
Plastics — Smoke generation —

Part 2:

**Determination of optical density by a
single-chamber test**

Plastiques — Production de fumée —

*Partie 2: Détermination de la densité optique par un essai en
enceinte unique*





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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5659-2 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 4, *Burning behaviour*.

This third edition cancels and replaces the second edition (ISO 5659-2:2006), which has been technically revised. It also replaces ISO 5659-1:1996 (*Plastics — Smoke generation — Part 1: Guidance on optical-density testing*), which will be withdrawn upon publication of this edition.

ISO 5659 consists of the following parts, under the general title *Plastics — Smoke generation*:

- *Part 2: Determination of optical density by a single-chamber test*
- *Part 3: Determination of optical density by a dynamic-flow method* (Technical Report)

Introduction

Fire is a complex phenomenon: its development and effects depend upon a number of interrelated factors. The behaviour of materials and products depends upon the characteristics of the fire, the method of use of the materials and the environment in which they are exposed (see also ISO/TR 3814^[1] and ISO 13943).

A test such as is specified in this part of ISO 5659 deals only with a simple representation of a particular aspect of the potential fire situation, typified by a radiant heat source, and it cannot alone provide any direct guidance on behaviour or safety in fire. A test of this type may, however, be used for comparative purposes or to ensure the existence of a certain quality of performance (in this case, smoke production) considered to have a bearing on fire behaviour generally. It would be wrong to attach any other meaning to results from this test.

The term “smoke” is defined in ISO 13943 as a visible suspension of solid and/or liquid particles in gases resulting from incomplete combustion. It is one of the first response characteristics to be manifested and should almost always be taken into account in any assessment of fire hazard as it represents one of the greatest threats to occupants of a building or other enclosure, such as a ship or train, on fire.

The responsibility for the preparation of ISO 5659 was transferred during 1987 from ISO/TC 92 to ISO/TC 61 on the understanding that the scope and applicability of the standard for the testing of materials should not be restricted to plastics but should also be relevant to other materials where possible, including building materials.

Plastics — Smoke generation —

Part 2:

Determination of optical density by a single-chamber test

1 Scope

1.1 This part of ISO 5659 specifies a method of measuring smoke production from the exposed surface of specimens of materials, composites or assemblies. It is applicable to specimens that have an essentially flat surface and do not exceed 25 mm in thickness when placed in a horizontal orientation and subjected to specified levels of thermal irradiance in a closed cabinet with or without the application of a pilot flame. This method of test is applicable to all plastics and may also be used for the evaluation of other materials (e.g. rubbers, textile-coverings, painted surfaces, wood and other materials).

1.2 It is intended that the values of optical density determined by this test be taken as specific to the specimen or assembly material in the form and thickness tested, and are not to be considered inherent, fundamental properties.

1.3 The test is intended primarily for use in research and development and fire safety engineering in buildings, trains, ships, etc. and not as a basis for ratings for building codes or other purposes. No basis is provided for predicting the density of smoke that might be generated by the materials upon exposure to heat and flame under other (actual) exposure conditions. This test procedure excludes the effect of irritants on the eye.

NOTE This test procedure addresses the loss of visibility due to smoke density, which generally is not related to irritancy potency (see Annex E).

1.4 It is emphasized that smoke production from a material varies according to the irradiance level to which the specimen is exposed. The results yielded from the method specified in this part of ISO 5659 are based on exposure to the specific irradiance levels of 25 kW/m² and 50 kW/m².

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943, *Fire safety — Vocabulary*

ISO 14934-3, *Fire tests — Calibration and use of heat flux meters — Part 3: Secondary calibration method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943 and the following apply.

3.1

assembly

fabrication of materials and/or composites

NOTE 1 Sandwich panels are an example of an assembly.

NOTE 2 The assembly may include an air gap.

3.2

composite

combination of materials which are generally recognized in building construction as discrete entities

NOTE Coated or laminated materials are examples of composites.

3.3

essentially flat surface

surface which does not deviate from a plane by more than 1 mm

3.4

exposed surface

surface of the product subjected to the heating conditions of the test

3.5

irradiance

radiant flux incident on an infinitesimal element of the surface containing the point divided by the area of that element

3.6

material

basic single substance or uniformly dispersed mixture

NOTE Metal, stone, timber, concrete, mineral fibre and polymers are examples.

3.7

mass optical density

MOD

measure of the degree of opacity of smoke in terms of the mass loss of the material

3.8

optical density of smoke

D

measure of the degree of opacity of smoke, taken as the negative common logarithm of the relative transmission of light

3.9

product

material, composite or assembly about which information is required

3.10

specific optical density

D_s

optical density multiplied by a factor which is calculated by dividing the volume of the test chamber by the product of the exposed area of the specimen and the path length of the light beam

NOTE See 11.1.1.

3.11

specimen

representative piece of the product to be tested together with any substrate or surface coating.

NOTE The specimen may include an air gap.

3.12

intumescent material

dimensionally unstable material, developing a carbonaceous expanded structure of thickness > 10 mm during the test, with the cone heater 25 mm from the specimen

4 Principles of the test

Specimens of the product are mounted horizontally within a chamber and exposed to thermal radiation on their upper surfaces at selected levels of constant irradiance up to 50 kW/m².

The smoke evolved is collected in the chamber, which also contains photometric equipment. The attenuation of a light beam passing through the smoke is measured. The results are reported in terms of specific optical density.

5 Suitability of a material for testing

5.1 Material geometry

5.1.1 The method is applicable to essentially flat materials, composites and assemblies not exceeding 25 mm in thickness.

5.1.2 The method is sensitive to small variations in geometry, surface orientation, thickness (either overall or of the individual layers), mass and composition of the material, and so the results obtained by this method only apply to the thickness of the material as tested.

NOTE It is not possible to calculate the specific optical density of one thickness of a material from the specific optical density of another thickness of the material.

5.2 Physical characteristics

Materials submitted for evaluation by this method could have faces which differ or could contain laminations of different materials arranged in a different order in relation to the two faces. If either of the faces is likely to be exposed to a fire condition when in use, then both faces shall be evaluated.

6 Specimen construction and preparation

6.1 Number of specimens

6.1.1 The test sample shall comprise a minimum of 12 specimens if all four modes are to be tested: six specimens shall be tested at 25 kW/m² (three specimens with a pilot flame and three specimens without a pilot flame) and six specimens shall be tested at 50 kW/m² (three specimens with a pilot flame and three specimens without a pilot flame).

If fewer than four modes are to be tested, a minimum of three specimens per mode shall be tested.

6.1.2 An additional number of specimens as specified in 6.1.1 shall be used for each face, in accordance with the requirements of 5.2.

6.1.3 An additional 12 specimens (i.e. three specimens per test mode) shall be held in reserve if required by the modes specified in 10.9.

6.1.4 In case of intumescent materials, it is necessary to make a preliminary test with the cone heater at 50 mm from the specimen, so at least two additional specimens are required.

6.2 Size of specimens

6.2.1 The specimens shall be square, with sides measuring 75 mm ± 1 mm.

6.2.2 Materials of 25 mm nominal thickness or less shall be evaluated at their full thickness. For comparative testing, materials shall be evaluated at a thickness of $1,0 \text{ mm} \pm 0,1 \text{ mm}$. All materials consume oxygen when they burn in the chamber, and the smoke generation of some materials (especially rapid-burning or thick specimens) is influenced by the reduced oxygen concentration in the chamber. As far as possible, materials shall be tested in their end-use thickness.

6.2.3 Materials with a thickness greater than 25 mm shall be cut to give a specimen thickness of 25 mm $\pm 0,1 \text{ mm}$, in such a way that the original (uncut) face can be evaluated.

6.2.4 Specimens of multi-layer materials with a thickness greater than 25 mm, consisting of core material(s) with facings of different materials, shall be prepared as specified in 6.2.3 (see also 6.3.2).

6.3 Specimen preparation

6.3.1 The specimen shall be representative of the material and shall be prepared in accordance with the procedures described in 6.3.2 and 6.3.3. The specimens shall be cut, sawn, moulded or stamped from identical sample areas of the material, and records shall be kept of their thicknesses and, if required, their masses.

6.3.2 If flat sections of the same thickness and composition are tested in place of curved, moulded or speciality parts, this shall be stated in the test report. Any substrate or core materials for the specimens shall be the same as those used in practice.

6.3.3 When coating materials, including paints and adhesives, are tested with the substrate or core as used in practice, specimens shall be prepared following normal practice, and in such cases the method of application of the coating, the number of coats and the type of substrate shall be included in the test report.

6.4 Wrapping of specimens

6.4.1 All specimens shall be covered across the back, along the edges and over the front surface periphery, leaving a central exposed specimen area of $65 \text{ mm} \times 65 \text{ mm}$, using a single sheet of aluminium foil (approximately $0,04 \text{ mm}$ thick) with the dull side in contact with the specimen. Care shall be taken not to puncture the foil or to introduce unnecessary wrinkles during the wrapping operation. The foil shall be folded in such a way as to minimize losses of any melted specimen material at the bottom of the specimen holder. After mounting the specimen in its holder, any excess foil along the front edges shall be trimmed off.

6.4.2 Wrapped specimens of a thickness less than 25 mm shall be backed with a low density (nominal 65 kg/m^3) refractory fibre blanket.

Wrapped specimens of a thickness of 25 mm shall be tested without a refractory fibre blanket.

6.4.3 For resilient materials, each specimen in its aluminium foil wrapper shall be installed in the holder in such a way that the exposed surface lies flush with the inside face of the opening of the specimen holder. Materials with uneven exposed surfaces shall not protrude beyond the plane of the opening in the specimen holder.

6.4.4 When thin impermeable specimens, such as thermoplastic films, become inflated during the test owing to gases trapped between the film and backing, they shall be maintained essentially flat by making two or three cuts (20 mm to 40 mm long) in the film to act as vents.

6.5 Conditioning

6.5.1 Before preparing the specimens for test, they shall be conditioned to constant mass at $23 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$ and a relative humidity of $(50 \pm 10) \%$ where constant mass shall be considered to have been reached

when two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0,1 % of the mass of the test specimen or 0,1 g, whichever is the greater.

6.5.2 While in the conditioning chamber, specimens shall be supported in racks so that air has access to all surfaces.

Forced-air movement in the conditioning chamber may be used to assist in accelerating the conditioning process.

The results obtained from this method are sensitive to small differences in specimen conditioning. It is important therefore to ensure that the requirements of 6.5 are followed carefully.

7 Apparatus and ancillary equipment

7.1 General

The apparatus (see Figure 1) shall consist of an air-tight test chamber with provision for containing a specimen holder, radiation cone, pilot burner, light transmission and measuring system and other, ancillary facilities for controlling the conditions of operation during a test.

7.2 Test chamber

7.2.1 Construction

7.2.1.1 The test chamber (see Figure 1 and Figure 2) shall be fabricated from laminated panels, the inner surfaces of which shall consist of either a porcelain enamelled metal not more than 1 mm thick or an equivalent coated metal which is resistant to chemical attack and corrosion and capable of easy cleaning. The internal dimensions of the chamber shall be 914 mm \pm 3 mm long, 914 mm \pm 3 mm high and 610 mm \pm 3 mm deep. It shall be provided with a hinged front-mounted door with an observation window and a removable opaque door cover to the window to prevent light entering the chamber. A safety blow-out panel, consisting of a sheet of aluminium foil of thickness not greater than 0,04 mm and having a minimum area of 80 600 mm², shall be provided in the chamber, fastened in such a way as to provide an airtight seal.

The blow-out panel may be protected by a stainless-steel wire mesh. It is important that any such mesh is spaced at least 50 mm from the blow-out panel to prevent any obstruction in the event of an explosion.

NOTE A design with a wide door occupying a complete side of the smoke chamber has been found suitable for facilitating cleaning and maintenance operations.

7.2.1.2 Two optical windows, each with a diameter of 75 mm, shall be mounted, one each in the top and bottom of the cabinet, at the position shown in Figure 2, with their interior faces flush with the outside of the chamber lining. The underside of the window in the floor shall be provided with an electric heater of approximately 9 W capacity in the form of a ring, which shall be capable of maintaining the upper surface of the window at a temperature just sufficient to minimize smoke condensation on that face (a temperature of 50 °C to 55 °C has been found suitable) and which shall be mounted around its edge so as not to interrupt the light path. Optical platforms 8 mm thick shall be mounted around the windows on the outside of the chamber and shall be held rigidly in position relative to each other by three metal rods, with a diameter of at least 12,5 mm, extending through the chamber and fastened securely to the platforms.

7.2.1.3 Other openings in the chamber shall be provided for services as specified and where appropriate. They shall be capable of being closed so that a positive pressure up to 1,5 kPa (150 mm water gauge) above atmospheric pressure can be developed inside the chamber (see 7.2.2) and maintained when checked in accordance with 7.6 and 9.6. All components of the chamber shall be capable of withstanding a greater positive internal pressure than the safety blow-out panel.

7.2.1.4 An inlet vent with shutter shall be provided in the front of the chamber at the top or on the roof of the chamber and away from the radiator cone, and an exhaust vent with shutter shall be provided in the bottom of the chamber lead, via flexible tubing with a diameter of 50 mm to 100 mm, to an extraction fan capable of creating a negative pressure of at least 0,5 kPa (50 mm water gauge).

