INTERNATIONAL STANDARD

ISO 21367

First edition
2007-05-01

Plastics — Reaction to fire — Test method for flame spread and combustion product release from vertically oriented specimens

Plastiques — Réaction au feu — Méthode d'essai de propagation de flamme et de dégagement de produits de combustion à partir d'éprouvettes orientées verticalement

Reference number
ISO 21367:2007(E)

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Published in Switzerland

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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 21367 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 4, *Burning behaviour*.

Plastics — Reaction to fire — Test method for flame spread and combustion product release from vertically oriented specimens

WARNING — Avoidance of misleading inferences

This standard method of test should be used solely to measure and describe the properties of materials, products or systems in response to heat or flame under controlled laboratory conditions, and should not be considered or used by itself for describing or appraising the fire hazard of materials, products or systems under actual fire conditions or as the sole source on which regulations pertaining to smoke production can be based.

WARNING — Avoidance of danger to test operators

So that suitable precautions to safeguard health are taken, the attention of all concerned in fire tests is drawn to the fact that harmful gases are evolved in combustion of test specimens.
Attention is drawn to the hazards arising from the hot radiator, and the use of a mains-voltage electricity supply.

1 Scope

This International Standard specifies a test method for plastics for the determination of the heat release rate, ignitability, surface spread of a flame, falling droplets/particles and smoke production using a “medium” scale specimen that simulates the early development stage of the fire. This test method can be used as a screening test for intermediate scale and large scale tests in addition to its use in factory production control, research and product development.

This test method provides data that is suitable for comparing reaction-to-fire performance of many materials, products, composites or assemblies under end use application conditions.

The results of this test method are limited to specimens with heat release rates of less than 10 kW.

WARNING — Specimens having the dimensions specified in this International Standard may generate heat release rates well in excess of 10 kW. In such cases, the test shall be stopped immediately once the heat release rate exceeds 10 kW.

2 Normative references

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

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 554, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 5660-1, *Reaction-to-fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate (cone calorimeter method)*

ISO 13943, *Fire safety — Vocabulary*

ISO/TS 14934-1, *Fire tests — Calibration and use of radiometers and heat flux meters — Part 1: General principles*

3 Terms and definitions

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

3.1
essentially flat surface
surface whose irregularity from a plane does not exceed ± 1 mm

3.2
flashing
existence of flame on or over the surface of the specimen for a period of less than 1 s

3.3
ignition
onset of sustained flaming

NOTE See 3.10.

3.4
heat flux
amount of thermal energy emitted, transmitted or received per unit area and unit time

3.5
material
single substance or uniformly dispersed mixture

NOTE Types of material include metal, stone, timber, concrete, mineral fibre, polymers.

3.6
oxygen consumption principle
proportional relationship between the mass of oxygen consumed during combustion and the heat released

3.7
product
material, composite or assembly about which information is required

3.8
specimen
representative piece of the product that is to be tested together with any substrate or treatment

3.9
sustained flaming
existence of flame on or over the surface of the specimen for periods of over 10 s

3.10
transitory flaming
existence of flame on or over the surface of the specimen for periods equal or more than 1 s but less than 10 s

4 Symbols

Symbol	Designation	Units
C	orifice flow meter calibration constant	$(\mathrm{m \cdot kg\ K})^{1/2}$
Δh_c	net heat of combustion	$\mathrm{kJ\ g^{-1}}$
ΔP	orifice meter pressure differential	Pa
q	heat release rate	kW
r_o	stoichiometric oxygen/fuel mass ratio	(dimensionless)
t	time	s
t_d	delay time of the oxygen analyser	s
t_ig	time to ignition (onset of sustained flaming)	s
Δt	sampling time intervals	s
T_e	absolute temperature of gas at the orifice meter	K
$X_{\mathrm{O_2}}$	oxygen analyser reading, mole fraction of oxygen	(dimensionless)
$X_{\mathrm{O_2}}^{0}$	initial value of oxygen analyser reading	(dimensionless)
$X_{\mathrm{O_2}}^{1}$	oxygen analyser reading, before delay time correction	(dimensionless)

5 General principles

In an open ventilation condition, the test specimen is held in a vertical position and is subjected to an irradiative heat source at its base in the presence of a pilot flame.

The smoke and gases that are generated are collected by a hood in the extraction duct, where an oxygen-depletion measurement device measures the heat release rate, and an opacimeter measures the smoke opacity.

The vertical and lateral flame spread and the falling of flaming droplets and/or particles are also measured.

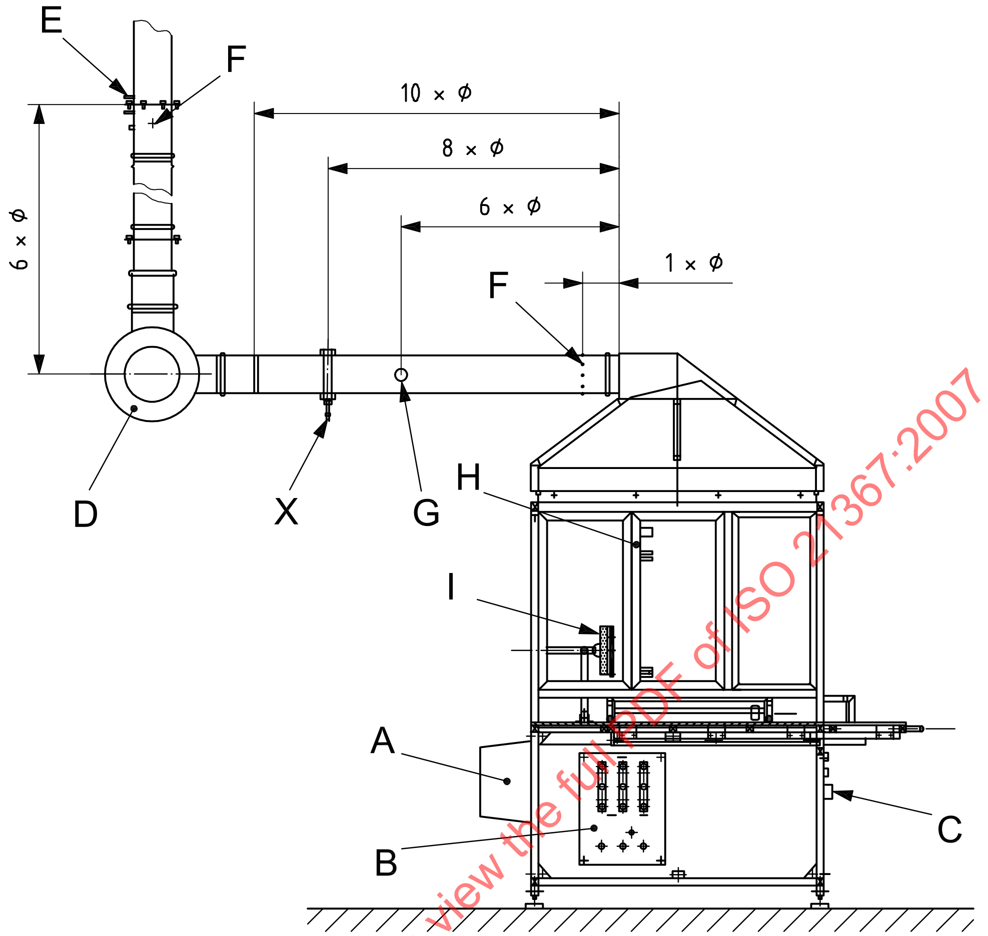
NOTE An alternative method for measuring the heat release rate using a set of thermocouples is outlined in Annex B.

6 Test apparatus

6.1 General.

An example of the test apparatus is given in Figure 1 and should consist of the following components:

- stainless steel hood;
- radiant electric heater (see 6.2);
- dummy specimen (see 6.3);
- backing board and spacers (see 6.4);
- specimen holder (see 6.5);
- pilot burner (see 6.6);
- exhaust gas system with flow measuring instrumentation (see 6.7);
- gas sampling system (see 6.8);
- oxygen analyser (see 6.9);
- opacimeter for the smoke opacity measurement (see 6.10);
- heat flux meter (see 6.11);
- calibration burner (see 6.12);
- data collection and analysis system (see 6.13).



Key

A	regulation of the ventilation
B	gas flow meter
C	radiant electric heater control device
D	fan
E	restrictive orifice with differential pressure measurement
F	thermocouples
G	opacimeter
H	specimen holder
I	electric radiant heater
X	probe sampler

Figure 1 — Example of apparatus

The individual components of the apparatus are described in detail in the following subclauses.

