such that the sample pressure at the opacimeter is unchanged and the pressure in the damping chamber is unchanged. The valve in the exhaust system must not be altered. Note the positions of valves A and B. Arrangement shall be made to record photo-electric cell output and the mean temperature in the smoke chamber (as defined in 7.7.1).

7.7.9.3 Test procedure

With the opacimeter supplied with exhaust gas at about 1,7 m^{-1} opacity and at the maximum sample pressure, record opacimeter reading and mean temperature in the smoke chamber with the relief valve operating normally (valve A shut and valve B fully open) and with it closed and valves A and B adjusted as described above. Repeat at least four times.

7.7.9.4 Evaluation

Correct the readings of the opacimeter for any changes of mean temperature in the smoke chamber. The pressure relief valve and pre-chamber shall be deemed to be satisfactory if the average difference between the corrected readings of the opacimeter with the valve operating and shut is less than 0,05 m^{-1}.

7.7.10 *By-pass characteristics* (4.3)

7.7.10.1 Object

Some opacimeters will be fitted with a by-pass at the entrance; this must have flow characteristics similar to the opacimeters or sampling conditions may be changed between the two by-pass positions with consequent delays in stabilizing readings. The characteristics of the by-pass must therefore be checked.

7.7.10.2 Preparation of test

The opacimeter shall be connected to a normal engine exhaust sampling system and a well-insulated thermocouple of response better than 5 s inserted in the exhaust gas just upstream of the by-pass. If a range of waste pipes is allowed on the by-pass exit then the extremes of these should be available.

7.7.10.3 Test procedure

Record the readings of the thermocouple as the by-pass is switched between the "smoke entry" and "by-passing" positions. Repeat with extremes of by-pass exit conditions.

7.7.10.4 Evaluation

The difference in thermocouple reading between the two by-pass positions shall not be more than 5 °C.

7.7.11 *Flow characteristics* (6)

7.7.11.1 Object

For correct sampling it is necessary to ensure that the velocity in the sampling probe is as close as possible to that of the main flow; thus the following test must be undertaken to determine the flow rate through the sampling line and opacimeter for different sampling pressures.

7.7.11.2 Preparation of test

The sample inlet to the opacimeter shall be connected to a supply of air sufficient to maintain the maximum pressure at the opacimeter recommended by the manufacturer. A gasmeter or orifice shall be provided for measurement of flowrate. Arrangements shall be provided for temporarily blocking shut all relief valves fitted to the sample inlet to the opacimeter.

7.7.11.3 Test procedure

With the correct waste exit conditions and at the upper and lower limits of scavenge air pressure, measure the flow of air to the sample inlet, as a function of pressure at the entrance to the opacimeter, between the operating limits specified by the manufacturer :

a) with any relief valve operating normally, and

b) with any relief valve blocked shut.

Note the "leakage" of the scavenge air for information.

7.7.11.4 Evaluation

The results shall be presented as a graph of sample pressure (millibars) against air flow (litres/second) for the two conditions a) and b). The temperature to which the results are referred should be stated on the graph.

7.7.12 *Soiling of lamp and photo-electric cell* (5.1.13)

7.7.12.1 Object

Continued operation of an opacimeter may lead to deposition of soot on the bulb and photo-electric cell and

this will affect the reading. The manufacturer states the necessary intervals between cleaning and it must be verified that the opacimeter can be satisfactorily operated for this period without cleaning.

7.7.12.2 PREPARATION OF TEST

Clean the lamp and photo-electric cell and with the photo-electric cell output connected to a recorder adjust the sensitivity of the latter to give a deflection such that a change of 0,5 % can be assessed.

7.7.12.3 TEST PROCEDURE

Pass smoke of about 1,7 m^{-1} opacity at maximum sample pressure through the opacimeter (with scavenge air, where used, set to minimum pressure) for at least 10 s or for the time necessary to take a reading (whichever is the longer). Stop the flow of smoke, fill the smoke chamber with clean air as for a normal zero check and note the recorder reading. Repeat the cycle of passing smoke and checking the zero throughout the interval claimed by the manufacturer, or for twelve readings (whichever is the shorter).

7.7.12.4 EVALUATION

The freedom of the lamp and photo-electric cell from soiling shall be deemed satisfactory if the change of recorder reading during the test is less than 0,5 %.