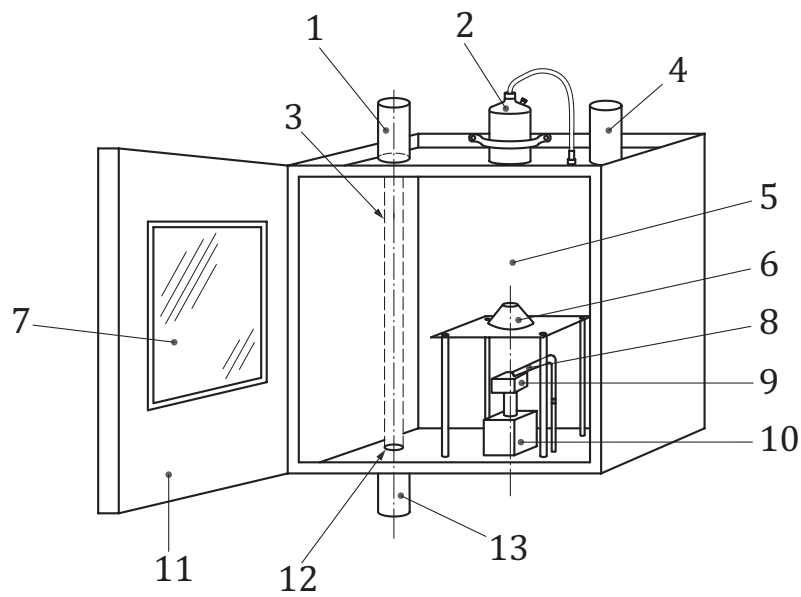
7.2.2 Chamber pressure control facilities

Provision shall be made for controlling the pressure inside the test chamber. A manometer, with a range of up to 1,5 kPa (150 mm water gauge) shall be provided for connection to a pressure regulator and to a tube in the top of the chamber. The manometer can be either electronic or a suitable fluid in a tube (water or an appropriate indicating fluid).

A suitable pressure regulator (see Figure 3) consists of a vented water-filled bottle and a length of flexible tubing of diameter 25 mm, inserted 100 mm below the water surface: the other end of the tubing is connected to the manometer and the chamber. The regulator shall be vented to the exhaust system.



a) Typical example of commercially available test apparatus



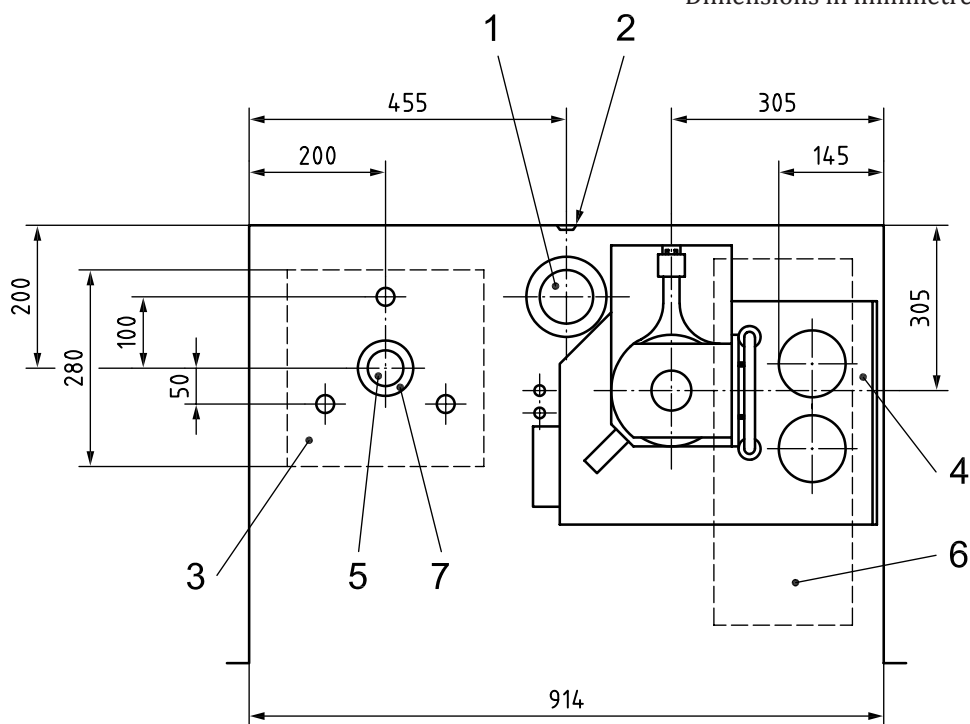
b) Schematic drawing of typical test apparatus

Key

- | | |
|------------------------------|--------------------------------|
| 1 optical measurement system | 8 pilot burner |
| 2 pressure controller | 9 specimen in specimen holder |
| 3 optical path | 10 weighing device |
| 4 exhaust | 11 full front open door |
| 5 chamber | 12 optical system floor window |
| 6 conical heater | 13 light source |
| 7 window | |

Figure 1 — Test apparatus

Dimensions in millimetres (not to scale)

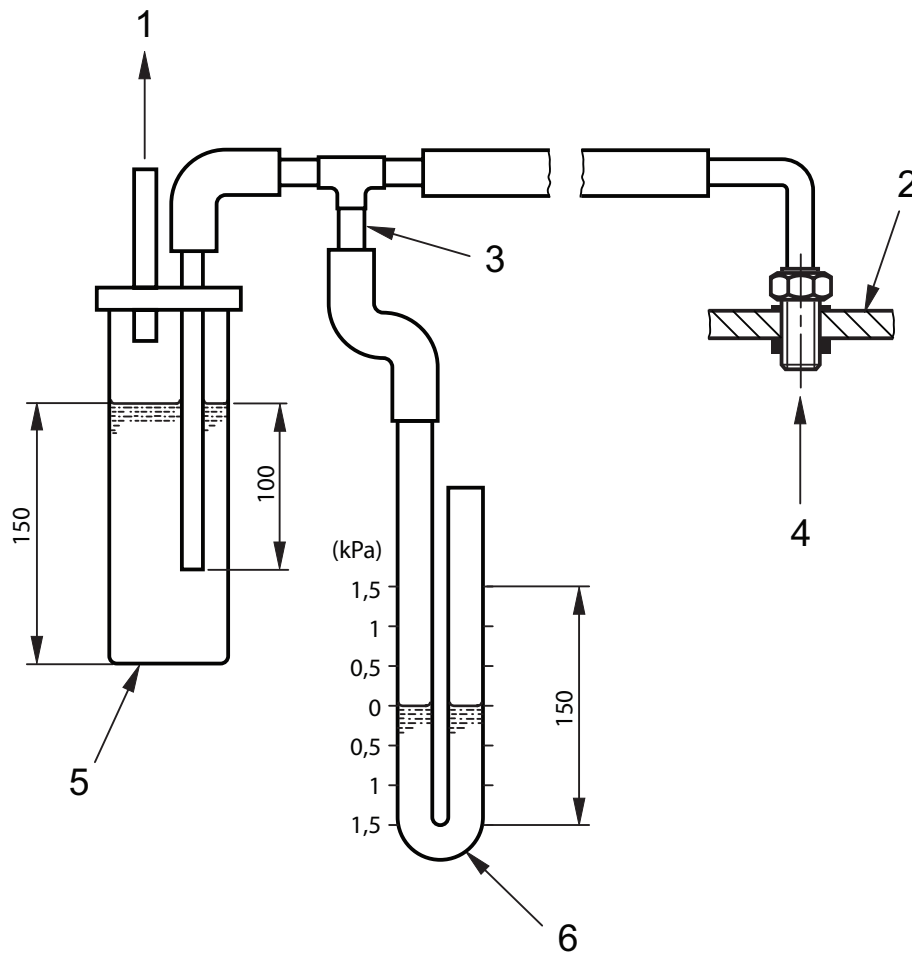


Key

- | | |
|--------------------------|------------------|
| 1 exhaust vent | 5 optical window |
| 2 wall thermocouple | 6 blow-out panel |
| 3 optical platform | 7 window heater |
| 4 radiator cone assembly | |

Figure 2 — Plan view of typical chamber

Dimensions in millimetres

**Key**

- | | | | |
|---|---|---|--|
| 1 | to exhaust system | 4 | effluent from chamber |
| 2 | chamber wall | 5 | water bottle |
| 3 | restriction to prevent chamber blow-out | 6 | glass manometer opt U-tube (filled to zero mark with water-dye solution) |

Figure 3 — Typical chamber pressure relief manometer

7.2.3 Chamber wall temperature

A thermocouple measuring junction, made from wires of diameter not greater than 1 mm, shall be mounted on the inside of the back wall of the chamber, at the geometric centre, by covering it with an insulating disc (such as polystyrene foam) having a thickness of approximately 6,5 mm and a diameter of not more than 20 mm, attached to the wall of the chamber with a suitable cement. The thermocouple junction shall be connected to a recorder or meter and the system shall be suitable for measuring temperatures in the range 35 °C to 80 °C (see 10.2.2).

7.3 Specimen support and heating arrangements

7.3.1 Radiator cone

7.3.1.1 The radiator cone shall consist of a heating element, of nominal rating 2600 W, contained within a stainless-steel tube, approximately 2 210 mm in length and 6,5 mm in diameter, coiled into the shape of a truncated cone and fitted into a shade. The shade shall have an overall height of $45 \pm 0,4$ mm, an internal

diameter of 55 mm \pm 1 mm and an internal base diameter of 110 mm \pm 3 mm. It shall consist of two layers of 1 mm thick stainless steel with a 10 mm thickness of ceramic-fibre insulation of nominal density 100 kg/m³ sandwiched between them. The heating element shall be clamped at the top and bottom of the shade.

7.3.1.2 The radiator cone shall be capable of providing irradiance in the range 10 kW/m² to 50 kW/m² at the centre of the surface of the specimen.

When the irradiance is determined at two other positions 25 mm each side of the specimen centre, the irradiance at these two positions shall be not less than 85 % of the irradiance at the centre of the specimen.

The temperature controller for the radiator cone shall be a proportional, integral differential-type 3-term controller with solid-state relay, thyristor stack fast-cycle or phase angle control of not less than 10 A maximum rating. Capacity for adjustment of integral time up to 50 s and differential time up to 30 s shall be provided to permit reasonable matching with the response characteristics of the heater. The temperature at which the heater is to be controlled shall be set on a scale capable of being held steady to \pm 2 °C. An input range of temperature of 0 °C to 1 000 °C is suitable; an irradiance of 50 kW/m² is typically given by a heater temperature in the range 770 °C to 840 °C for the specimen position 25 mm below the edge of the heater. Automatic cold-junction compensation of the thermocouple shall be provided.

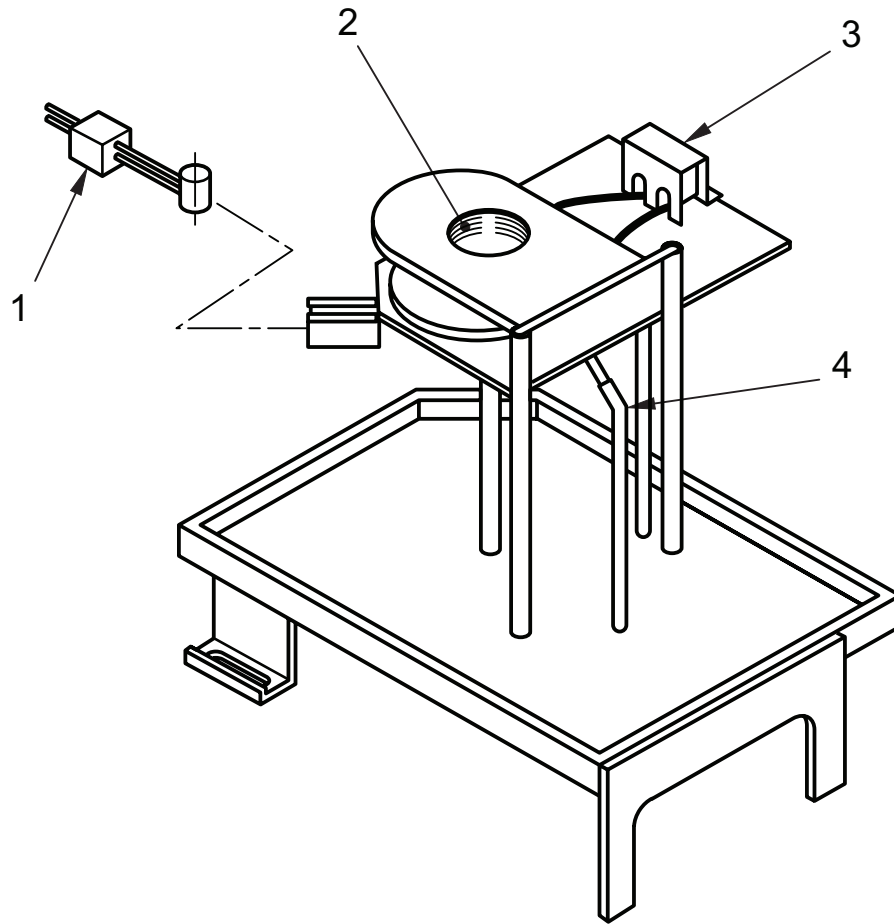
NOTE 1 The heater temperature range for testing with 50 mm distance between the edge of the radiator cone and specimen is given in Table D.3.