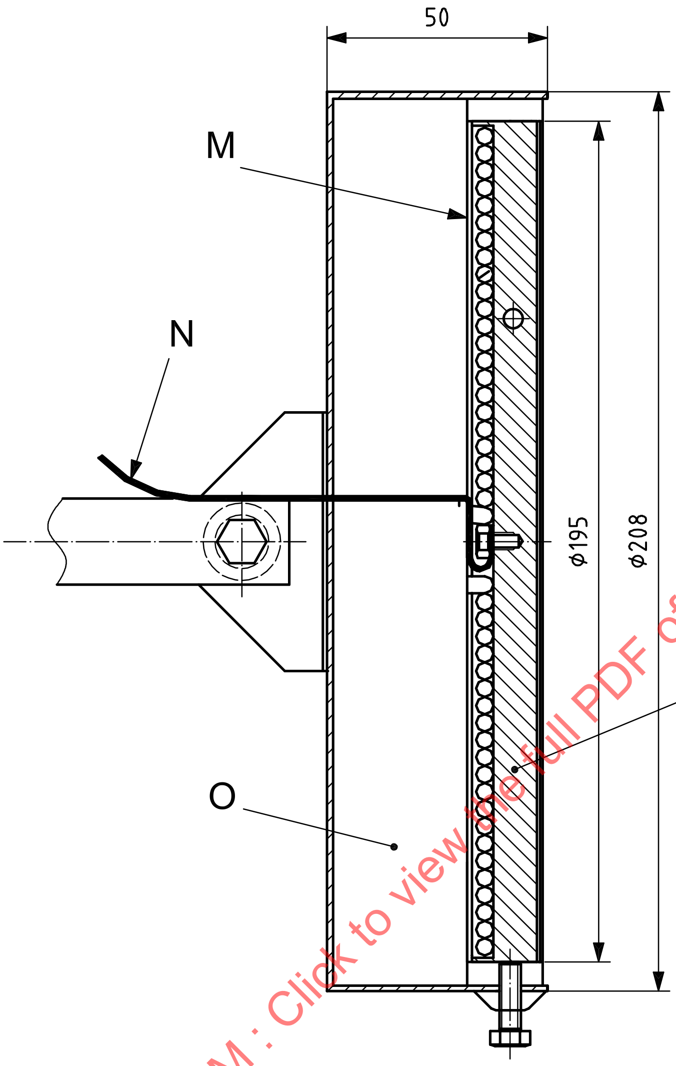
NOTE For factory production control with a simplified version of the apparatus, thermocouples inside the exhaust duct could be used to replace the oxygen monitoring for the heat release measurement. An example of a schematic representing the assembly is given in Figure 1.

6.2 Radiant electric heater.

6.2.1 A radiant electric heater shall be capable of producing irradiance on the surface of the specimen of up to 75 kW/m^2 when the distance between the radiant heater and the specimen is at least 50 mm. The heat flux shall be uniform at least over the central 100 mm × 100 mm area of exposed specimen surface. The following radiant electric heaters (see 6.2.2 and 6.2.3) can satisfy these requirements.

6.2.2 If a cylindrically shaped radiant electric heater (Figure 2) is used, the active element of the heater shall consist of an electric heater rod, capable of delivering 9 kW at the operating voltage, tightly wound into the shape of a spiral with an external diameter of 190 mm. The heater element is welded on a nickel-chromium alloy plate, which has a thickness of 10 mm, and encased in a cylindrical metal box. The radiation from the heater shall be maintained at a preset level by controlling the electric power level.

Dimensions in millimetres



Key

M electric heater rod

N thermocouple

O insulating material (ceramic fibre)

P inconel plate

Figure 2 — Electric heater

6.2.3 If a conically shaped radiant electric heater is used, the heater shall be in accordance with ISO 5660-1.

6.3 Dummy specimen.

The dummy specimen shall consist of a calcium silicate board with a surface area of 700 mm × 500 mm, a thickness of (12 ± 3) mm and a density of (800 ± 150) kg/m^3. It shall be placed on the specimen holder during warm up and before and after each test.

6.4 Backing boards and spacers.

Backing boards shall be cut from non-combustible board (for example, calcium silicate board) (12 ± 3) mm thick with the same dimensions as the dummy specimen and an oven-dry density of (800 ± 150) kg/m^3. Spacers used to create the air gap specified in 7.6 shall be made of the same material as the backing board, cut into wide strips and attached to the whole perimeter of the backing board.

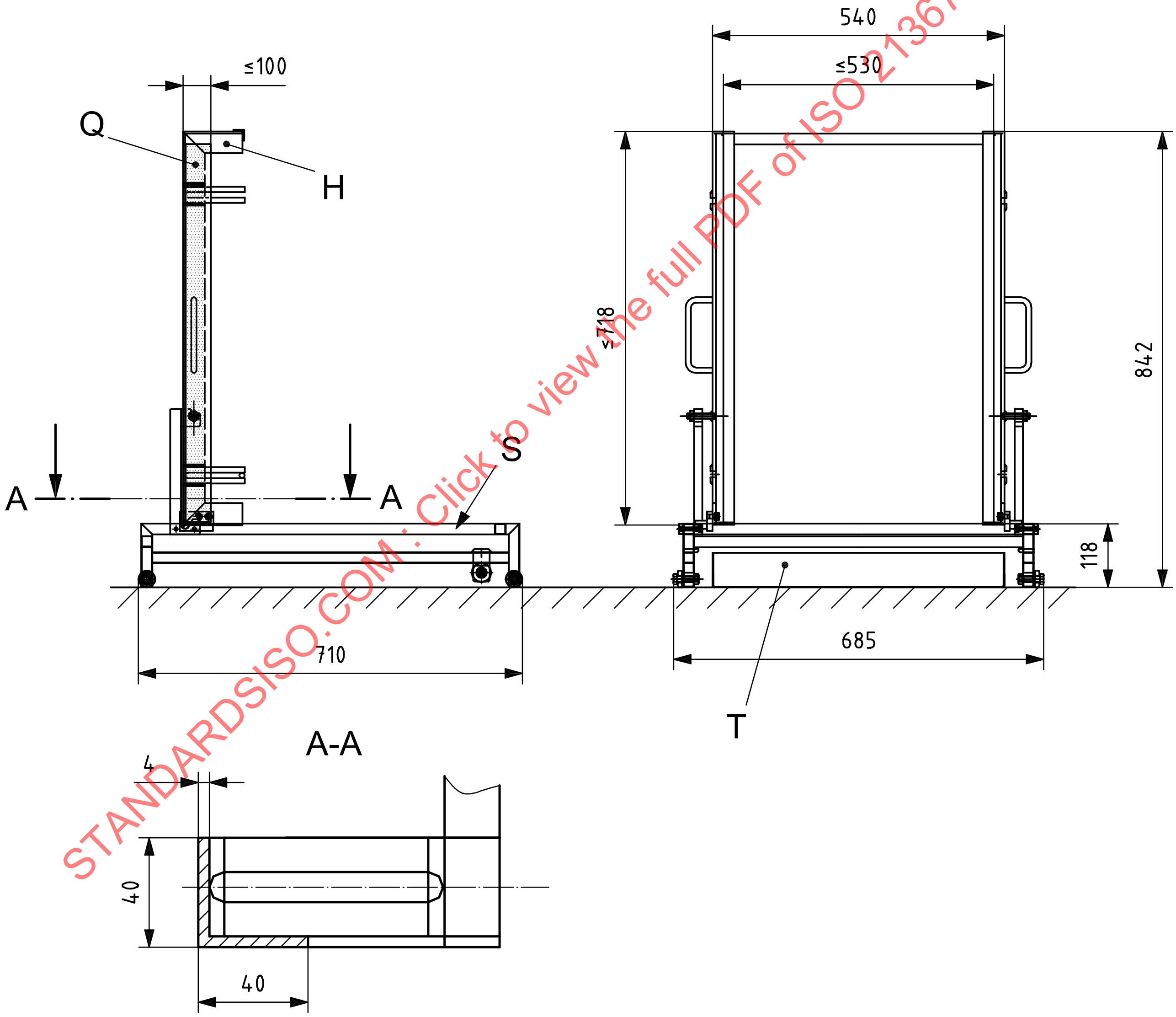
Backing boards and spacers may be re-used if they are not contaminated by combustible residues. Immediately before re-use, however, they shall be conditioned in the atmosphere specified in 7.5 for a minimum of 24 h. If there is any doubt about the cleanliness of a backing board or spacer, it shall be placed in a ventilated oven at a temperature of approximately 250 °C for a period of 2 h to remove any volatile residue. If there is still any doubt about the condition, it shall be discarded.