8 VERIFICATION OF IN-SERVICE CONFORMITY OF OPACIMETERS

8.1 Scope and field of application

This clause gives the minimum checks which must be made in service to verify that an opacimeter of a type which has been verified in accordance with clause 7 continues to conform to the specification when in use.

8.2 Items to be checked

In service it is necessary to check that the following items are correct :

1 Colour temperature of light source.

2 Photo-electric cell circuit setting and accuracy.

3 Sample pressure indicator.

4 Scavenge air setting :

a) setting of blower;

b) performance characteristics of blower (if not covered by a)).

5 Sample temperature sensor.

6 Pipe fittings (for example waste pipes).

7 Gas tightness of casing.

8 Gas tightness of by-pass valve (if fitted).

9 Mechanical and chemical condition of all moving parts and installation items.

10 Division of flow (occasional check for opacimeters with central entry to the smoke chamber).

8.3 Details of checks

8.3.1 *General*

Most of the items can be checked against the list of operating limits provided by the manufacturer but it should be verified that the necessary instruments and fittings (voltmeters, manometers, controls, and orifices) are supplied as standard equipment with the opacimeter. The accuracy of the temperature sensor should periodically be checked by standard methods.

8.3.2 *Division of flow*

At intervals of about 1 month, with normal usage, opacimeters with central smoke entries should be checked to ensure that the temperatures in the two halves of the smoke chamber remain within the limits of the specification. Unless instrumentation is already provided by the manufacturer the check consists of inserting well insulated temperature sensors at the points in the two halves corresponding to the mean temperatures. When smoke or hot air at the maximum temperature limit specified by the manufacturer is passed through the opacimeter the difference in temperature between the two halves of the smoke chamber shall be less than 7 °C.

9 TEST REPORT OF OPACIMETER VERIFICATION

Opacimeter manufacturer : . . . . . .

Type : . . . . . .

No. : . . . . . .

9.1 Data supplied by manufacturer

[Enumerate]

9.2 Results of verification of instruments

9.2.1 *Colour temperature* (7.6.1)[1]

Bulb type . . . . . .

Operating limits . . . V to . . . V (given by manufacturer)

Corresponding colour temperature . . . K to . . . K

Corresponding reading with coloured filter[2] . . . o.u. to . . . o.u.

9.2.2 *Photo-electric cell response to changing wavelength and temperature* (7.6.2)

Photo-electric cell type . . . . . Filter type . . . . . .

Spectral characteristics a)[3] . . . . . b)[3] . . . . . .

Photo-electric cell temperature . . . . . °C

Wavelength for maximum response . . . . . nm

Response at 430 nm . . . . . % of max.

Response at 680 nm . . . . . % of max.

Overall response a)[3] . . . . . b)[3] . . . . . .

Photo-electric cell temperature . . . . . °C

Indicator reading, lamp on, circuit connected . . . . . 0[1] . . . 0[1] o.u.

Indicator reading as above, plus calibrating screen . . . . . .

9.2.3 *Accuracy of measuring circuit and calibration* (7.6.3)

Bulb voltage setting . . . . . .

Indicator reading with V

lamp switched off, circuit . . . . . 100 o.u.[4]

lamp switched off, circuit connected . . . . . o.u.

Test No.	Photo-electric cell temperature °C	Effective obscuration %	Readings on the obscuration scale %	Error
1 2 3 4 etc.				

Calibrating screen equivalent opacity claimed by manufacturer . . . . . m^{-1}

measured . . . . . m^{-1}

difference . . . . . m^{-1}

1) Numbers in parentheses refer to the corresponding clause of the opacimeter specification.

2) Delete if inapplicable : o.u. = obscuration units (%).

3) Condition a), ambient temperature; condition b), photo-electric cell temperature at maximum specified by manufacturer.

4) By adjustment.