The irradiance of the radiator cone shall be controlled by reference to the reading of two type K sheathed thermocouples mounted diametrically opposite and in contact with, but not welded to, the element. The thermocouples shall be of equal length and wired in parallel to the temperature controller and be positioned one-third of the distance from the top surface of the cone.

NOTE 2 While phase angle control is allowed for in the temperature controller of the radiator cone, it should be noted that this will usually require electrical filtering to avoid risk of low-level signal lines.

7.3.2 Framework for support of the radiator cone, specimen holder and heat flux meter

The radiator cone shall be located and secured from the vertical rods of the support framework so that for non-intumescent materials the lower rim of the radiator cone shade junction is 25 mm \pm 1 mm above the upper surface of the specimen when oriented in the horizontal position. For intumescent materials this distance shall be 50 mm. Details of the radiator cone and supports are shown in Figure 4 and Figure 5.

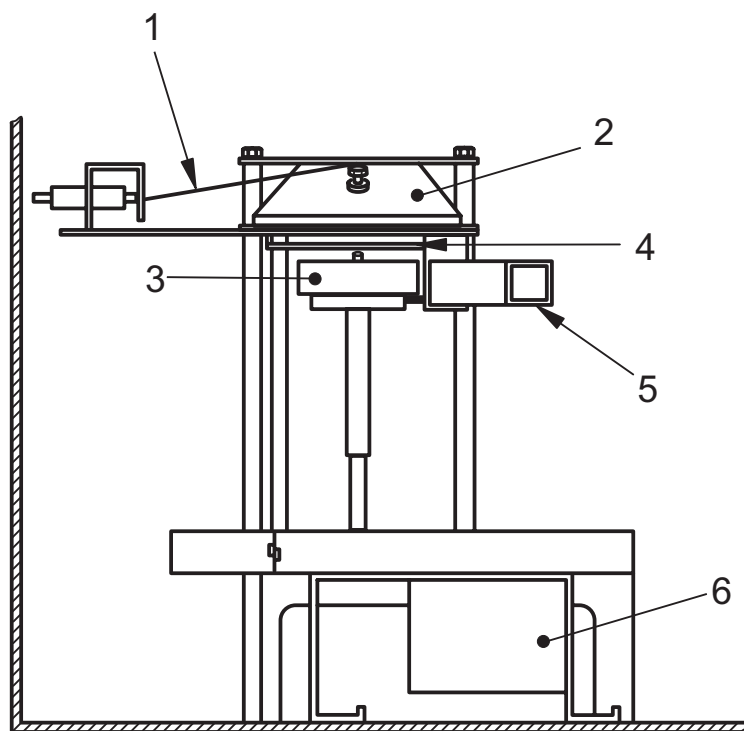


Key

- 1 heat flux meter and mount
- 2 heating element

- 3 thermocouple mount and shield
- 4 pilot burner

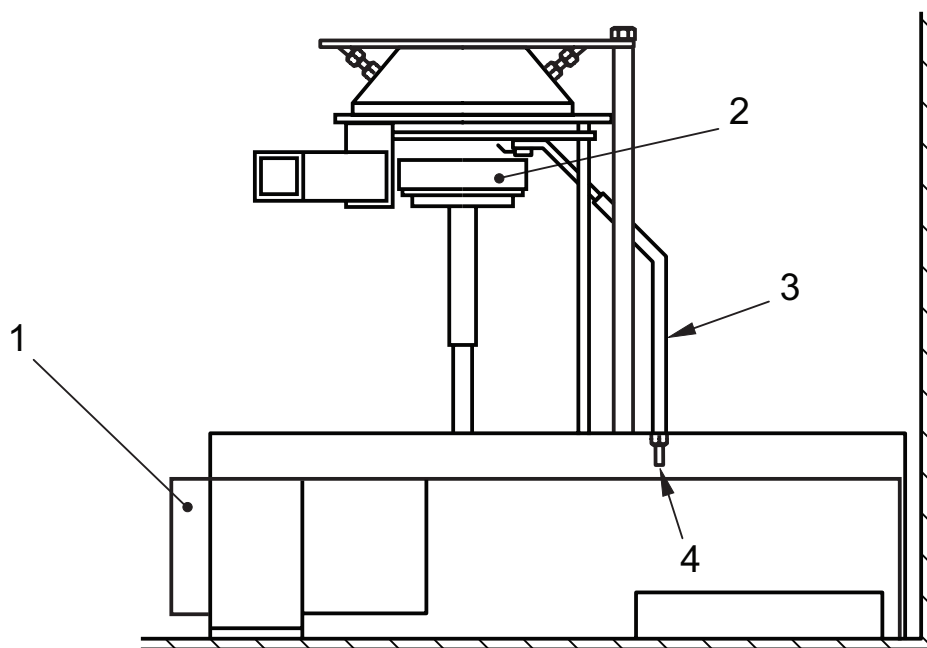
Figure 4 — Typical framework for support of radiator cone, specimen holder and flux meter



Key

- | | |
|-------------------|--------------------------|
| 1 thermocouple | 4 radiator shield |
| 2 radiator cone | 5 heat flux meter |
| 3 specimen holder | 6 spark ignition housing |

Figure 5 — Typical arrangement of radiator cone, specimen holder and radiator shield (side view)



Key

- | | |
|--------------------------|---------------------------------------|
| 1 spark ignition housing | 3 pilot burner and ignition electrode |
| 2 specimen holder | 4 propane and air |

Figure 6 — Typical arrangement of radiator cone, specimen holder and radiator shield (front view)

7.3.3 Radiator shield

A remotely controllable metallic and/or inorganic shield (see Figure 5 and Figure 6) of minimum diameter 130 mm and upper surface situated (when in place) approximately mid-way between the base of the radiator cone and the specimen surface shall be provided to stop irradiance of the specimen before and after the required exposure period.

NOTE This facility is necessary in order to enable repeat tests to be carried out without switching off the radiator cone.

7.3.4 Heat flux meter

7.3.4.1 The heat flux meter shall be of a thermopile (Schmidt-Boelter) type with a design range of at least 50 kW/m². The body shall have an external diameter of approximately 12,7 mm. The target receiving the radiation (see Figure 4) shall have a flat, circular face of approximately 10,0 mm diameter, coated with a durable matt-black finish. The target shall be water-cooled.

7.3.4.2 The heat flux meter shall be connected, directly to a suitable recorder or meter in accordance with 7.8.6, so that it is capable, when calibrated, of recording heat fluxes of 25 kW/m² and 50 kW/m² to an accuracy of ± 1 kW/m².

If a recorder which only displays a mV output is used, the mV value shall be converted to kW/m² using the calibration factor (or equation if appropriate) specific to the heat flux meter.

7.3.4.3 The heat flux meter system shall be calibrated by comparing its response with that of a primary reference standard when exposed to heat fluxes of 25 kW/m² ± 1 kW/m² and 50 kW/m² ± 1 kW/m² averaged over the 10 mm diameter area of the heat flux meter in accordance with Annex A.

7.3.5 Specimen holder

Details of the specimen holder are shown in Figure 7. The base shall be lined with low-density (nominal density 65 kg/m³) refractory fibre blanket with a minimum thickness of 10 mm (unless the specimen is 25mm thick, see 6.4.2.). A retainer frame shall always be used to reduce unrepresentative edge-burning of composite specimens. Lifting of the retainer frame and touching the pilot flame shall be avoided. If there is a risk of this happening, drill holes in the holder/frame and use two screws to hold retainer frame in place.

A wire grid can be used for retaining specimens prone to delamination or to distortion. Any such wire grid shall be 75 mm square with 20 mm-square holes constructed from 2 mm stainless-steel rod welded at all intersections. When testing intumescent specimens, the wire grid shall not be used.

Dimensions in millimetres

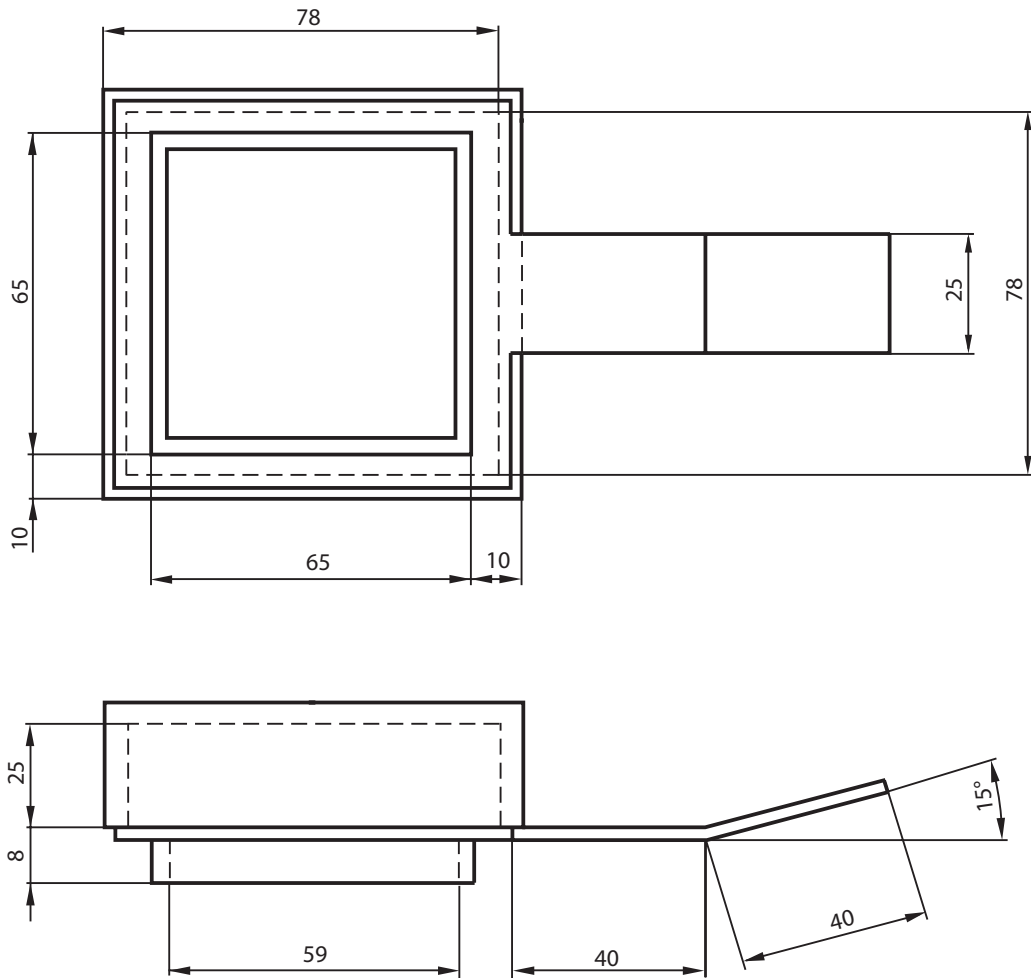


Figure 7 — Typical specimen holder

7.3.6 Pilot burner

The single-flame burner, shown in Figure 6, shall have a horizontal flame length of $30 \text{ mm} \pm 5 \text{ mm}$ and for non-intumescent materials shall be positioned horizontally 10 mm above the top face of the specimen. For intumescent materials, the burner shall be positioned 15 mm down from the cone heater bottom edge. The colour of the flame shall be blue with a yellow tip. A small spark ignition device shall be sited next to the outlet tube of the burner so that the flame may be ignited by the operator without opening the door of the chamber.

The nozzle of the pilot-burner shall be positioned vertically above the centre of one of the edges of the opening in the top of the edge frame, with the flame extending horizontally towards a position above the centre of the specimen.

7.4 Gas supply

A mixture of propane of at least 95 % purity and at a minimum pressure of $3,5 \text{ kPa} \pm 1 \text{ kPa}$ ($350 \text{ mm} \pm 100 \text{ mm}$ water gauge) and air under a pressure of $170 \text{ kPa} \pm 30 \text{ kPa}$ ($17 \text{ m} \pm 3 \text{ m}$ water gauge) shall be supplied to the burner. Each gas shall be fed via needle valves and flow meters to a point at which they are mixed and supplied to the burner. The flow meter for the propane supply shall be capable of measuring $100 \text{ cm}^3/\text{min}$ and that for the air a flow of $500 \text{ cm}^3/\text{min}$.

7.5 Photometric system

7.5.1 General

The photometric system shall consist of a light source in accordance with 7.5.2, a lens in a light-tight housing mounted below the optical window in the floor of the cabinet, and a photo detector with lens, filters and shutter, in accordance with 7.5.3, in a light-tight housing above the optical window in the top of the chamber.

A schematic drawing of a typical system is shown in Figure 8. Equipment shall be provided to control the output the light source, and to measure the amount of light falling on the photo detector.