6.5 Specimen holder.

6.5.1 The specimen holder shall be composed of a frame that is fixed on a carriage (Figure 3).

6.5.2 The frame shall be constructed of stainless steel with a thickness of (3,5 ± 0,2) mm in a rectangular shape, and shall be able to support test specimens with a surface area of (700 ± 5) mm × (500 ± 5) mm and a maximum thickness of 90 mm (Figure 3).

Dimensions in millimetres



Key

H	steel frame
Q	sample
S	carriage
T	tray

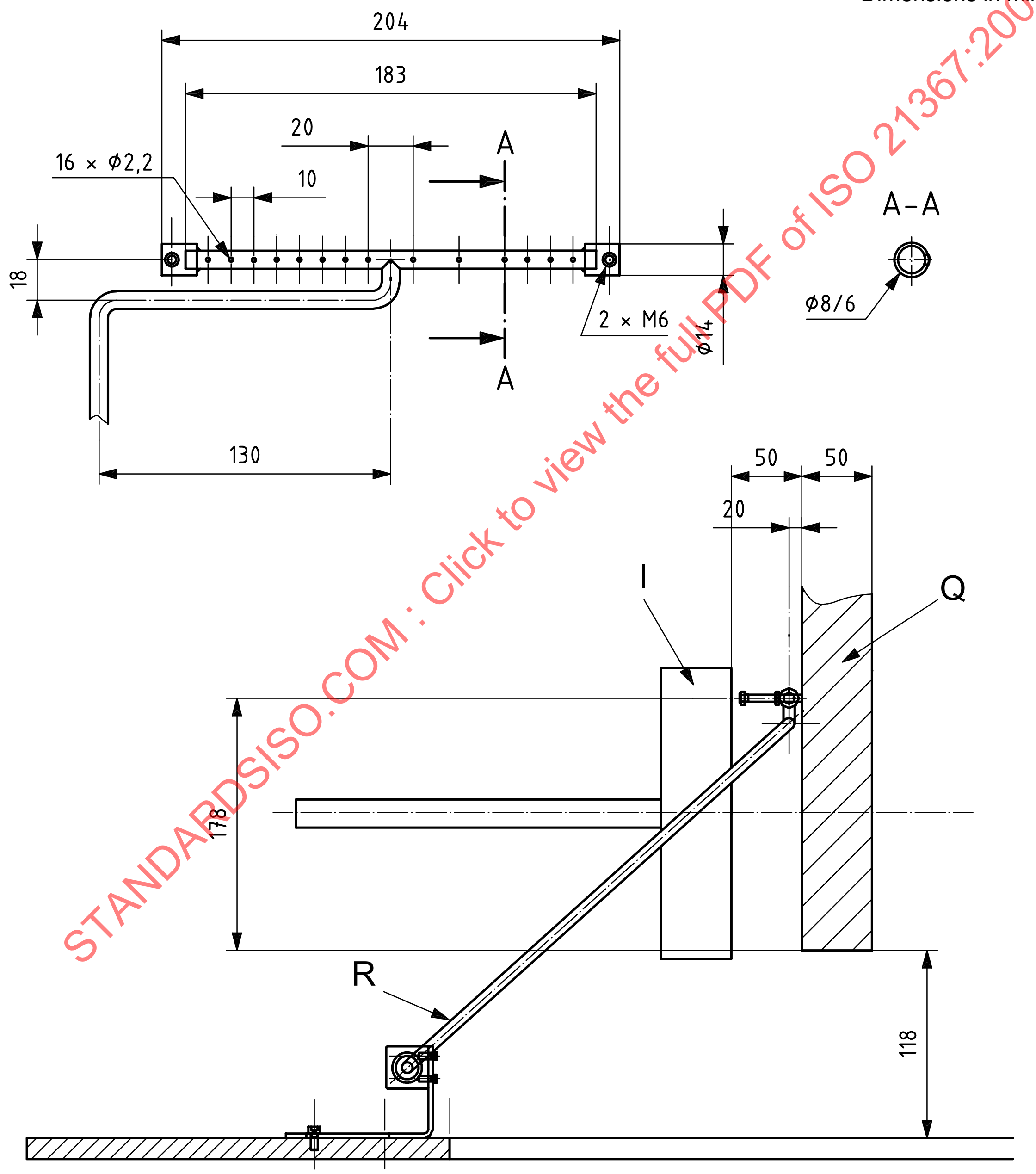
Figure 3 — Specimen holder

6.6 Pilot burner.

6.6.1 The pilot burner shall be a stainless steel tube of 6 mm internal diameter. It has 16 holes of 1 mm diameter and shall be placed, when operating, between the test specimen and the heater (Figure 4). The burner shall be adjustable to compensate for the thickness modification of the specimen during combustion. Two metallic spacers shall be located at each side of the burner to maintain a constant distance of (20 ± 5) mm between the specimen surface and the pilot flame.

6.6.2 An air/gas mixture shall be used to fuel the burner to obtain flames that are 20 mm long. The flow delivered to the burner shall be (3 ± 0,1) l/min for air and (1 ± 0,1) l/min for propane gas to obtain horizontal flames.

Dimensions in millimetres



Key

I electric heater

Q sample

R pilot burner ramp

Figure 4 — Pilot burner

6.7 Exhaust gas system with flow measuring instrumentation.

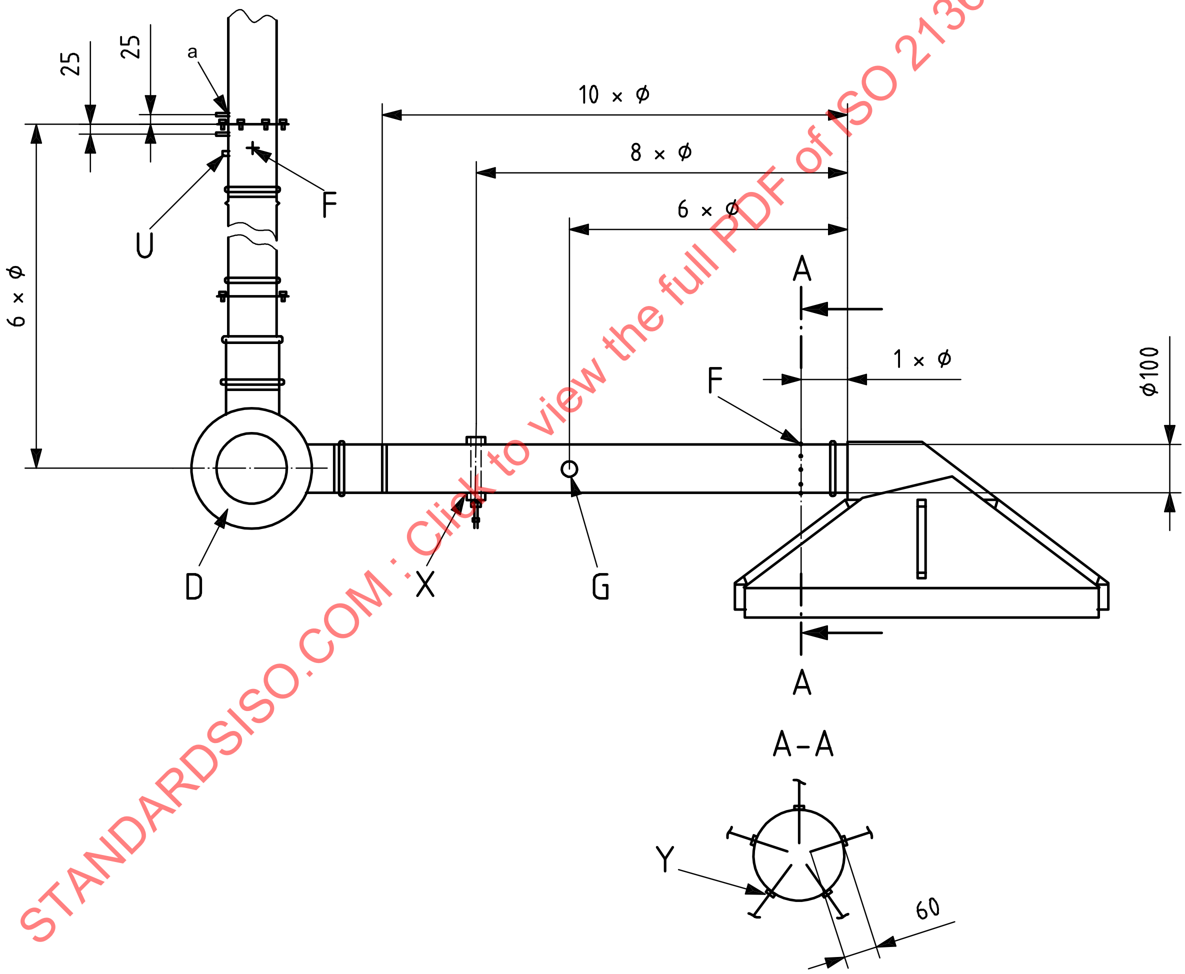
6.7.1 The exhaust gas system (Figure 5) shall consist of a centrifugal exhaust fan rated for the operating temperatures, a hood intake and exhaust ducts for the fan, and an orifice-plate flow meter. The distance between the lower edge of the hood and the top of the specimen shall be at least 105 mm. The exhaust system shall be capable of developing flows that reach the working conditions in the duct at standard conditions of temperature and pressure.