9.3 Results of verification of flow characteristics in relation to internal design

9.3.1 *Temperature distribution* (7.7.1)

Test conditions a) b) c)

Sample temperature[1] . . . . °C (t_a', t_b' and t_c')

Sample pressure . . . . mbar

Scavenge air pressure . . . . mbar

Stabilizing time . . . . min (before traverse is made)

Test results : See figure 4

Minimum temperature of test gas (before mixing with scavenge air)[2] . . . °C

Mean temperature t_a under condition a) . . . . °C

t_b b) . . . . °C

t_c c) . . . . °C

Distance l_m (from the point of smoke entry) for condition b) at which the measured temperature equals the mean temperature

[2] For an opacimeter with smoke entry at one end of tube : l_m . . . . mm

[2] For an opacimeter with central smoke entry : l_{m1}, left of entry . . . mm

l_{m2}, right of entry . . mm

0,5 ($l_{m1} + l_{m2}$) . . . . mm

Differences between temperature at l_{m1} and temperature at l_{m2}

for condition a) . . . . °C

for condition b) . . . . °C

Maximum difference between assessed (t_a', t_b', t_c') and measured (t_a, t_b, t_c) mean temperatures expressed in kelvins . . . K

9.3.2 *Unsteadiness of reading* (7.7.2)

Test conditions

Recorder characteristics response . . . . seconds to 90 % full scale

sensitivity . . . . m^{-1}/mm (at test opacity)

chart speed . . . . mm/s

Sampling system (brief description) . . . . .

Test condition (sample) . . . . max. . . . min.

Opacity of test gas . . . . m^{-1}

Sample pressure . . . . mbar

Scavenge air pressure . . . . mbar

Sample temperature . . . . °C

Test results : See figures 5 and 6

Unsteadiness over 10 s . . . . m^{-1} (range)

1) Mean temperature in the smoke chamber assessed from the sample temperature indicator provided by the manufacturer.

2) Delete if inapplicable.

9.3.3 *Internal reflection and diffusion* (7.7.3)

Test conditions

Diameter of sensitive area of photo-electric cell	mm
Diameter of lens	mm
Distance from lens to screen	mm
Diameter of central hole in screen	mm
Distance from screen to photo-electric cell	mm
Test gas opacity	m^{-1}

Test results

a) Reading with screen in position	m^{-1}
Reading with screen removed	m^{-1}
Δ_a	m^{-1}
b) Reading with screen in position	m^{-1}
Reading with screen removed	m^{-1}
Δ_b	m^{-1}
c) Reading with screen in position[1]	m^{-1}
Reading with screen removed	m^{-1}
Δ_c	m^{-1}

9.3.4 *Photo-electric cell temperature* (7.7.4)

Test conditions

Sample pressure	mbar
Scavenge air pressure	mbar
Sample temperature	°C
Stabilizing time	min.
Scavenge air temperature	°C

Test results

Photo-electric cell temperature	°C

9.3.5 *Effective length* (7.7.5)

a) Comparison with known opacimeter

Reference opacimeter manufacturer : . . . . . .

Type : . . . . . .

Number : . . . . . .

Effective length : . . . . . mm

Accuracy of effective length : ± . . . mm at 95 % confidence

1) With smoke passing through the smoke chamber
$\Delta_b - \Delta_a = \ldots m^{-1}$
$\Delta_c - \Delta_a = \ldots m^{-1}$

Reference opacimeter				Opacimeter under test				
Sample pressure mbar	Sample temperature °C	Opacimeter reading o.u.	Corrected opacimeter reading[1] o.u.	Sample pressure mbar	Sample temperature °C	Opacimeter reading o.u.	Corrected opacimeter reading[1] o.u.	Calculated effective length mm

Scavenge air pressure[2] Reference opacimeter : . . . mbar
Opacimeter under test : . . . mbar

Average	
Standard deviation	
95 % confidence limits[3]	mm %

Sampling system (brief details) . . . . . .

b) Comparison of results from one opacimeter with and without modification of operation

Modified opacimeter				Opacimeter operating normally			
Sample pressure mbar	Sample temperature[4] °C	Opacimeter reading[5] o.u.	Effective length mm	Sample pressure mbar	Sample temperature[4] °C	Opacimeter reading[6] o.u.	Calculated effective length mm

Scavenge air pressure with opacimeter operating normally : . . . mbar

Average	mm
Standard deviation	mm
95 % confidence limits	mm %

7) $\frac{\text{Effective length as modified}}{\text{Effective length operating normally}} = \ldots$

1) This correction is to bring the readings to the reference temperatures.

2) Delete if inapplicable.

3) Taking into account the known accuracy of the reference opacimeter.

4) If these temperatures differ by more than 40 °C then experimental data must be given validating the adjustment for the difference in temperature in the method of calcultaing effective length.

5) Relative to "zero" after the modification is made.