7.5.2 Light source

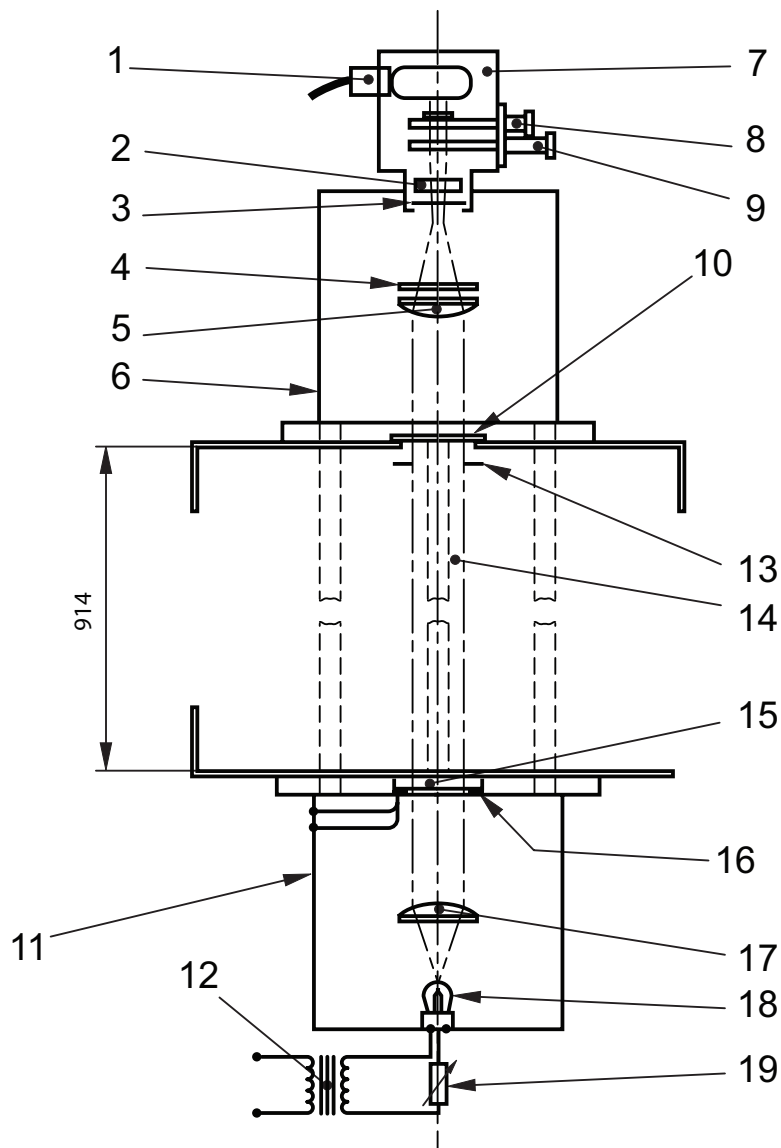
The light source shall be a 6,5 V incandescent lamp. Power for the lamp shall be provided so that the voltage across the lamp, as determined by a voltmeter, is maintained at $4\text{ V} \pm 0,2\text{ V}$. The lamp shall be mounted in the lower light-tight box, and a lens to provide a collimated light beam of 51 mm diameter, passing towards and through the optical window in the floor of the chamber, shall be mounted, with provision for adjustment, to control the collimated beam in direction and diameter. The housing shall be provided with a cover to allow access for adjustments to be made to the position of the lens.

7.5.3 Photo detector

7.5.3.1 The light-measuring system shall consist of a photo multiplier tube connected to a multi-range amplifier coupled to a recording device in accordance with 7.8.6, capable of continuously measuring relative light intensity against time as percentage transmission over at least five orders of magnitude with an S-4 spectral sensitivity response similar to that of human vision and a dark current less than 10^{-9} A. The system shall have a linear response with respect to transmittance and an accuracy of better than $\pm 3\%$ of the maximum reading on any range.

For selection of photo multiplier tubes, as applicable, the minimum sensitivity shall allow a 100 % reading to be obtained with a 0,5 neutral-density filter and a ND-2 range-extension filter (see 7.5.3.2) in the light path. Provision shall be made for adjusting the reading of the instrument under given conditions over the full range of any scale.

NOTE The required accuracy of the photo detector can be obtained more easily if the measuring systems incorporate scale ranges of 30, 3, 0,3, etc., as well as ranges of 100, 10, 1, etc.



Key

- | | | | |
|----|---------------------------------|----|------------------------------|
| 1 | photomultiplier tube and socket | 11 | optical system lower housing |
| 2 | opal diffuser filter (optional) | 12 | transformer |
| 3 | aperture disc | 13 | opaque disc template |
| 4 | natural density compensating | 14 | parallel light beam |
| 5 | lens | 15 | optical window |
| 6 | optical system housing | 16 | optical window heater |
| 7 | optical system upper housing | 17 | lens |
| 8 | range-extension filter (ND-2) | 18 | light source |
| 9 | shutter | 19 | adjustable resistor |
| 10 | optical window | | |

Figure 8 — Typical photometric system

7.5.3.2 The photo multiplier tube shall be mounted in the upper section of the detector housing. Below it, there shall be an assembly, which provides for the positioning of a filter and of a shutter, in or out of the path of the collimated light beam. The filter, referred to as the range-extension filter (ND-2), shall be a glass neutral-density filter of nominal optical density 2. When in the closed position, the shutter shall

prevent all light in the test chamber from reaching the photo multiplier tube. An optional opal diffuser may be permanently mounted below the shutter.

7.5.3.3 The lower part of the upper housing shall support a lens with a diameter greater than 51 mm capable of being adjusted so that the collimated beam is focused to form a small intense spot of light at the disc aperture between the upper and lower parts of the housing. Above the lens, there shall be a mount for supporting one or more compensating filters from a set of nine neutral-density filters with optical density varying from 0,1 to 0,9 in steps of 0,1. The housing shall be provided with a cover to allow access for adjustments to be made to the position of the lens and for inserting or removing filters.

7.5.3.4 A neutral-density filter, with a nominal optical density of 3,0, large enough to cover the lower optical window, the actual optical density having been determined by calibration between 550 nm and 650 nm, shall be available for calibrating the photometric system.

Handle all filters by their edges only, because fingerprints can greatly affect their rating. Make no attempt to clean the surface of a filter; once the surface has been damaged or spoiled, the filter shall be replaced.

7.5.4 Additional equipment

7.5.4.1 A template for checking the collimated light beam shall be provided, consisting of an opaque disc marked with a concentric ring of 51 mm diameter, and capable of fitting snugly between the support pillars. It shall be capable of being attached to, and centred on, the underside of the upper optical window in the chamber.

7.5.4.2 A piece of white cloth, tissue or a set of neutral-density filters of sufficient size to completely cover the lower optical window of the chamber, and capable of transmitting an amount of light to give a mid-scale reading of the photometric system when switched to the scale with a range of 1 % transmission, shall be available for calibrating the range-extension filter.

7.5.4.3 A piece of opaque material, sufficiently large to cover the lower optical window, shall be available for blocking the light from the light source to prevent it from entering the chamber.

7.6 Chamber leakage

With the specified items of equipment properly assembled ready for test and after the heater has been on at 25 kW/m² for 10 min or at 50 kW/m² for 5 min, the chamber shall be sufficiently airtight to comply with the requirements of the leakage rate test given in 9.6.

NOTE The most likely sources of leakage have been found to be the door seal, the inlet and outlet vents and the safety blow-out panel.

7.7 Cleaning materials

Appropriate materials shall be available for cleaning the inside of the chamber.

NOTE An ammoniated spray detergent and soft scouring pads have been found effective for cleaning the chamber walls, and ethyl alcohol and soft tissue for the optical windows. Use of a tray of 0,880 N ammonia overnight inside the chamber also helps to reduce acidity inside the chamber and the sampling lines.

7.8 Ancillary equipment

7.8.1 Balance

This shall have a capacity exceeding the mass of the specimen and shall be readable and accurate to 0,5 % of the specimen mass.

7.8.2 Timing device

A timing device capable of recording elapsed time to the nearest second over a period of at least 1 h with accuracy within 1 s in 1 h shall be used for timing operations and observations.

7.8.3 Linear measuring devices

Rules, callipers, gauges or other devices of suitable accuracy shall be used for checking the dimensions, etc., specified with given tolerances.

7.8.4 Auxiliary heater

An auxiliary heater of 500 W capacity capable of raising the air temperature uniformly without local heating of the walls may be used if required to help the chamber to reach the stabilized temperature more rapidly under adverse conditions. Alternatively, the walls of the chamber may be heated externally to help the chamber temperature to stabilize.

7.8.5 Protective equipment

Protective clothing, such as gloves, goggles, respirators, etc., and handling equipment such as tongs, shall be available when the type of specimen being tested demands them.

7.8.6 Recorder

The recorder shall be capable of recording continuously the millivolt output of the photo detector (7.5.3) to an accuracy of better than 0,5 % full range deflection. The recorder shall also be capable of recording the heat flux meter output (see 7.3.4.2) to the required accuracy.

7.8.7 Water-circulating device

To cool the heat flux meter, a device for water circulation shall be provided.

8 Test environment

8.1 The test apparatus shall be protected from direct sunlight, or any strong light source, to avoid the possibility of spurious light readings.

8.2 Adequate provision shall be made for removing potentially hazardous and objectionable smoke and gases from the area of operation, and other suitable precautions shall be taken to prevent exposure of the operator to them, particularly during the removal of specimens from the chamber or when cleaning the apparatus.

9 Setting-up and calibration procedures

9.1 General

Assemble the apparatus, connect to the services and control devices as specified in Clause 7, and check for proper functioning of the various systems, including the electrical connections to ensure good electrical contact.

Heat up the radiator cone gradually from cold and do not allow it to heat up or remain operating without a blank specimen holder, a specimen in its holder or the heat flux meter being in position under it.

9.2 Alignment of photometric system

9.2.1 General

Carry out the procedure detailed in 9.2.2 and 9.2.3 in the initial setting-up of the apparatus, after the replacement of the light source or after some accidental misalignment has occurred, and then always follow this by the procedure for selecting appropriate compensating filter(s) in accordance with 9.3.

9.2.2 Beam collimation

9.2.2.1 Check the optical platforms for rigidity. Attach the opaque-disc template to the lower face of the upper optical window with the marked ring downwards and centred on the window. Switch on the light source and adjust its projected image on the template so that the light beam completely fills the 51 mm diameter ring with no more light outside the ring than is necessary to satisfy this requirement.

9.2.2.2 Make the adjustments by removing the cover to the light-source enclosure, releasing the lower-lens mount fixings and repositioning the lens mount so that the light pattern on the template is centred and of the correct size. Alternatively, reposition the lens using external adjustments, if provided.

NOTE In cases of severe maladjustment, it might be necessary to reposition the lamp socket.

9.2.2.3 Re-fix the lens mount and replace the cover, ensuring that the test cabinet has been adequately resealed. Remove the template from the upper optical window.

This adjustment may also include the optimizing of the lens mount position so that the reading given by the photo-detector is a maximum; this operation will require removal of the template and shall be followed by a final check on the position of the image as described above.

9.2.3 Beam focusing

Open the cover to the housing on top of the test chamber, remove the compensating filter holder and slacken the lens mount. With the photo-detector system switched off and the light source switched on, adjust the lens mount for focusing and alignment so that the converging beam forms a small intense spot of light on the aperture to the photo-multiplier tube housing. Tighten the lens mount, check the beam-focusing adjustment, replace the compensating-filter holder, and close and seal the enclosure cover.

9.3 Selection of compensating filter(s)

Clean the faces of both optical windows inside the test chamber. Switch on the photometric system with the range-extension filter in the light path, the shutter open, an ND-0,5 compensating filter above the upper lens and the multi-range meter set to the range capable of recording 100 % light transmission. Operate the control for adjusting the reading of the instrument to determine whether a reading of 100 % can actually be obtained. If it can, no change in compensating filter is required; if not, use another compensating filter to satisfy this requirement.

An indication of the appropriate filter, or combination of filters, can be obtained conveniently by removing any compensating filter in the housing above the test chamber, closing the housing cover, placing a compensating filter, or filters, over the lower optical window inside the test chamber and checking the instrument reading. The choice of compensating filter determined this way shall be confirmed by the specified procedure.

Alternatively, the voltage to the photomultiplier tube may, if possible, be adjusted in order to ensure that a reading of 100 % can be reached.

9.4 Linearity check

Switch on the photometric system with the range-extension filter in the light path and the shutter closed. Adjust the zeroing device to give a reading of 0 % transmission with the instrument range switched to a full-scale reading of 0,1 % transmission; switch the instrument to the other ranges to check that the recorded transmission remains 0 %.

Open the shutter and ensure that the range-extension filter is in the light path. Adjust filter span control to give a reading of 100 % transmission with the instrument range switched to a full-scale reading of 100 % transmission.

Place the calibrated filter, with a nominal optical density of 3,0, in the light path over the lower optical window and measure the percentage transmission. The difference between the observed reading and the calibrated value, when expressed as a percentage of the average of the two values, shall be ≤ 5 %.

9.5 Calibration of range-extension filter

Bring the apparatus to its normal operating condition at 25 kW/m² in accordance with 10.2 with the chamber wall temperature remaining steady at 40 °C \pm 5 °C. Switch on the photometric system with the range-extension filter in the light path and, with the shutter closed. Adjust the zeroing device to give a reading of 0 % transmission with the instrument range switched to a full-scale reading of 0,1 % transmission.