The internal diameter of the duct shall be at least 100 mm.

NOTE 1 The location of the fan indicated in Figure 5 is one of the possible options.

NOTE 2 A duct of 100 mm diameter is suitable to measure up to 10 kW.

Dimensions in millimetres



Key

D	fan
F	thermocouples
G	opacimeter
U	thermocouple
X	probe sampler
Y	five 10 mm diameter holes distributed around a circle at 72° intervals
[a]	Differential pressure measurement from orifice-plate flow meter.

Figure 5 — Example of exhaust system

6.7.2 A restrictive orifice with an internal diameter of (100 ± 5) mm shall be located between the hood and the duct to promote mixing.

6.7.3 A vertical probe sampler, with holes and an internal diameter of 8 mm (see Figure 6), shall be located in the fan intake duct for gas sampling. The probe sampler shall contain 54 small holes, each with a diameter of (2 ± 0,1) mm, to maintain a uniform stream composition, with the holes facing away from the flow to avoid soot clogging.

Dimensions in millimetres

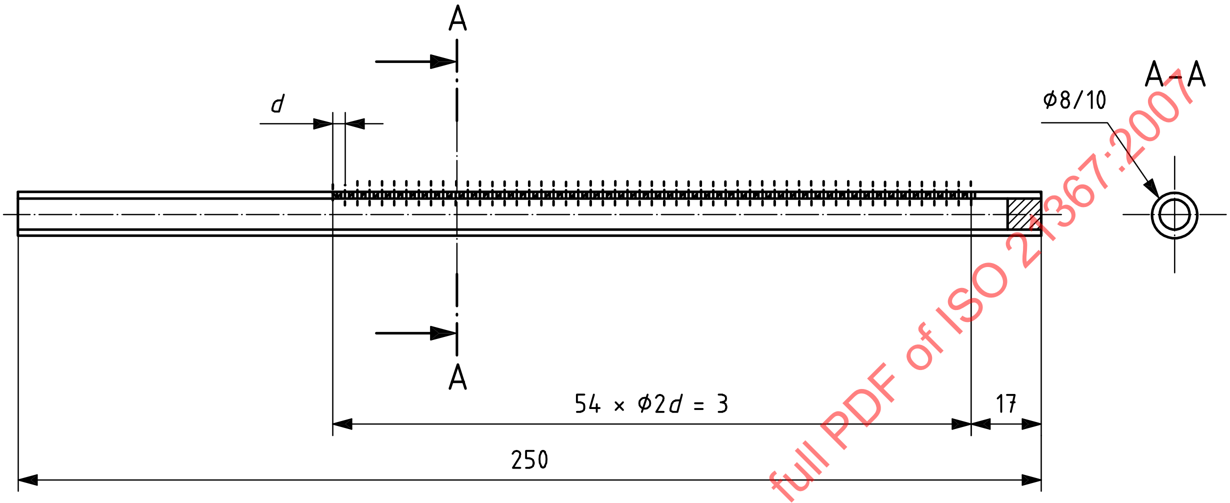


Figure 6 — Gas probe

6.7.4 The temperature of the gas stream shall be measured using a 1 mm external-diameter sheathed-junction thermocouple that is upstream from the measuring orifice plate.

6.7.5 The flow rate shall be determined by measuring the differential pressure across a sharp-edge orifice of the plate flow meter in the exhaust stack, at least 1 300 mm downstream from the fan (if the fan is located as shown in Figure 5). The orifice of the plate flow meter has an internal diameter of (80 ± 1) mm and a thickness of (1,6 ± 0,1) mm. It is acceptable to place the orifice plate between the probe sampler and the fan. However, in that case the length of the straight duct section on both sides of the orifice plate shall be at least five times the diameter of the duct.

6.8 Gas sampling apparatus.

The gas sampling apparatus shall incorporate a pump, a glass microfibre filter (to prevent entry of soot), a cold trap (to remove most of the moisture), a bypass system (set to divert all flow except that required for the gas analysers), a further moisture trap and a trap for CO_2 removal. Other arrangements that satisfy this International Standard may be used. The transport delay time of the oxygen analyser, t_d, shall be determined according to 9.1.3.

6.9 Oxygen analyser.

The oxygen analyser shall be able to detect the paramagnetic properties of oxygen, with a range of at least 0 % to 25 % oxygen. The analyser shall exhibit a noise and drift of not more than 100 µl/l of oxygen over a period of 30 min, as measured according to 9.1.4. Since oxygen analysers are sensitive to stream pressures, the stream pressure shall be regulated (upstream of the analyser) to minimize flow fluctuations and the readings from the analyser shall be compensated with an absolute pressure transducer to allow for atmospheric pressure variations. The analyser and the absolute pressure transducer shall be located in an isothermal environment. The temperature of the environment shall be maintained to within ± 2 °C of a preset value between 30 °C and 70 °C. The oxygen analyser shall have a 10 % to 90 % full-scale response time of less than 12 s, as measured according to 9.1.3.

6.10 Opacimeter for the smoke opacity measurement.

A light attenuation system of the white light type, mounted with a flexible connection to the sides of the exhaust duct, consists of the following (see Figure 7).

6.10.1 Lamp, of the incandescent filament type and operating at a colour temperature of (2 900 ± 100) K. The lamp shall be supplied with stabilized direct current, stable to within ± 0,5 % (including temperature and short-term and long-term stability).

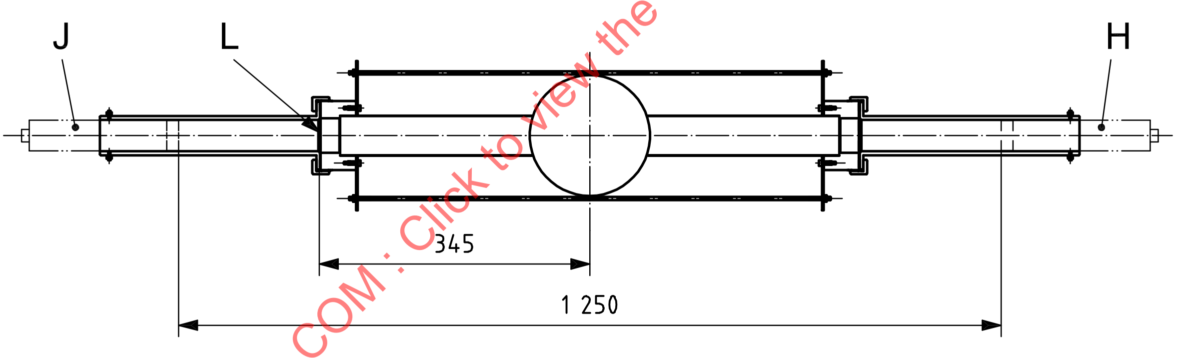
6.10.2 Lens system, to align the light to a parallel beam with a diameter of at least 20 mm. The photocell aperture shall be placed at the focus of the lens in front of it and it shall have a diameter, d, chosen with regard to the focal length of the lens, f, so that d/f is less than 0,04.