6) Relative to "zero" before the modification is made.

7) Where this ratio is greater than 1,25 separate data must be given to validate the sample temperature measurements with the modified opacimeter.

Modification (brief details) . . . . . .

Sample temperature measurement position

Opacimeter operating normally . . . . . .

Opacimeter modified . . . . . .

NOTE – Recordings of opacimeter readings during the test must be included in the report.

9.3.6 *Effect of pressure* (7.7.6)

Test conditions

Sample pressure . . . . . mbar (maximum specified of manufacturer)

Scavenge air pressure . . . . . mbar

Sample temperature . . . . . °C

Opacity . . . . . m^{-1}

Test results

(A table of results similar to that in 7.7.5 must be provided depending on the method of measuring effective length.)

Number of readings . . . . . .

Average effective length . . . . . .

Standard deviation . . . . . .

95 % confidence limits on average . . . . . mm . . . %

$$\frac{\text{Effective length at maximum sample pressure}}{\text{Effective length at minimum sample pressure}} = \ldots$$

Maximum pressure/depression in smoke chamber . . . . . mbar

Position of measurement . . . . . .

9.3.7 *Gas tightness of opacimeter* (7.7.7)

a) Gas tightness of by-pass

Sample pressure . . . . . mbar

Scavenge air pressure . . . . . mbar

Sample temperature . . . . . °C

Gas opacity . . . . . m^{-1}

	Individual readings	Average m^{-1}	Standard deviation
Smoke by-passing normally			
Reduced pressure at by-pass			

Method of obtaining reduced pressure at by-pass . . . . . .

b) Gas tightness of casing

Sample pressure . . . . . mbar

Scavenge air pressure . . . . . mbar

Sample temperature . . . . . °C

Gas opacity . . . . . m^{-1}

Leak capacity . . . . . l/s

Leak position . . . . . l/s (leakage of casing before sealing . . . l/s)

	Individual readings m^{-1}/o.u.*	Average	Standard deviation
Readings with no leakage			
Readings with leakage			

* Delete if inapplicable.

9.3.8 *Waste exit conditions* (7.7.8)

Opacity of test gas . . . . . m^{-1}

Change of opacimeter reading with change of waste conditions . . . . . m^{-1}

9.3.9 *Effect of opacimeter design* (7.7.9)

			Individual readings	Average	Standard deviation
Relief valve inoperative	Sample pressure	mbar			
	Scavenge air pressure	mbar			
	Sample temperature	°C			
	Opacimeter reading	m^{-1}			
	Corrected opacimeter reading	m^{-1}			
Relief valve operative	Sample pressure	mbar			
	Scavenge air pressure	mbar			
	Sample temperature	°C			
	Opacimeter reading	m^{-1}			
	Corrected opacimeter reading	m^{-1}			

9.3.10 *By-pass characteristics* (7.7.10)

Sample pressure . . . . . mbar

Scavenge air pressure . . . . . mbar

Sample temperature . . . . . °C

Opacity . . . . . m^{-1}

Thermocouple at by-pass position . . . . . second, response

Temperature at by-pass :

with smoke by-passing . . . . . °C

with smoke passing through smoke chamber . . . . . °C

difference . . . . . °C

9.3.11 *Flow characteristics* (7.7.11)

Brief description of test installation . . . . . .