Switch the amplifier to its 100 % transmission range, open the shutter and ensure that the range-extension filter is in the light path. Adjust the spanning device to give a reading of 100 % transmission. Place the white cloth, sheets of tissue or filter(s) with an optical density of about 2,5 (see 7.5.4.2) over the lower optical window, and switch to the 1 % transmission range. Add further filters or sheets of tissue to obtain a reading of approximately 0,5 % – do NOT adjust the controls of the photometric system. Record the transmission as T_{with} .

Without disturbing the cloth, tissue or filter(s), reset to 100 % transmission and withdraw the ND-2 range-extension filter from the light path. Note the transmission reading T_s and use it to determine, from Equations (1) and (2), the value of the range-extension filter optical density d_f and the appropriate correction factor C_f for readings obtained when the range-extension filter is not in the light path.

$$d_f = \log_{10} \frac{T_s}{T_{\text{with}}} \quad (1)$$

$$C_f = 132(d_f - 2) \quad (2)$$

NOTE For materials having known performance, this calibration procedure is not needed unless the optical density is greater than 4.

9.6 Chamber leakage rate test

Measure the air-tightness of the test chamber on each occasion of use (with the door, vents and spare gas sampling pipes closed) by introducing compressed air into the test chamber through one of the gas sampling pipes (or other compressed-air inlet) until the pressure recorded on the manometer is over 0,76 kPa (76 mm water gauge) and then shutting the supply off. The air-tightness of the test chamber shall be such that the time taken for the recorded pressure to drop from 0,76 kPa to 0,50 kPa (76 mm to 50 mm water gauge), determined using the timing device, shall be not less than 5,0 min.

9.7 Burner calibration

Set the flow rates of propane and air to achieve the flame length specified in 7.3.6.

NOTE Flow rates of approximately 50 cm³/min of propane and 300 cm³/min of air have been shown to give the correct flame length.

9.8 Radiator cone calibration

9.8.1 Clean the apparatus of any residues left from previous tests and, when a cone calibration is to follow soon after a test, flush the chamber (with the door shut and the exhaust and inlet vents open) with air for 2 min. Mount the heat flux meter in the specimen position with the distance from the radiator cone as specified in 7.3.2, and connect to the electrical and water services.

For intumescent materials mount the working heat flux meter in position with a distance of 50 mm between the cone heater bottom edge and the surface of the heat flux meter, and on the centre-line of the cone heater.

9.8.2 Bring the apparatus to its normal operation condition in accordance with 10.2 with the chamber wall temperature remaining steady in accordance with 10.2.2, and move the radiation shield away from the cone.

9.8.3 With the chamber door closed, the inlet vent open and the exhaust vent closed, supply water to the heat flux meter to cool the heat flux meter body. Monitor the heat flux meter output to determine when thermal equilibrium has been reached, and then adjust the cone, as necessary, to give a steady millivolt reading corresponding to the calibrated value equivalent to an irradiance of 25 kW/m² or 50 kW/m², as required. If the door is opened for any reason during calibration, allow sufficient time after closing the door for thermal equilibrium to be reached before taking the final millivolt reading.

NOTE With some water circulators, it may be necessary to have the chamber door slightly open to allow access for the tubing.

Allow about 10 min for stabilizing between adjustments.

9.8.4 Repeat the procedure of 9.8.3 as necessary to calibrate the equipment in three positions, i.e. at the centre and 25 mm each side of the centre.

9.8.5 Return the radiation shield to the position below the cone and remove the heat flux meter from the test chamber so that tests on specimens can proceed immediately. Continue to circulate water through the heat flux meter until the meter is cool enough for the protective cap to be replaced without melting or distortion.

9.9 Cleaning

Clean the inside walls of the chamber and the supporting framework for the cone and specimen holder using materials as described in 7.7, whenever periodic visual inspection indicates the need. Because the test is sensitive to variations in the composition of specimens, clean the apparatus when changing from tests on one material to another so that the results are not affected by chemical or physical interaction between the specimen and the residues left from previous tests on products.

NOTE Even when testing specimens of the same material, accumulations of residue can reduce the amount of deposition of smoke, resulting in an increase in the measured value of the specific optical density.

9.10 Frequency of checking and calibrating procedure

9.10.1 Undertake regular checking and calibration at periods as given in Table 1.

NOTE Products of combustion of some materials may cause corrosion of the cone heating element which may be compensated for by adjusting the applied voltage for a limited amount of change. If the cone cannot be made to give the required output, a new heating element may be required.

9.10.2 Follow the relevant setting-up procedure after any part of the equipment has been renewed or repaired.

10 Test procedure

10.1 General

The test may be carried out in the absence or in the presence of a pilot flame.

The preferred conditions are as follows:

- a) specimens are exposed to an irradiance of 25 kW/m² in the presence or absence of a pilot flame;
- b) specimens are exposed to an irradiance of 50 kW/m² in the presence or absence of a pilot flame.

If required, a full test evaluation will require exposure of test specimens to all 4 modes detailed in 10.9.1.

NOTE Some materials will not ignite when exposed to the conditions given in a) and b), but the smoke generated in a non-flaming mode is measured under these exposure conditions whether ignition of the test specimen has occurred or not.

10.2 Preparation of test chamber

10.2.1 Prepare the test chamber in accordance with the requirements of Clause 9 with the cone set at 25 kW/m² or 50 kW/m². For materials that intumesce more than 10 mm, the distance between cone heater and the specimen shall be 50 mm and the pilot burner shall be positioned 15 mm down from the cone heater bottom edge.

10.2.2 If a test has just been completed, flush the test chamber with air until it is completely clear of smoke with the test chamber door closed and exhaust and inlet vents open. Inspect the inside of the cabinet and clean the walls and the supporting framework if necessary (see 9.9). Clean the faces of the optical windows inside the chamber before each test. Allow the apparatus to stabilize until the chamber wall temperature is within the range 40 °C ± 5 °C for tests with the radiator cone at 25 kW/m² or within the range 55 °C ± 5 °C for tests with the radiator cone at 50 kW/m². Close the inlet valve.

For testing intumescent materials, the chamber wall temperature shall be within the range 50 °C ± 10 °C for tests with the radiator cone at 25 kW/m² or within the range 60 °C ± 10 °C for tests with the radiator cone at 50 kW/m².

If the temperature is too high, the exhaust fan may be used to draw in cooler air from the laboratory.

10.3 Tests with pilot flame

For tests with the pilot flame, with the burner in its correct position turn on the gas and air supplies and ignite the burner, check the flame length and colour and, if necessary, adjust the flow rates to ensure that the flame is as specified in 7.3.6.

10.4 Preparation of the photometric system

Set the zero and then open the shutter to set the full-scale 100 % transmission reading. Close the shutters again and check and reset the zero if necessary, using the most sensitive (0,1 %) range. Recheck the 100 % setting. Repeat the sequence of operations until accurate zero and 100 % readings are obtained on the amplifier and recorder when the shutters are opened and closed.

10.5 Loading the specimen

Place a wrapped specimen, prepared in accordance with 6.3 and 6.4 in the holder. Place the holder and specimen on the supporting framework below the radiator cone. Remove the radiation shield from below the cone and simultaneously start the data recording system and close the inlet vent. The test chamber door and the inlet vent shall be closed immediately after the start of the test.

If preliminary tests indicate that the pilot flame has become extinguished before the shield is removed, immediately relight the pilot burner and release the shield at the same time.

10.6 Recording of light transmission

Record the percentage light transmission and time continuously from the start of the test (i.e. when the radiation shield was removed). Switch the range of the photo detector amplifier system to the next decade when required, so that readings less than 10 % of full-scale deflection are avoided.

If the transmission levels become very low and below 0,000 1 %, i.e. the smoke density becomes very high, this shall be reported as smoke density D_s above 792, i.e. $D_s > 792$.

If the light transmission falls below 0,01 %, cover the observation window in the chamber door and withdraw the range-extension filter from the light path.

Table 1 — Frequency of checks and calibrations

Item of equipment	Minimum frequency of checks and calibrations	Procedure (subclause reference)
Test chamber interior	Inspect before testing every specimen and before any calibration	9.9
Radiator cone	Once every test day and when radiator cone is renewed or replaced	9.8
Chamber (leakage rate)	Once every test day and when safety blow-out panel or new seals are fitted	9.6
Heat flux meter	Every 12 months and when meter is cleaned or recoated	7.3.4.3 and Annex A
Photometric system:		
calibration	Before testing every specimen	
alignment	Every 6 months and when light source is replaced or when damage occurs	9.2
compensating filters	Every 6 months and when transmission through windows deteriorates	9.3
linearity	Every 6 months and when transmission through windows deteriorates	9.4
range-extension filter	Every 6 months	9.5

10.7 Observations

Note any particular burning characteristics of the specimen, such as delamination, intumescence, shrinkage, melting and collapse, and note the time from the start of the test at which the particular behaviour occurs, including the time of ignition and the duration of flaming. Also note the smoke characteristics, such as the colour and nature of the settled particulate matter.

The smoke generation from some materials differs significantly depending on whether combustion occurs in a non-flaming or flaming mode (see Annex E). It is important, therefore, to record as much information as possible about the mode of combustion during each test.

NOTE Coated and faced materials, including sheet laminates, tiles, fabrics and other materials secured to a substrate with an adhesive, and composite materials not attached to a substrate, can be subject to delamination, cracking, peeling or other types of separation affecting their smoke generation.

If the pilot flame is extinguished by gaseous effluent during a test and fails to re-ignite within 10 s, the gas supply to the pilot burner shall be immediately switched off (see 7.3.6).

If inflation of a thin specimen that has not been cut (see 6.4.4) has occurred, the results from that specimen shall be ignored and an extra cut specimen tested.

10.8 Termination of test

10.8.1 Carry out the test for a period of 10 min. If required, it is permissible for this test to be conducted for periods in excess of 10 min, if minimum light transmittance values have not been reached during a 10 min exposure. The maximum time for any single test exposure shall be 30 min.

10.8.2 Extinguish the burner if the pilot flame has been used.

NOTE The burner is extinguished in order to obviate the possibility of air mixing with any combustion products present and causing an explosion.

10.8.3 Move the radiation shield below the cone.

10.8.4 Switch on the exhaust fan and, when the manometer indicates a small negative pressure, open the inlet vent and continue exhausting until a maximum value of light transmission is recorded, with the appropriate range selected, and noted as the “clear beam” reading T_C , for use in calculating D_C to evaluate the level of deposits on the optical windows.

10.9 Testing in different modes

10.9.1 Measure the percentage light transmission of four sets of three specimens for each material in accordance with the following schedule:

- Mode 1: Irradiance 25 kW/m², no pilot flame;
- Mode 2: Irradiance 25 kW/m², pilot flame;
- Mode 3: Irradiance 50 kW/m², no pilot flame;
- Mode 4: Irradiance 50 kW/m², pilot flame.

10.9.2 For each individual specimen, determine the percentage value of light transmission and from this calculate the appropriate specific optical density as given in 11.1. If the value of D_{Smax} for any individual specimen differs from the average value for the set of three specimens of which it is part by more than 50 % of that average for no apparent reason, test an additional set of three specimens from the same sample in the same mode and record the average of all six results obtained.

NOTE Even in the same test condition, a specimen may burn with flaming and the others may burn without flaming. This would be an apparent reason and this may occur due to the different smoke emitting propensities of some materials when they burn without flames compared to when they burn with flames.

11 Expression of results

11.1 Specific optical density D_s

NOTE The variability in the specific optical density D_{s10} at 10 min from the start of the test has been investigated in a preliminary interlaboratory trial (see Annex B).

11.1.1 For each specimen, produce a graph of light transmission against time and determine the minimum transmission T_{\min} . T_{\min} shall be converted to specific optical density $D_{s\max}$ by calculation to two significant figures using the following equation:

$$D_{s\max} = 132 \log_{10} \frac{100}{T_{\min}} \quad (3)$$

where

132 is a factor derived from the expression V/AL for the test chamber, where

- V is the volume of the chamber;
- A is the exposed area of the specimen;
- L is the length of the light path.

If required, D_s at 10 min (D_{s10}) may be obtained from light transmission at 10 min (T_{10}) using Equation (3) replacing T_{\min} with T_{10} .

The transmission used in this equation is the measured transmission. For the first four decades, this is the value recorded by the system. For the final two decades (where the range-extension filter is removed from the light path), calculate the transmission relative to the actual measuring range of 0,01 % or 0,001 %.

NOTE If the measuring range is set to 1 % with the range-extension filter removed, then the actual measuring range is 0,01 %. If the displayed transmission value is 0,523, then the actual measured transmission is 0,005 23 %.

11.1.2 If required, to each value of $D_{s\max}$ and D_{s10} determined in 11.1.1, add the correction factor C_f , which depends upon the use of the range-extension filter. The value of C_f is

- a) zero
 - 1) if the filter is in the light path at the time the transmission was recorded ($T \geq 0,01$ %), or
 - 2) if the photometric system is not equipped with a removable filter;
- b) as determined by the procedure described in 9.5 if the filter is moved out of the light path at the time it is measured ($T < 0,01$ %).