6.10.3 Detector, with a spectrally distributed responsivity agreeing with the CIE $V(\lambda)$ function (the CIE photopic curves) to an accuracy of at least ± 5 %. The detector output shall, over an output range of at least two decades, be linear within 3 % of the measured transmission value or 1 % of the absolute transmission.

For the calibration of the light attenuation system, see 9.3.4. The 90 % response time of the system shall be not more than 3 s.

Air shall be introduced in the side ducts so that the optics remains clean. Pressurized air may be used to achieve this.

Dimensions in millimetres



Key

H and J	lamp and detector
L	filter holder

Figure 7 — Smoke opacity measurement

6.11 Heat flux meter.

A working heat flux meter shall be used to calibrate the radiant electric heater (9.2.4). During the calibration, the heat flux meter shall be positioned in a hole made in a dummy specimen (6.3), which has been placed on the specimen holder, at a location equivalent to the centre of the irradiated zone on the specimen surface. This heat flux meter shall be of the Schmidt-Boelter (thermopile) type with a design range of (100 ± 10) kW/m^2.

The target receiving the heat shall be flat, circular, approximately 12,5 mm in diameter and coated with a durable matt black finish that has a surface emissivity, e, of (0,95 ± 0,05). The target shall be water-cooled. Cooling temperatures that cause condensation of water on the target surface of the heat flux meter shall not be used.

Radiation shall not pass through any window before reaching the target surface. The instrument shall be robust, simple to set up and use, and stable in calibration. The instrument shall have an accuracy to within ± 3 %, and a repeatability to within ± 0,5 %.

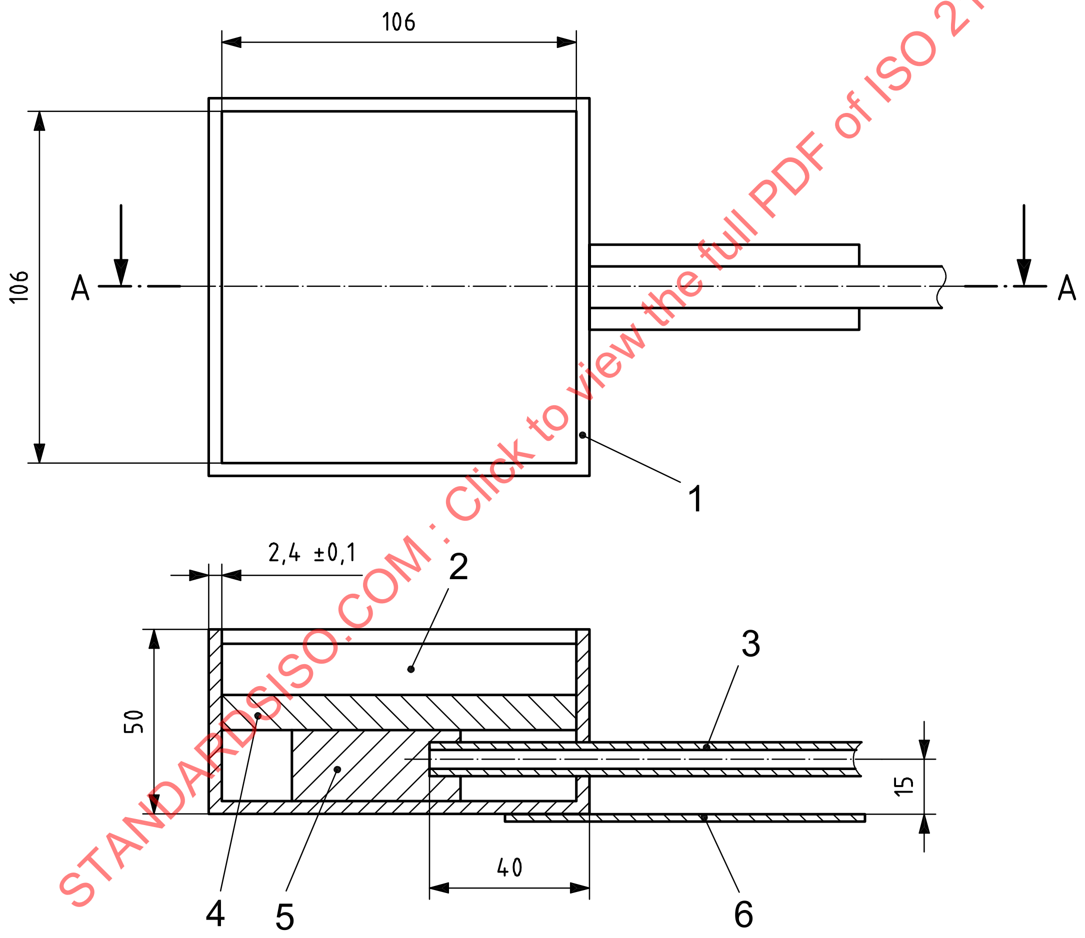
The calibration of the working heat flux meter shall be checked, according to 9.3.1, by comparison with two instruments of the same type as the heat flux meter and with a similar range, which are held as reference standards only and not used for any other purpose (see Annex D). One of the reference standards shall be fully calibrated according to ISO/TS 14934-1 at a standardizing laboratory at yearly intervals.

6.12 Calibration burner.

The calibration burner shall be made of metal (such as copper or steel) with 2,4 ± 0,1 mm thickness and have a rectangular shape. The gas outlet section shall be 106 mm × 106 mm in size and filled with sand (Figure 8).

A rotameter shall be used to control the propane flow.

Dimensions in millimetres



Key

1 square receptacle in stainless steel

2 sand within size distribution of 1 mm to 2 mm

3 tube, interior diameter 8 mm

4 layer of ceramic fibre (106 × 106 × 12) mm, density 100 kg/m^3

5 layer of ceramic fibre (50 × 50 × 22) mm, density 100 kg/m^3

6 handle

Figure 8 — Calibration burner

6.13 Data collection and analysis system.

The data collection and analysis system shall have facilities for recording the output from the oxygen analyser, the orifice-plate flow meter and the thermocouples. The data collection system shall have an accuracy corresponding to at least 50 µl/l of oxygen for the oxygen channel, 0,5 °C for the temperature measuring channels, 0,01 % of full-scale instrument output for all other instrument channels, and at least 0,1 % for time. The system shall be capable of recording data every second. The raw data recorded for each test must be stored so that it can be recovered and used to check the accuracy of the software.

7 Test specimen

7.1 Surface characteristics

7.1.1 A product having one of the following characteristics is suitable for evaluation using this method:

a) an essentially flat exposed surface, i.e. all surface irregularities are within ± 1 mm of plane;

b) a surface irregularity which is evenly distributed over the exposed surface provided that

   1) at least 50 % of the surface of a representative square area lies within a depth of 6 mm from a plane across the highest points of the exposed surface, and/or

   2) any cracks, fissures or holes do not exceed 8 mm in width or 10 mm in depth, and the total area of such cracks, fissures or holes at the surface does not exceed 30 % of a representative square area of the exposed surface.

7.1.2 Where a product has areas of its surface which are distinctly different, but each of these separate areas satisfies the surface characteristics specified in 7.1.1, then each of these separate areas shall be tested to evaluate fully the product.

7.1.3 When an exposed surface does not comply with the requirements of either 7.1.1 a), or 7.1.1 b), the product may be tested in a modified form with an essentially flat exposed surface. The modification shall be stated in the report.

7.2 Exposed surface

The product shall be tested on that face which will normally be exposed in use, taking into account the following.

a) If it is possible for either or both of the faces to be exposed in use, then, if the core is asymmetrical, both faces shall be tested.

b) If the face of the product contains a surface irregularity that is specifically directional, e.g. corrugations, grain or machine-induced orientation which may, in use, run horizontally or vertically, the product shall be tested in both orientations.

c) If the exposed face contains distinct areas of different surface finish or texture, then the appropriate number of specimens shall be provided for each distinct area of such finish or texture to be evaluated.

d) Textile materials shall be tested for spread of flame in both the warp and the weft directions.

7.3 Number and size of specimen

7.3.1 At least six specimens shall be provided for test.

7.3.2 Three specimens shall be tested for each potentially exposed surface or orientation. With specimens which could be exposed from either side and which also have directional irregularities on one side only, at least nine specimens will be needed, i.e. three for testing with the irregularities in a vertical position, three with the irregularities in a horizontal position and three for testing the opposite side which is smooth.