Results : See figure 7

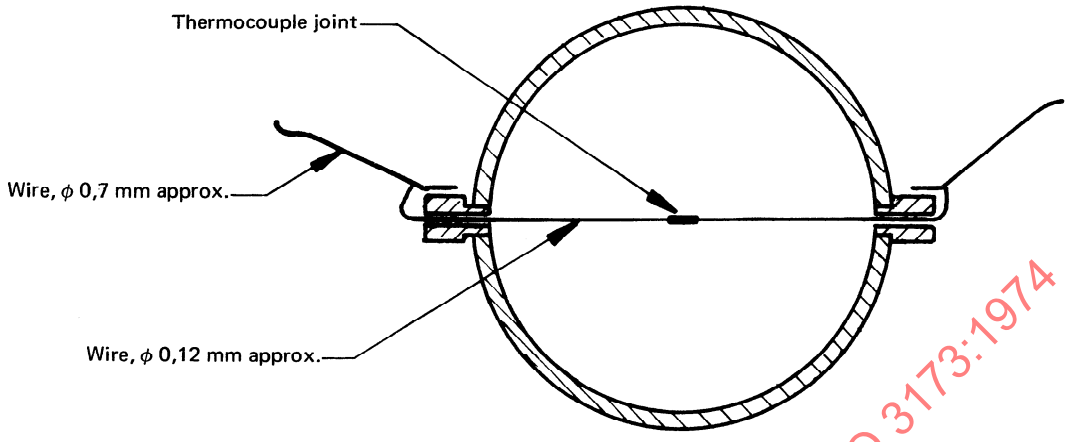

FIGURE 1 — **Diametral thermocouple**

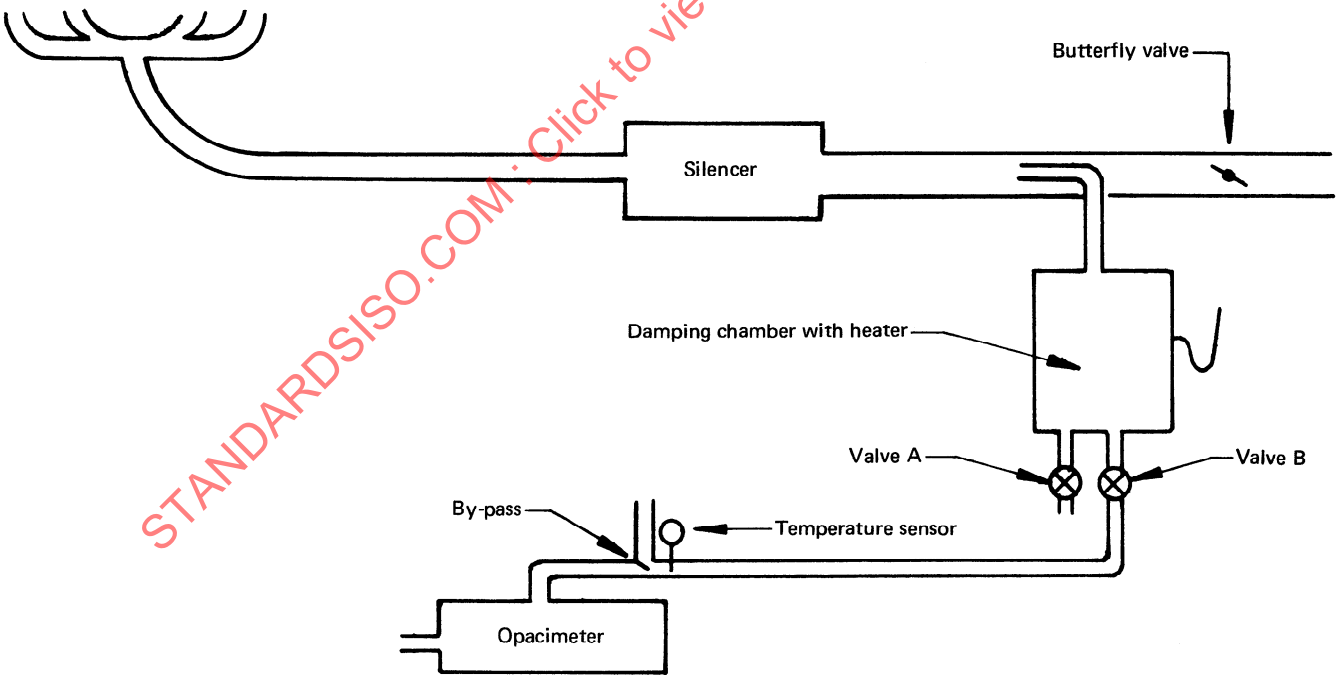

FIGURE 2 — **Test installation**