11.2 Clear-beam correction factor D_c

For each specimen, record the value of the "clear beam" reading T_c (see 10.8.4) to determine the correction factor D_c . Calculate D_c as for $D_{s\max}$ in 11.1. Do not record the correction factor D_c if it is less than 5 % of the maximum specific optical density determined from the graph (see 11.1).

12 Precision

The variability in the specific optical density D_{s10} at 10 min from the start of the test has been investigated in a preliminary interlaboratory trial, see Annex B.

Results of an interlaboratory test on intumescent materials are summarized in Annex D.

13 Test report

The test report shall include a reference to this part of ISO 5659 together with the following information:

- a) the name and address of the laboratory undertaking the test;
- b) where applicable, the name and address of the manufacturer or supplier of the product tested;
- c) the date(s) of the test;
- d) a full description of the product tested, including such aspects as its name, type, form, essential dimensions, mass or density, colour and coverage rate of any coating;
- e) a full description of the specimen construction and preparation (see 6.2.3 and 6.3);
- f) the specimen face tested (see 6.1.2);
- g) if calculated, the neutral-density correction factor C_F ;
- h) the mode of testing (see 10.9.1), if limited testing was carried out;
- i) whether the wire grid (see 7.3.5) was used;
- j) the number of specimens tested for each type of exposure (see 10.9);
- k) the thickness of each specimen tested;
- l) for each valid specimen tested, the mode of testing, the graph of light transmission against time and the maximum specific optical density $D_{S,max}$ and, if required, the specific optical density, $D_{S,10}$ at 10 min from the start of the test (see 11.1), together with the duration of the test (see 10.8);
- m) for each valid specimen tested, the clear-beam correction factor D_C (see 11.2);
- n) observations of the specimens and the times from the start of the test at which the observations were made (see 5.1 and 10.7), together with details of any invalid tests and the reasons for these;
- o) the mean value of $D_{S,max}$ and $D_{S,10}$, if required, for each mode of testing;
- p) the statement: "These results relate only to the behaviour of the specimens of the product under the particular conditions of test; they are not intended to be the sole criterion for assessing the potential smoke obscuration hazard of the product in use."

Annex A

(normative)

Calibration of heat flux meter

Calibration of the heat flux meter shall be conducted in accordance with ISO 14934-3 whenever a check is made on the adjustment of the heater and its temperature controller. This shall be done by comparison with two instruments of the same type as the working heat flux meter and of similar range, held as reference standards and not used for any other purpose. One of the heat flux meter reference standards shall be fully calibrated at an accredited laboratory at yearly intervals. This meter shall be used to adjust the heater temperature controller (see Figure 4 and Figure 5). It shall be positioned at a location equivalent to the centre of the specimen face during this procedure.

NOTE The use of two reference standards rather than one provides a greater safeguard against change in sensitivity of the reference instruments.

Annex B (informative)

Variability in the specific optical density of smoke measured in the single-chamber test

A preliminary interlaboratory trial has been carried out in which replicate batches of 16 materials were tested in accordance with this part of ISO 5659 by eight laboratories. The interlaboratory trial showed that the specific optical density D_{s10} of some materials was more variable than that of others. The variability increased particularly for materials which did not ignite readily at 25 kW/m² and for materials which showed higher D_{s10} values in non-flaming combustion than in flaming combustion.

The preliminary interlaboratory trial has shown that this part of ISO 5659 can enable users to discriminate between materials which generate low and high levels of smoke. Table B.1 and Table B.2 give the repeatabilities and reproducibilities of D_{s10} for five plastics and five building materials, derived in accordance with ISO 5725:1986 [8].

Repeatability r is the value below which the difference between two D_{s10} values obtained with the same method on identical test material, under the same conditions (same laboratory, same apparatus, same operator and a short interval of time), may be expected to lie with a probability of 95 %.

Reproducibility R is the value below which the difference between two D_{s10} values obtained with the same method on identical test material, under different conditions (different laboratories, different operators, different apparatus), may be expected to lie with a probability of 95 %.

The preliminary interlaboratory trial has indicated that it is not meaningful to quote a single value for the variation of the test. The D_{s10} data show that smoke generation depends upon the ignition behaviour of materials. Since ignition times are sensitive to irradiance, it is clear that careful attention has to be paid to the measurement of irradiance.

Table B.1 — Repeatability and reproducibility of specific optical density for plastics

Material	Thickness mm	Irradiance kW/m ²	Mean D_{s10}	Repeatability (within laboratory)		Reproducibility (between laboratories)	
				r	% of mean	R	% of mean
PMMA	1,0	25	11	4	38	10	91
		25 + pf	55	13	24	29	53
		50	54	11	20	17	32
ABS	1,1	25	312	77	25	311	100
		25 + pf	441	146	33	205	46
		50	435	102	23	192	44
Rigid polyurethane foam (28 kg/m ³)	25,0	25	49	16	32	61	124
		25 + pf	48	24	51	26	54
		50	145	48	33	97	67
Flexible polyurethane foam (27 kg/m ³)	25,0	25	178	49	27	114	64
		25 + pf	80	28	35	56	70
		50	127	46	36	80	63
Expanded polystyrene (non-fire-retardant; 14 kg/m ³)	25,0	25	112	75	67	196	175
		25 + pf	102	75	74	130	128
		50	270	88	33	195	72

NOTE + pf indicates a test carried out in mode 2 (i.e. with pilot flame).

Table B.2 — Repeatability and reproducibility of specific optical density for building materials

Material	Thickness mm	Irradiance kW/m ²	Mean <i>D</i> _{s10}	Repeatability (within laboratory)		Reproducibility (between laboratories)	
				<i>r</i>	% of mean	<i>R</i>	% of mean
Pine	12,1	25	403	97	24	300	74
		25 + pf	26	15	55	56	211
		50	196	191	98	191	98
Chipboard	12,2	25	411	47	12	187	45
		25 + pf	58	59	102	88	153
		50	481	96	20	464	97
Plywood	4,2	25	251	31	12	132	52
		25 + pf	33	15	47	58	175
		50	113	58	51	82	72
Medium-density fibreboard	11,9	25	420	127	30	281	67
		25 + pf	68	42	62	72	106
		50	688	114	17	413	60
Paper-faced plasterboard	12,7	25	20	8	42	21	107
		25 + pf	8	8	104	25	314
		50	17	11	64	23	132

+ pf indicates a test carried out in mode 2 (i.e. with pilot flame).

Annex C (informative)

Determination of mass optical density

C.1 Scope

This annex gives, for information only, a method which may be used to determine the mass optical density of a material (see 3.7). Values of mass optical density determined by this method are specific to the specimen or assembly material in the form and thickness tested and are not to be considered inherent, fundamental properties.

C.2 Principles of the test

The conditions of thermal exposure and of smoke collection are the same as for specific optical density. Additional mass measurements are carried out on the specimen during the test so that a mass loss/time curve is determined and mass optical density is also calculated.

C.3 Test specimens

C.3.1 The same specifications for suitability of materials shall apply (see Clause 5). Similarly, the same number of specimens, and the same preparation and conditioning procedures shall be used (see Clause 6).

C.3.2 Each test specimen shall be weighed wrapped in its aluminium foil and held in its specimen holder, to give the initial mass (m_i).

C.4 Ancillary equipment

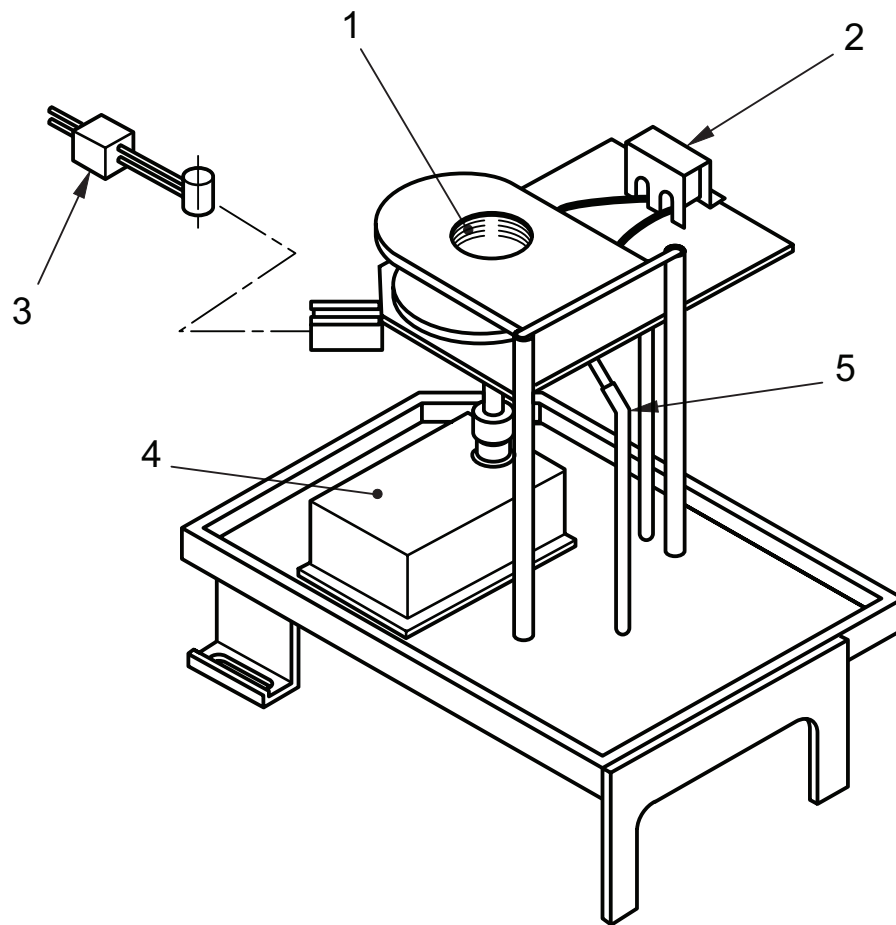
C.4.1 The load cell shall have a measuring range of 500 g to a weighing accuracy of $\pm 0,1$ g. The load cell shall be mounted in an enclosure (see Figure C.1, Figure C.2 and Figure C.3) with a close-fitting labyrinth seal between the sample support rod and the enclosure to minimize ingress of smoke particles and corrosive fumes.

The load cell assembly shall be easily removable from the smoke chamber so that the procedure for determination of specific optical density may be performed without unnecessary exposure of the load cell if mass optical density data are not required.

The load cell enclosure shall be fitted with one fixed foot and two adjustable feet to level the unit on the baseplate. The load cell shall also have means for centring the load cell assembly beneath the cone radiator.

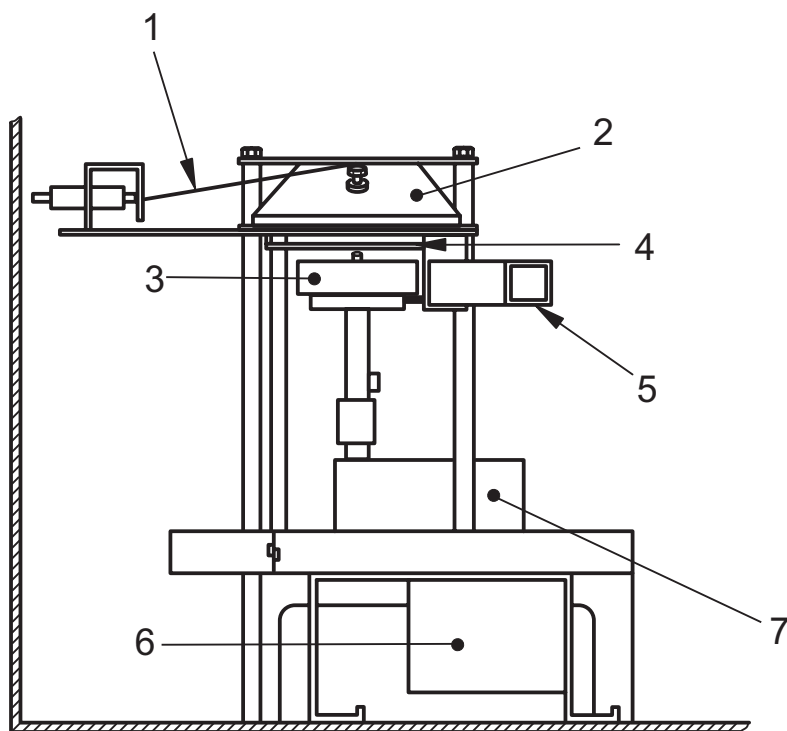
C.4.2 The load cell shall have a safe operating temperature range from 15 °C to 70 °C. A mineral-fibreboard shield shall be positioned over the top and sides of the load cell enclosure during thermal exposure of the test specimen so that excessive temperature rise within the enclosure is prevented and drift of the load cell is avoided.

C.4.3 The load cell shall be connected to a controller which drives the load cell and which is situated outside the smoke chamber. This controller should preferably be fitted with a digital weight display, scalable millivolt output and tare facility.