7.3.3 The specimens shall be (700 ± 5) mm high by (500 ± 5) mm wide, have a maximum thickness of 90 mm and be representative of the product.

7.3.4 The thickness of specimens of products with irregular surfaces (see 7.1) shall be measured from the highest point of the surface. Products of thickness 90 mm or less shall be tested using their full thickness. For products of normal thickness greater than 90 mm, the unexposed face shall be cut away to reduce the thickness to 90 mm $^{0}_{-3}$ mm.

7.4 Construction of specimen

7.4.1 For thin materials or composites used in the fabrication of an assembly, the presence of air or an air gap and/or the nature of any underlying construction may significantly affect the characteristics of the exposed surface. The influence of the underlying layers should be understood and care taken to ensure that the test result obtained on any assembly is relevant to its use in practice.

7.4.2 When the product is a surface coating, it shall be applied to the selected substrate using a method and application rate recommended for its end-use.

7.4.3 When the product is a material or composite which would normally be attached to a substrate, then it shall be tested in conjunction with the selected substrate using the recommended fixing technique, e.g. bonded with the appropriate adhesive or mechanically fixed. The procedure for fixing the specimens to the substrate shall be clearly stated in the test report.

7.5 Conditioning of specimens

7.5.1 Before the test, specimens shall be conditioned to constant mass at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 5) % in accordance with ISO 554. Constant mass is considered to be 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 piece or 0,1 g, whichever is the greater. Materials such as polyamides, which require more than one week in conditioning to reach equilibrium, may be tested after conditioning in accordance with ISO 291. This conditioning period shall be not less than one week, and shall be described in the test report.

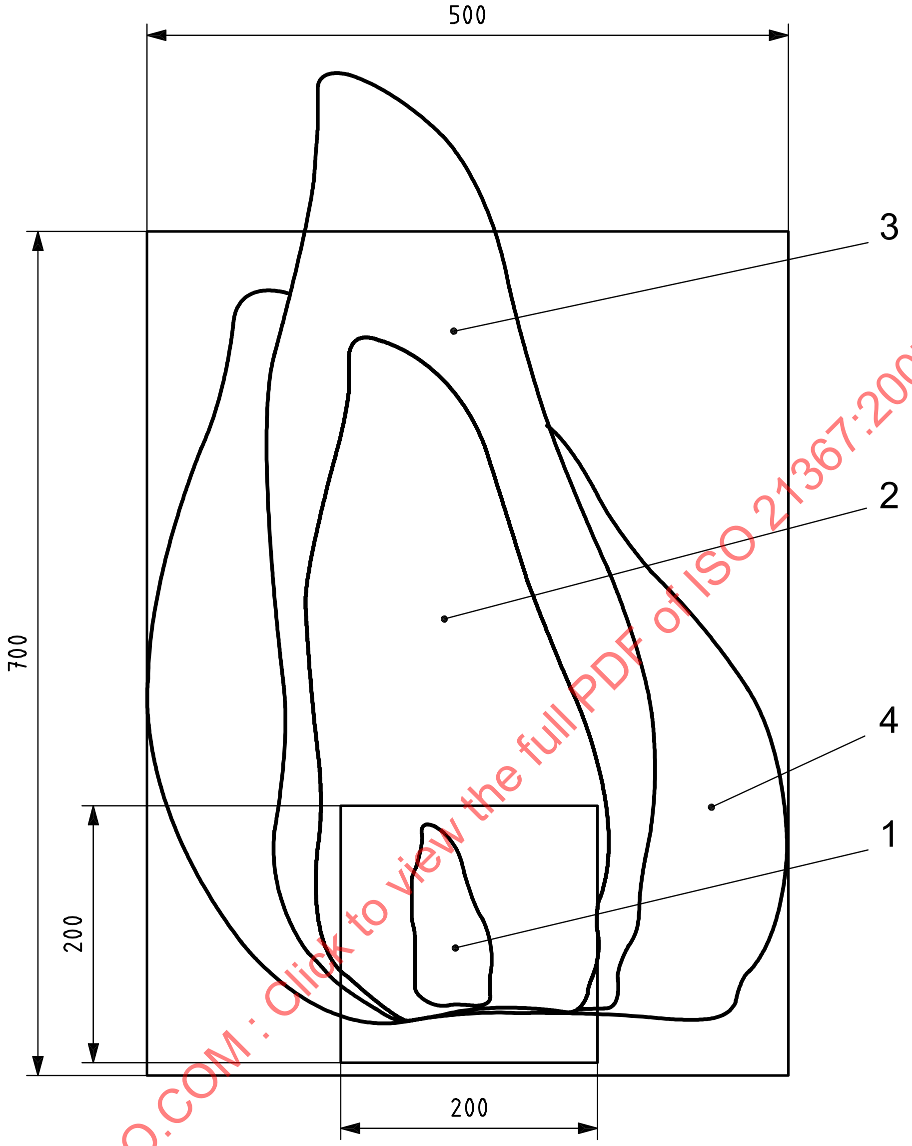
7.5.2 Backing boards and spacers (see 6.4) shall be conditioned for at least 12 h before use in the conditions specified in 7.5.1.

7.6 Preparation

7.6.1 Reference line

On the surface of the specimen, draw an outline of a square (see Figure 9) with an area of 200 mm × 200 mm (200 mm from the bottom of the specimen and 100 mm from each part of the specimen axis) in front of the cylindrically shaped radiant electric heater.

Dimensions in millimetres



Key

1 flame spread classification zone 1

2 flame spread classification zone 2

3 flame spread classification zone 3

4 flame spread classification zone 4

Figure 9 — Flame spread classification zones of surface of test specimen

7.6.2 Products without air gaps

Where a product will normally be used without an air gap behind it, after the conditioning procedures specified in 7.5, the specimen shall then be placed on a backing board and both inserted in a specimen holder.

7.6.3 Products with air gaps

Where a product will normally be used with an air gap behind it, then, after the conditioning procedures specified in 7.5, the specimen shall be placed over conditioned spacers positioned around its perimeter and mounted on a backing board so that an air gap is provided between the unexposed face of the specimen and the backing board (see 6.4).

8 Test environment

The apparatus shall be located in a draught-free environment in an atmosphere of relative humidity of between 20 % and 80 %, and a temperature between 15 °C and 30 °C.

9 Calibration

9.1 Preliminary calibration

9.1.1 General

The calibrations in this section shall be performed before testing or when commissioning an apparatus, and shall be performed after maintenance, repair or replacement of the heater assembly or irradiance control system (see 9.1.2) and the oxygen analyser or other major components of the gas analysis system (see 9.1.3 and 9.1.4).

9.1.2 Heat flux control system response characteristics

Turn on the power to the cylindrically shaped radiant electric heater and the exhaust fan. Adjust the irradiance control system so that the electric heater produces the required irradiance to within ± 2 % and set the exhaust flow rate to (0,095 ± 0,005) m^3/s. Insert the heat flux meter into the calibration position (see 6.11). When the heat flux has reached equilibrium, record the power on the wattmeter of the electric heater.

9.1.3 Oxygen analyser delay and response times

The electric heater shall not be turned on for this calibration.

Turn on the exhaust fan, and set the exhaust flow rate to (0,095 ± 0,005) m^3/s. Determine the delay time of the oxygen analyser by delivering a propane flow rate that is approximately equivalent to 5 kW to the calibration burner. Set the calibration burner underneath the hood, light the burner and allow the flame to stabilize. Leave the burner in position for three minutes, then turn off the propane supply and remove the burner from underneath the hood. Record the output of the analyser from the ignition of the burner until three minutes after the extinction of the burner flame.

Calculate the turn-on delay, which is the time difference between ignition of the burner and the oxygen reading reaching 50 % of its ultimate deflection. Calculate the turn-off delay similarly. The delay time, t_d, is the mean of at least three turn-on and turn-off delays. The oxygen concentration at a given time shall be taken as the concentration registered after the time interval t_d. Calculate the response time of the oxygen analyser, which is taken as the average time for the oxygen analyser output to change from 10 % to 90 % of its ultimate deflection for the turn-on and turn-off experiments.

NOTE For the purpose of measurement of oxygen analyser delay and response times, propane flow rate need not be controlled accurately because the delay and response times are not sensitive to the oxygen level.

9.1.4 Oxygen analyser output noise and drift

The electric heater shall not be turned on for this calibration.