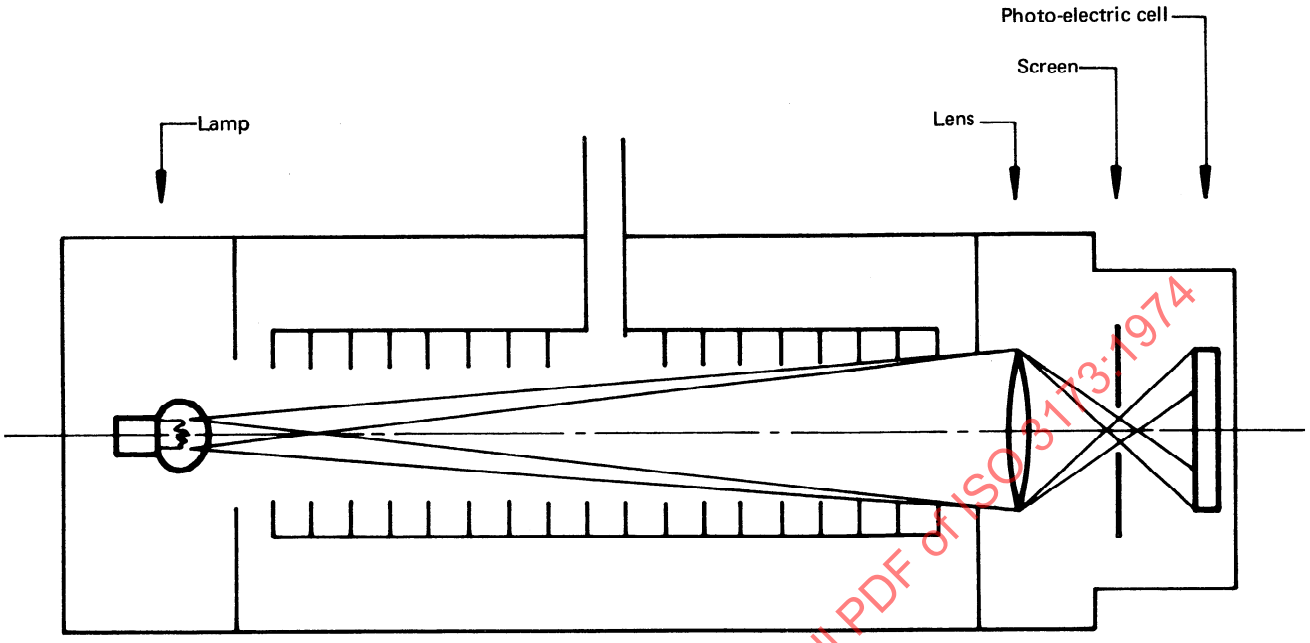

FIGURE 3 – **Opacimeter**

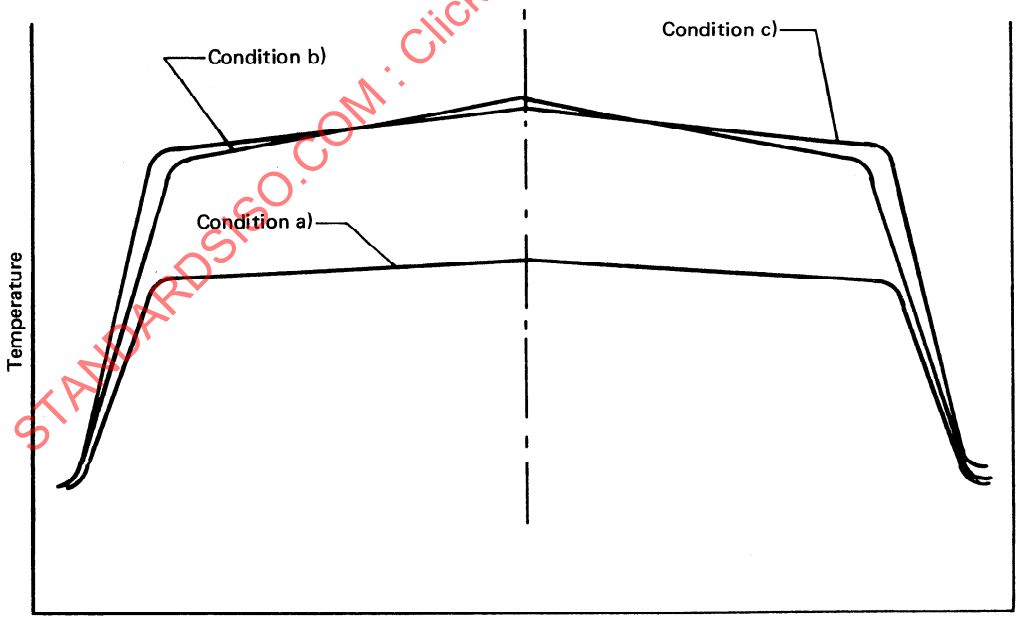

FIGURE 4 – **Position along smoke chamber**