**Key**

- | | | | |
|---|-------------------------------|---|--------------|
| 1 | heating element | 4 | load cell |
| 2 | thermocouple mount and shield | 5 | pilot burner |
| 3 | heat flux meter and mount | | |

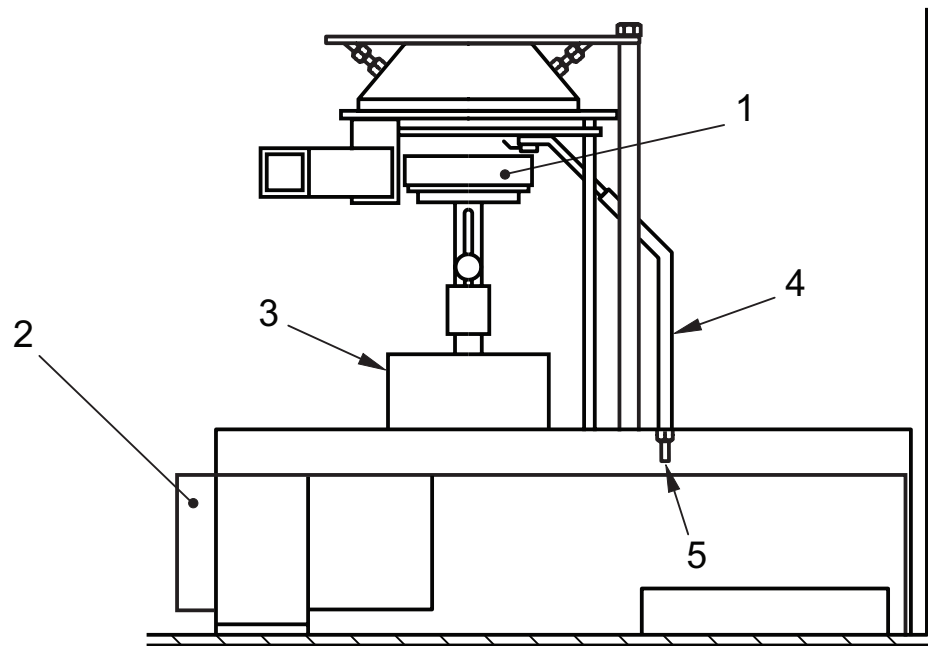
Figure C.1 — Typical framework for support of radiator cone, specimen and flux meter



Key

- | | |
|---------------------------------|--------------------------|
| 1 thermocouple | 5 heat flux meter holder |
| 2 radiator cone heating element | 6 spark ignition supply |
| 3 specimen holder | 7 load cell |
| 4 radiator shield | |

Figure C.2 — Typical arrangement of radiator cone, specimen holder and radiator shield with load cell for mass optical density determination (side view)



Key

- | | |
|--------------------------|---------------------------------------|
| 1 specimen holder | 4 pilot burner and ignition electrode |
| 2 spark ignition housing | 5 propane and air |
| 3 load cell | |

Figure C.3 — Typical arrangement of radiator cone, specimen holder and radiator shield (front view)

C.5 Calibration procedure

The load cell calibration shall be checked with standard reference masses in the range of the test specimen mass before each series of tests.

C.6 Test procedure

C.6.1 Preparation of test chamber

Prepare the test chamber, pilot flame and photometric system as described in 10.1, 10.2, 10.3 and 10.4.

C.6.2 Loading the specimen

Place a wrapped specimen, prepared in accordance with 6.3 and 6.4, including backing fibre blanket if required, in its holder. Place the holder and specimen on the pan of the load cell below the radiator cone and immediately close the test chamber door. Set the load cell controller to record the initial mass (m_i) of the test specimen, backing board and specimen holder. Remove the radiator shield from below the cone and simultaneously start the data recording system and close the inlet vent.

Alternatively, the specimen holder and backing material mass may be tared before putting the wrapped specimen into the holder so that the mass of the specimen is measured by the load cell controller.

C.6.3 Recording of light transmission and mass loss

Record the percentage light transmission, mass of specimen and holder, and time continuously from the start of the test (i.e. when the radiation shield was removed) or at time intervals no greater than 30 s.

Perform the test and carry out the observations in accordance with 10.5 and 10.6 respectively.

C.6.4 Termination of test

C.6.4.1 Carry out the test for a period of 10 min (see 10.8.1) and extinguish the burner if the pilot flame has been used (see 10.8.2).

C.6.4.2 Move the radiation shield below the cone.

C.6.4.3 Switch on the exhaust fan to remove smoke and fumes from the test chamber (see 10.8.4).

C.6.4.4 Record the final mass (m_f) of the test specimen, backing board and specimen holder.

C.6.5 Repeat tests

The same criteria shall apply as in 10.8.1 and 10.8.2.

C.7 Expression of results

For each specimen, calculate the mass optical density MOD at 10 min, in square metres per kilogram (m^2/kg), using the following equation:

$$\text{MOD} = \frac{D}{L} \times \frac{V}{\Delta m}$$

where

D is the optical density of the smoke (see 3.10);

L is the length of the light path;

V is the chamber volume;

Δm is the loss in mass of the test specimen (i.e. $m_i - m_f$).

The chamber volume V shall be taken as $0,51 \text{ m}^3$ and the length of the light path L as $0,915 \text{ m}$.

NOTE The mass optical density may be calculated at times other than 10 min, by using the specimen mass/time graph recorded during the test.

C.8 Test report

The test report shall include all the information required in Clause 13 and, for each valid specimen tested, the following information:

- a) the graph of specimen mass against time;
- b) the mass optical density at 10 min, from the start of the test.

Annex D (informative)

Precision data from tests on intumescent materials

D.1 Background

An inter-laboratory exercise was organized in order to give background data for amendments to the test method for intumescent materials using specimen-heater distance of 50 mm.

D.2 Specimens

Two types of specimen were used:

- polycarbonate, 6 mm thickness;
- polyvinyl chloride (PVC) floor covering, 3 mm thickness.

D.3 Participating laboratories

Nine laboratories participated in the tests for PVC flooring, and 10 laboratories participated in the test for polycarbonate.

D.4 Test method

Tests were conducted according to this part of ISO 5659 except that the specimen supporting system was adjusted to have 50 mm distance between the specimen exposed surface and the conical radiant heater bottom edge. Calibration of heat flux level to specimen surface was conducted by heat flux meters set at the specimen position (50 mm below the bottom edge of the conical radiant heater), and the conical heater temperature was set to deliver a heat flux of 25 (kW/m²) and 50 (kW/m²) to the specimen at that position.

The pilot burner was kept at the position specified in this part of ISO 5659, i.e. 15 mm down from the cone heater bottom edge.

Tests were conducted in three test conditions:

- a) heat flux to the specimen: 25 kW/m², and with pilot flame;
- b) heat flux to the specimen: 25 kW/m², and without pilot flame;
- c) heat flux to the specimen: 50 kW/m², and without pilot flame.

D.5 Test results

Tables D.1 and D.2 show the test results. Repeatability and reproducibility were calculated according to ISO 5725-2 [9]. Outliers were eliminated in accordance with ISO 5725-2. Table D.3 gives the cone heater temperature and the inside-wall temperature of the smoke chamber, which were measured during the inter-laboratory exercise.

Table D.1 — Test results for polycarbonate

Test condition	Parameter	Average <i>A</i>	Repeatability <i>r</i>	<i>r/A</i> %	Reproducibility <i>R</i>	<i>R/A</i> %	Number of laboratories
25 kW/m ²	<i>D</i> _{s10}	8,4	1,6	20,1	3,8	45,2	6
With pilot flame	<i>D</i> _{smax}	17,1	2,1	10,4	5,4	31,8	6
25 kW/m ²	<i>D</i> _{s10}	8,7	1,2	15,9	2,5	28,4	5
Without pilot flame	<i>D</i> _{smax}	22,2	1,8	8,1	3,7	16,7	6
50 kW/m ²	<i>D</i> _{s10}	a	a	a	a	a	a
Without pilot flame	<i>D</i> _{smax}	a	a	a	a	a	a

^a Most of the laboratories reported that the *D*_{s10} and *D*_{smax} exceeded 500.

Table D.2 — Test results for PVC flooring

Test condition	Parameter	Average <i>A</i>	Repeatability <i>r</i>	<i>r/A</i> %	Reproducibility <i>R</i>	<i>R/A</i> %	Number of laboratories
25 kW/m ²	<i>D</i> _{s10}	260,8	47,8	18,8	74,7	28,6	9
With pilot flame	<i>D</i> _{smax}	296,0	57,9	20,1	96,3	32,5	9
25 kW/m ²	<i>D</i> _{s10}	472,6	41,6	9,8	124,0	26,2	9
Without pilot flame	<i>D</i> _{smax}	504,0	22,7	4,8	101,9	20,2	9
50 kW/m ²	<i>D</i> _{s10}	376,6	26,8	6,8	110,4	29,3	8
Without pilot flame	<i>D</i> _{smax}	491,6	28,7	6,0	95,9	19,5	8

Table D.3 — Smoke chamber temperatures during test

Heat flux level to specimen kW/m ²	Conical heater temperature °C	Maximum inside wall temperature of the smoke chamber during the test °C
25	from 658 to 716	63
50	from 855 to 919	90

Annex E (informative)

Guidance on optical density testing

E.1 Introduction

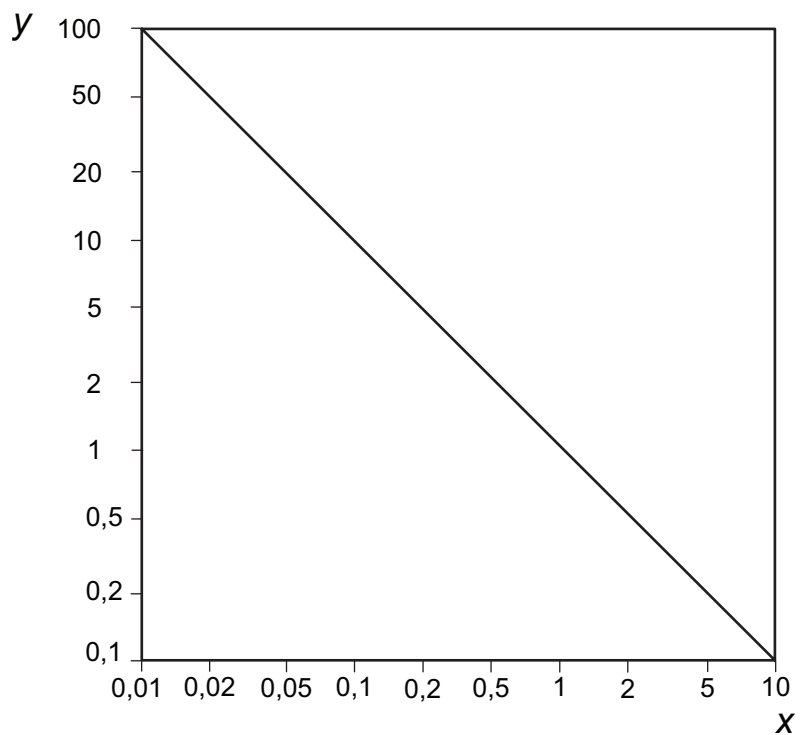
Smoke represents a major hazard in fires due to its capacity to obscure vision by the absorption and scattering of light. Consequently, two threats are obvious: the inhalation of hazardous gases and fumes and the obscuration of light by smoke particulates leading to disorientation. These threats interact in a complicated manner, but are usually dealt with by separate procedures.

Smoke particulates reduce the visibility due to light absorption and scattering. Consequently, people may experience difficulties in finding exit signs, doors and windows. Visibility is often determined as the distance at which an object is no longer visible. It depends on many factors, such as temperature, humidity and smoke irritancy. Of particular interest for fire safety are the close relationships that have been established between visibility and measurements of the optical density of smoke. Results of Jin [3] are depicted simply in Figure E.1. Visibility is approximately inversely proportional to the extinction coefficient k so that $w = y/k$ where w is the visibility and y is the constant of proportionality. There is a broad spread in the experimental data for visibility since it depends on other factors such as external illumination, the brightness of light-emitting signs and the reflectance of light-reflecting signs. Calculations of visibility using this relationship should be regarded cautiously as estimates. As a further example of these effects, Jin chose a y -value of 3 for light-reflecting signs and a y -value of 8 for light-emitting signs; the spread of data for these signs is shown in Figure E.2, where the lower spread for light-emitting signs typifies the conditions used in the smoke chamber.

The generation of smoke and the measurement of the optical density are often measured simultaneously with other fire properties, such as heat release or flame spread. The measurements may be in small, intermediate, large or real scale. They may be performed in small-scale, closed systems and are called cumulative or static methods. They may also be performed in a flow-through system, and these are called dynamic methods.

The smoke chamber, as in this part of ISO 5659, is also being used for toxicity measurements when effluent gases are extracted and analysed at specified times during a test (see References [10], [11] and [12]).