Turn on the exhaust fan, and set the exhaust flow rate to (0,095 ± 0,005) m^3/s. Feed the oxygen analyser with oxygen-free nitrogen gas. After five minutes, switch the feed to dried ambient air from the exhaust duct at the flow rate and pressure as for the sample gases. After reaching equilibrium, adjust the oxygen analyser output to (20,95 ± 0,01) %. Record the oxygen analyser output at 3 s intervals for a period of 30 min.

Determine the output drift by use of a least-squares fitting procedure to fit a straight line through the data points. When a straight line has been fitted, the absolute value of the difference between the readings at 0 and at 30 min represents the output short-term drift.

Determine the output noise by calculating the root-mean-square deviation around the linear trend line using the following formula:

$$\text{rms} = \sqrt{\frac{\sum_{i=1}^{i=n} x_i^2}{n}}$$

where

rms is the root-mean-square deviation around the linear trend line;

x_i is the absolute difference between the data point and the linear trend line;

n is the number of 3 s intervals for a period of 30 min.

Record the rms output noise value in terms of microlitres per litre (µl/l) of oxygen.

9.2 Operating calibrations

9.2.1 General

The following calibrations shall be performed at the start of testing each day, and in the order given. The heater calibration shall also be performed when changing to a different irradiance level.

9.2.2 Oxygen analyser

Zero and calibrate the oxygen analyser. This calibration shall be performed with the electric heater either operating fully or not at all, but shall not be performed during heater warm-up. Turn on the exhaust fan, and set the exhaust flow rate to (0,095 ± 0,005) m^3/s. For zeroing, feed the analyser with oxygen-free nitrogen gas with the same flow rate and pressure as for the sample gases. Adjust the analyser response level to (0,00 ± 0,01) %. For calibration, feed the analyser with dried ambient air, and adjust for a response level of (20,95 ± 0,01) %. Carefully monitor the analyser flow rates, and set the flow rate to be equal to the flow rate used when testing specimens. After each specimen has been tested, ensure that a response level of (20,95 ± 0,01) % is obtained using dried ambient air.

9.2.3 Heat release rate calibration using oxygen consumption

Perform a heat release rate calibration to determine the orifice flow meter calibration constant, C. This calibration shall be performed with the electric heater either operating fully or not at all, but shall not be performed during heater warm-up. Turn on the exhaust fan, and set the exhaust flow rate to (0,095 ± 0,005) m^3/s.

Start collecting baseline data at 3 s intervals for a period of at least 1 min. Introduce propane into the calibration burner using a calibrated flow meter at a flow rate corresponding to a heat release rate, q_b, of (10 ± 0,5) kW, based on the net heat of combustion of propane (46 360 kJ/kg). When the output from all the instruments reaches equilibrium, record data at 3 s intervals over a 5 min period.

Calculate the orifice flow meter calibration constant, C, according to Equation (1) in Clause 11, using the averages from over the 5 min period of the measured values of q_b, T_e, ΔP, X_{O_2}.

$X_{O_2}^0$ is determined as the average of the oxygen analyser output measured during the 1 min baseline measurements.

An alternative procedure for performing this calibration consists of burning a suitable liquid fuel (e.g. ethanol) with a given net heat of combustion.

9.2.4 Electric heater calibration

When changing to a different irradiance level, adjust the irradiance control system so that the electric heater produces the required irradiance to within ± 2 %, as measured by the heat flux meter. Insert the heat flux meter into the calibration position (see 6.11).

When stabilized, operate the electric heater for at least 10 min at a set point before beginning this calibration.

9.3 Less frequent calibrations

9.3.1 Working heat flux meter calibration

At maximum intervals of 100 working hours, check the working heat flux meter against the reference heat flux meter (see Annex D).

Make comparisons at irradiance levels of 10, 25, 35, 50, 65 and 75 kW/m^2. Ensure that the readings from the two flux meters agree to within ± 2 %. If the operating heat flux meter is found to disagree with the reference meter by a constant factor that is within a ± 2 % spread over the whole flux range, establish a new calibration factor for the operating heat flux meter and use for the electric heater calibration described in 9.2.4. If the operating heat flux meter cannot be brought to within a ± 2 % agreement over the entire range by the use of a single, new factor, replace the operating meter.

9.3.2 Linearity of heat release rate measurements

At maximum intervals of 100 working hours, and with the calibration burner regulated at 10 kW according to 9.2.3, perform a further calibration with a flow rate corresponding to 1,5 kW ± 0,15 kW, 3 kW ± 0,3 kW and 4,5 kW ± 0,5 kW using the basic procedure as described in 9.2.3. With the value for C from the 10 kW calibration, the measured heat release rate at 1,5 kW and 3 kW shall be within ± 5 % of the set value.

9.3.3 Accuracy of the calibration burner flow meter

The accuracy of the calibration burner flow meter shall be verified every six months or when the calibration factor determined according to 9.2.3 differs by more than 5 % from the value obtained during the first heat release rate calibration following the previous flow meter verification.

Use the calibration burner as described in 9.1.3 with a reference flow meter in series with the operating flow meter. Record data over a 3 min period. Both flow meters shall agree to within +3 %. If the difference between the two measurements exceeds +3 %, the operating flow meter shall be recalibrated as recommended by the manufacturer.

9.3.4 Opacimeter calibration

9.3.4.1 General

The opacimeter calibration shall be performed after the set up, maintenance, repair or replacement of any major components of the smoke measuring system and exhaust, and at least every six months.

9.3.4.2 Stability check

Perform the following steps with the smoke measuring equipment operating. Adjust the exhaust flow rate to (0,095 ± 0,005) m^3/s. Start the time measurement and record the output signal from the light receiver for a period of 30 min. Determine the drift by use of a least-squares fitting procedure to fit a straight line through the data points.

The absolute value of the difference between the readings at 0 min and at 30 min of this linear-trend line represents the drift. Determine the noise by computing the root-mean-square deviation around the linear trend line.

9.3.4.3 Optical filter check

The light system shall be calibrated with at least two neutral density filters with optical density, D', of 0,30 and 0,70. The optical density calculated with the measured light-receiver signal shall be within ± 5 % of the actual value of the filters.

Perform the calibration as follows.

a) Place a light-blocking insert into the filter holder and adjust the signal from the light receiver to zero;

b) Remove the light-blocking insert and adjust the signal from the light receiver to 100 %;

c) Start the time measurement and record the signal from the light receiver for a period of at least two minutes;

d) Introduce the filter with an optical density, D', that is equal to 0,3, and record the corresponding signal for at least one minute;

e) Repeat step d) for the optical density, D', of the 0,70 filter;

f) Calculate the mean transmission values for the filters.

10 Test procedure

10.1 Warning

WARNING — So that suitable precautions are taken to safeguard health, the attention of all concerned in fire tests is drawn to the possibility that toxic or harmful gases can be evolved during exposure of test specimens.

The test procedures involve high temperatures and combustion processes. Therefore, hazards can exist for burns and ignition of extraneous objects or clothing. The operator shall use protective gloves for insertion and removal of test specimens. Neither the radiant electric heater nor the associated fixtures shall be touched while hot except with the use of protective gloves. The exhaust system of the apparatus shall be checked for proper operation before testing and shall discharge into a building exhaust system with adequate capacity. The possibility of the violent ejection of molten hot material or sharp fragments from some kinds of specimens when irradiated cannot totally be discounted and it is therefore essential that eye protection be worn.

10.2 Initial preparation

Check the CO_2 trap and the final-moisture trap. Replace the solvent if necessary. Drain any accumulated water in the cold-trap separation chamber. Ensure that the normal operating temperature of the cold trap does not exceed 4 °C.

If any of the traps or filters in the gas-sampling-system line has been opened during the check, test the gas sampling system for leaks.

EXAMPLE This could be done by introducing pure nitrogen, at the same flow rate and pressure as for the sample gases, from a nitrogen source connected as closely as possible to the ring sampler. The oxygen analyser should then read zero.

Adjust the distance between the electric heater and the surface of the specimen to within 50 ± 1 mm if necessary.

Place a dummy specimen on the specimen holder. Switch on the power to the electric heater and the exhaust fan. Do not switch off the power to the gas analysers and pressure transducer on a daily basis.

Set the exhaust flow rate to (0,095 ± 0,005) m^3/s.

Perform the calibration procedures specified in 9.2.