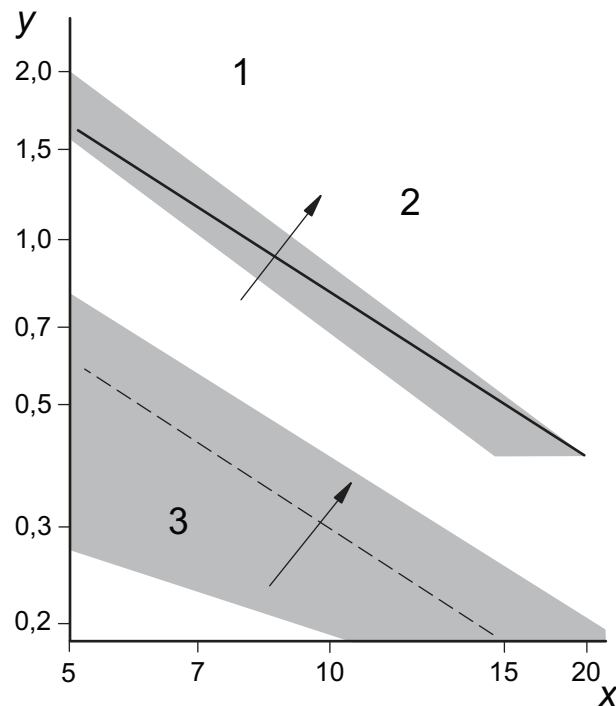
A distinction should be made between smoke and soot, which is particulate matter produced and deposited during and after combustion. Smoke is measured by optical means and soot is determined by actual weighing of particulates collected (gravimetric means). Since fire safety concerns are often with optical smoke measurements, the guidance on smoke tests will focus on obscuration of visibility. This part of ISO 5659 does not provide guidance on the determination of soot particles or on their potential health risks to occupants of a space affected by smoke.



Key

- x optical density (per metre smoke path)
- y visibility, m

Figure E.1 — Relationship between optical density and visibility

**Key**

x w (m)
 y k (m⁻¹)

1	light-emitting signs	Solid line	$w = y/k, \gamma = 8$
2	increasing brightness	Dashed line	$w = y/k, \gamma = 3$
3	increasing reflectance	Shaded area	experimental spread of data

Figure E.2 — Visibility (w) versus extinction coefficient (k)

The test in this part of ISO 5659 is intended primarily for use in ranking materials in research and development and fire safety engineering in buildings, trains, ships, etc. No basis is provided for predicting the density of smoke that may be generated by products upon exposure to heat and flame under other (actual) exposure conditions. This test procedure excludes the effect of irritants on the eye. The test procedure addresses the loss of visibility due to smoke density, which generally is not related to irritancy potency.

E.2 Objective

It is the objective of this annex to provide guidance on the applicability of the optical density measurements described in this part of ISO 5659.

This part of ISO 5659 has been developed for assessment of the smoke-generating potential of burning materials and products under a wider range of heat flux conditions than alternative single-chamber smoke tests, as well as to allow thermoplastics to be tested in a horizontal orientation.

E.3 Optical density measurements

E.3.1 Principles

Both white light and monochromatic laser-light may be used for smoke measurement. In the test given in this part of ISO 5659, white light is used.

Since light attenuation through smoke is dependent on the absorption and the scattering of light, and since the latter is dependent on wavelength, caution should be exercised when comparing data obtained from different measuring systems using different light sources.

The use of maximum specific optical density as a unit of smoke measurement is based on Bouguer's law of monochromatic light attenuation [6], which is expressed as follows:

$$T = T_0 e^{-\sigma L} \quad (\text{E.1})$$

where

- T is the percentage transmission;
- T_0 is the initial transmission (100);
- σ is the attenuation coefficient;
- L is the length, in metres, of the optical path;
- e is the base of natural logarithms.

For a mono-dispersed aerosol, the attenuation coefficient σ is found to be proportional to the product of particle size and the number of particles. If $\log_{10}(100/T)$ is defined as the optical density D , then

$$D = \log_{10}(100/T)$$

and hence

$$D = \sigma L / 2,303$$

While the smoke produced from fire usually does not have all the characteristics of a mono-dispersed aerosol, it has been found to behave in a photometric manner such that, for engineering purposes, the optical density may be considered to be proportional to the smoke particles produced.

NOTE This part of ISO 5659 is a cumulative smoke measurement method. Other tests (such as ISO 5660-2) measure smoke in a dynamic procedure where the smoke from the test specimen is drawn through an exhaust system at a defined flow rate and the extinction coefficient of the smoke stream is recorded at regular intervals by determining the transmitted intensity of a light beam passing through the smoke.

E.3.2 Calculation methods

E.3.2.1 General

In a cumulative (static) smoke test, the test specimen burns in a closed chamber and the smoke produced accumulates over time. In some tests, a fan stirs the smoke to prevent layering and to make it homogeneous.

The amount of smoke is measured by monitoring the attenuation of a light beam shining through the smoke. The extinction area of the smoke is a useful measure of the amount of smoke produced, and is a function of the opacity of the smoke, the volume of the chamber and the light path length.

$$S = \frac{V}{L} \ln \frac{I}{T} \quad (\text{E.2})$$

where

- S is the extinction area;
- V is the volume, in cubic metres, of the chamber;
- L is the length, in metres, of the optical path;;
- I/T is the percentage transmission.

This equation only applies if the smoke is homogeneous.

In some tests, including IEC 60695-6-31 [5] and this part of ISO 5659, the amount of smoke is calculated from the optical density of the smoke, and it is normalized to the surface area of the test specimen.

The quantity calculated is D_s , the specific optical density.

$$D_s = \left[\frac{V}{(AL)} \right] \log_{10} \left(\frac{I}{T} \right) \quad (\text{E.3})$$

For the single-chamber procedure in this part of ISO 5659, the factor V/AL is 132.

The thickness of the test specimen will affect the amount of smoke produced. D_s values should not be directly compared for specimens of different thicknesses. Conversely if comparisons are being made then test specimen thickness has to be kept constant.

The purpose of measuring D_s (or S) is to enable the prediction of visibility. However, the visibility within the test chamber is not usually what is required to be known. What is required is an estimation of visibility in a given scenario. It is possible to make such estimations based on data obtained in static tests such as IEC 60695-6-31 [5] or this part of ISO 5659 but it should be appreciated that such calculations are only estimates, as changing the fire model will probably change both the smoke production process and the way in which the smoke will age.

E.3.2.2 Measurements specific to this part of ISO 5659

The main measurement made when carrying out testing to this part of ISO 5659 is the amount of light transmitted by the smoke as a fraction (or percentage) of the initial light transmitted by the optical system. The minimum percent light transmitted is then used to calculate the maximum specific optical density for each mode of specimen exposure, e.g. irradiance of 25 kW/m² (with or without pilot flame) or irradiance of 50 kW/m² (with or without pilot flame). The choice of test specimen exposure conditions may be critical in determining the onset of ignition, and the smoke generated from the test specimen may vary considerably depending on whether the specimen combusts in a non-flaming or a flaming mode.

NOTE 1 Some test methods report smoke simply in terms of light transmission. The problem with such a reporting procedure is that people not familiar with the characteristics of smoke aerosols may erroneously assume that the percentage light transmittance is a reciprocal, linear function of the quantity of smoke produced.

The concept of specific optical density allows smoke development to be understood in terms that recognize the area of test specimen involved as well as the volume of the smoke chamber and the optical path length of the photometer. Specific optical density is dimensionless, but its value relates to the thickness of the specimen tested. Hence, the thickness of the test specimen should always be reported whenever specific optical density for a material is quoted.

The relationship between obscuration and test specimen mass loss is measured by a term called the mass optical density (MOD) which can be obtained using the single-chamber apparatus this in part of

ISO 5659 modified with a load cell so that the loss in mass of the specimen may be determined during the test. Mass optical density (MOD) is given by the following equation:

$$\text{MOD} = \left(\frac{D}{L} \right) \left(\frac{V}{\Delta m} \right) \quad (\text{E.4})$$

where Δm is the loss in mass, in grams, of the test specimen.

NOTE 2 See Annex C for a method of determining mass optical density.

In the procedure in this part of ISO 5659, light transmission measurements are made over a 10-min period of exposure of the test specimen to a cone radiator. This time period is usually sufficiently long to allow the rate of smoke generation to be determined. There is no requirement in this part of ISO 5659 to record the maximum smoke density achieved. Some specimens will show a peak in the D_s/t graph, and smoke density may decrease after this peak during the 10-min exposure. Other test specimens may exhibit an increase in smoke density throughout the 10-min exposure, or achieve a maximum value and retain this level of smoke until the end of the 10-min period.

The early stages of smoke generation are the most important in terms of life threat, and so in the interests of economy of testing, and especially to allow more specimens to be included in the test procedure to improve repeatability, the procedure in this part of ISO 5659 is restricted to 10 min to obtain D_{s10} . Longer accumulation times may be used at the discretion of the testing laboratory if the interest is in obtaining $D_{s\text{max}}$ but the exposure time should be kept constant throughout any series of comparative tests and should be recorded in the test report.

In this part of ISO 5659, higher D_s values will be measured as the test specimen thickness increases. For comparative purposes, different products should always be evaluated at the same thickness. It is recognized, however, that products may not always be available at the same thickness and so for some practical exercises products may be evaluated at their end-use thickness, although this should be stated whenever the results for these products are quoted. For inherently smoky products, it is recommended that these are tested at about 1 mm thickness to avoid smoke saturation within the smoke chamber and to avoid excessive oxygen consumption.

In addition, for products generating high levels of smoke, it is recommended that the test should be stopped before the specified duration of 10 min. If this is done, the result should be reported as $D_s(t)$, where t is the time from zero during which smoke measurements are made.

In an approach to assessment of the rate of smoke generation in the first 4 min of the test in this part of ISO 5659, a parameter VOF4 may be derived (Reference [7]). VOF4 is defined as the cumulative value of specific optical densities in the first 4 min of the test. VOF4 is the area under the $D_s(t)$ versus time curve during the test period $t = 0$ to $t = 4$, using a trapezoidal area assumption and a finite element (t) of 1 min.

With $D_s(0) = 0$ and $t = 1$,

$$\text{VOF4} = D_s(1) + D_s(2) + D_s(3) + \frac{D_s(4)}{2} \quad (\text{E.5})$$

NOTE 3 VOF4 has units of minutes.

E.4 Factors affecting smoke production

E.4.1 General

Many factors affect the production of smoke and the properties of the smoke. Full characterization is not possible, but the influence of several important variables is recognized.

E.4.2 Mode of decomposition

Smoke is basically a product of incomplete combustion. It may be flaming or smouldering (non-flaming) combustion, which may produce quite different types of smoke. In smouldering combustion, volatiles are evolved at elevated temperatures. When they mix with cool air, they condense to form spherical droplets, which appear as a light-coloured smoke aerosol. Flaming combustion produces a black carbon-rich smoke in which the particles have a very irregular shape. The smoke particles from flaming combustion are formed in the gas phase and in regions where the oxygen concentrations are low enough to cause incomplete combustion. The carbonaceous smoke particles in the flames emit radiant energy (as black-body emission), which is seen as yellow luminosity.

The particle size of the spherical droplets from smouldering combustion is generally in the order of 1 μm , while the size of the irregular soot particles from flaming combustion is often larger but much harder to determine and is dependent on the measuring technique.

It is often observed for wood fires that the amount of smoke is less with flaming combustion than with smouldering. For plastics, however, no such generalization can be made: the smoke produced under smouldering conditions can be less or more than under flaming conditions. For these reasons, it is important to record in a smoke test whether ignition occurs, as well as the times of ignition and extinction of flames on the test specimen. In addition, cold smoke may be generated from the rear of composites; this may differ substantially in colour and composition from the smoke released from the exposed surface.

The heat flux to which the test specimen is exposed may influence how the product burns. It is good practice to evaluate the smoke generated from products at low levels of incident irradiance (e.g. 15 kW/m^2 to 25 kW/m^2) as well as at higher levels (e.g. 40 kW/m^2 to 50 kW/m^2). In this way, the effects of the growth phases of a fire on the smoke-generating propensity of a product can be assessed.

E.4.3 Ventilation and burning environment

Smoke production depends upon the fire scenario and not just on what product is being burnt. It is known that, for some products, generation of smoke is increased considerably by restricted ventilation.

The rate of burning and the area involved in burning should always be considered when determining smoke production in real fire scenarios. A product generating small quantities of smoke per elemental burning area may actually give large quantities of smoke in a real fire environment due to rapid spread of flames over large surface areas.

E.4.4 Time and temperature

The particle size distribution of smoke aerosols changes with time since smoke particles coagulate as they age. Some properties also change with temperature so that the properties of aged, or cold, smoke may be different from young, hot smoke. These factors are important for fire engineers when they are considering potential smoke movement in large buildings and other hazardous areas (such as trains in tunnels or ships). They also have to be considered when designing smoke tests.

E.4.5 Removal mechanisms for smoke particles

Large smoke particles may be removed by a number of mechanisms. In cumulative test procedures where the cone radiator is immersed in the combustion gases, reheated decomposition may occur as the smoke particles recirculate through the combustion chamber. Other mechanisms for removal of larger particles include deposition of particles on the internal surfaces of the chamber and the action of fan stirrers. Aspects of these mechanisms also occur in real fires when smoke circulates within a fire compartment. Because these effects are possible in cumulative smoke tests, it is recognized that the early stages of the exposure (for example, the first 10 min) are the most relevant for determination of the rate of smoke generation.

E.5 Applicability of results

Realistic assessments of the fire performance of a product can only be obtained by testing a real-scale specimen in the form and orientation in which it is actually used. An isolated test such as that given in this part of ISO 5659 can only indicate the response of a product to the fire model selected. It is emphasized that no fire or smoke test can in normal circumstances measure fire or smoke hazard. In addition, it cannot be assumed that satisfactory results of a single standard fire or smoke test will guarantee a given level of safety.

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