10.3 Procedure

10.3.1 Ignite the pilot burner and keep it lit throughout the test. Perform the test when the equipment has reached thermal equilibrium.

10.3.2 Record the pre-test conditions.

10.3.3 Considering that the start time is $t = 0$:

- at $t = 0$ minus 60 s, start the data logger system (the standard scan interval is 3 s, unless a short burning time is anticipated); adjust the pilot flame if needed;
- at $t = 0$ minus 30 s, move the specimen holder back, remove the dummy specimen and insert the test specimen on the specimen holder, start to move the specimen holder toward the heater;
- at $t = 0$ start the time measurement, locate the specimen holder in front of the heater.

10.3.4 Record the times when flashing or transitory flaming occurs. When sustained flaming occurs, record the time. Report these events in the test report.

10.3.5 Record the time when the top of the flame on the surface of the test specimen reaches the limit of each of the following zones 1 to 4 showing in Figure 9.

- Zone 1: sustained flaming combustion at the surface of the test specimen, inside the radiation area and in front of the burner (≈ 200 mm × 200 mm).
- Zone 2: sustained flaming combustion at the surface of the test specimen that is outside of the radiation area but does not reach the top edge or any of the lateral edges of the test specimen.
- Zone 3: sustained flaming combustion at the surface of the test specimen that is outside of the radiation area and reaches the top edge without reaching any of the lateral edges of the test specimen.
- Zone 4: sustained flaming combustion at the surface of the test specimen that is outside of the radiation area and reaches the top edge and one of the lateral edges of the test specimen.

10.3.6 Record flaming particles or droplets.

The fall of flaming droplets or particles shall be recorded when the droplets/particles reach the floor level below the specimen holder. The following occurrences shall be recorded:

a) the fall of a flaming droplet/particle that remains flaming for not more than 10 s after falling;

b) the fall of a flaming droplet/particle that remains flaming for more than 10 s after falling.

10.3.7 Record data until any of the following conditions have been met:

a) the elapsed time $t = 21$ min;

NOTE The 21 min threshold consists of a 20 min test period and an additional 1 min post-test period to collect data that will be time-shifted.

b) the elapsed time $t = 21$ min and the specimen has not ignited;

c) $X_{\mathrm{O}_2}^{0}$ returns to the pre-test value within 100 µl/l of oxygen concentration before $t = 10$ min;

d) the sample is moved back before the end of the test (see 10.3.8).

The minimum test duration shall be 10 min. Observe and record physical changes to the test specimen such as melting, swelling, and cracking.

10.3.8 The test specimen is moved before the end of the test if the maximum of heat release reaches 10 kW during 30 s.

10.3.9 After the end of data recording move the specimen holder back from in front of the heater and remove the test specimen from the specimen holder. Insert the dummy specimen and move the specimen holder in front of the heater.

10.3.10 Three test specimens shall be tested and reported as described in Clause 12.

NOTE The test data have limited validity if the specimen melts sufficiently to overflow the sample holder, if explosive spalling occurs, or if the specimen swells excessively and touches the spark igniter or the heater base plate.

11 Calculation

11.1 Calibration constant for oxygen consumption analysis

The heat release calibration specified in 9.2.3 shall be performed weekly to check for the proper operation of the instrument and to compensate for minor changes in determination of mass flow. A calibration that differs by more than 5 % from the previous one is not normal and suggests an instrument malfunction. The calibration constant, C, is calculated using:

$$C = \frac{q_{\mathrm{b}}}{(12{,}78 \times 10^{3}) \times (1{,}10)} \times \frac{1{,}105 - 1{,}5 X_{\mathrm{O_2}}}{X^{0}_{\mathrm{O_2}}{}^{\circ} - X_{\mathrm{O_2}}} \times \sqrt{\frac{T_{\mathrm{e}}}{\Delta P}} \qquad (1)$$

where

q_{b}	corresponds to the rate of heat release of the propane supplied (see 9.2.3);
$12{,}78 \times 10^{3}$	is $\Delta h_{\mathrm{c}}/r_{\mathrm{o}}$ for propane;
1,10	is the ratio of the molecular masses of oxygen and air;
1,105	is the air volumetric expansion factor.

11.2 Heat release rate

11.2.1 Prior to performing other calculations, calculate the oxygen analyser time shift, t_{d}, using the following equation:

$$X_{\mathrm{O_2}}(t) = X^{1}_{\mathrm{O_2}}(t + t_{\mathrm{d}})$$

11.2.2 Calculate the heat release rate, $q_{\mathrm{b}}(t)$, from:

$$q_{\mathrm{b}}(t) = \frac{\Delta h_{\mathrm{c}} \times 1{,}10}{r_{\mathrm{o}}} \times C \times \frac{X^{0}_{\mathrm{O_2}} - X_{\mathrm{O_2}}}{1{,}105 - 1{,}5 X_{\mathrm{O_2}}} \times \sqrt{\frac{\Delta P}{T_{\mathrm{e}}}}$$

where

$\Delta h_{\mathrm{c}}/r_{\mathrm{o}}$	for the specimen is taken as $13{,}1 \times 10^{3}$ kJ/kg, unless a more accurate value is known;
$X^{0}_{\mathrm{O_2}}$	is determined as the average of the oxygen analyser output measured during the one-minute baseline measurements.

11.3 Exhaust duct flow rate

Calculate the mass flow rate, $\dot{m}_\text{e}$, in grams per second, in the exhaust duct using the following equation:

$$\dot{m}_\text{e} = C \times \sqrt{\frac{\Delta P}{T_\text{e}}}$$

11.4 Smoke production rate (SPR)

11.4.1 Total SPR of specimen

11.4.1.1 Calculation of $\dot{V}(t)$

Calculate the volume flow rate in the exhaust duct using the following equation:

$$\dot{V}(t) = \dot{V}_{298}(t)\frac{T_\text{ms}(t)}{298}$$

where

$\dot{V}(t)$ is the volume flow rate in the exhaust duct, expressed in metres cubed per second (m^3/s);

$\dot{V}_{298}(t)$ is the volume flow rate in the exhaust duct, normalized to 298 K, expressed in metres cubed per second (m^3/s);

$T_\text{ms}(t)$ is the temperature in the general measurement section, expressed in kelvin (K).

11.4.1.2 Calculation of the smoke production rate, SPR(t)

Calculate the smoke production rate of specimen using the following equation:

$$\text{SPR}(t) = \frac{\dot{V}(t)}{L}\ln\left[\frac{\bar{I}}{I(t)}\right]$$

where

SPR(t) is the smoke production rate of specimen, in square metres per second (m^2/s);

$\dot{V}(t)$ is the non-normalized volume flow rate in the exhaust duct, expressed in metres cubed per second (m^3/s);

L is the length of the light path through the exhaust duct, expressed in metres (m); it is taken to be the internal diameter of the duct;

$I(t)$ is the signal from the light receiver, expressed as a percentage (%).

12 Test report

The test report shall be as comprehensive as possible and shall include any observations made during the test and any comments on difficulties experienced during testing. The units for all measurements shall be clearly stated in the report. The test report shall include the following:

a) reference to this International Standard;

b) name and address of test laboratory;

c) name and address of sponsor;

d) name and address of manufacturer/supplier;

e) date of the test;

f) operator;

g) trade name and specimen identification code or number;

h) composition or generic identification;

i) specimen thickness, expressed in millimetres (mm), and mass, expressed in grams (g). With composites and assemblies, a nominal thickness and density of each of the components shall be given, together with the apparent (overall) density of the whole;

j) colour of the specimens;

k) details of specimen preparation by the testing laboratory;

l) specimen mounting, surface tested, and special mounting procedures (i.e. for an intumescent specimen) that were used;

m) orifice flow meter calibration constant, C;

n) irradiance 1), expressed in kilowatts per square meter (kW/m^2), and exhaust system flow rate 1), expressed in cubic meters per second (m^3/s);

o) number of replicate specimens tested under the same conditions. This shall be a minimum of three, except for exploratory testing;

p) time, t, to sustained flaming 1), expressed in seconds (s);

q) time, t, to reach the zones 1, 2, 3 and 4;

r) the fall of a flaming droplet/particle that remains flaming for not more than 10 s after falling;

s) heat release rate (11.2) and smoke production rate (11.4);

t) test duration 1), e.g. the time between the start and the end of the test according to 10.3.8, expressed in seconds (s);

u) graph depicting the curves of heat release rate, expressed in kilowatts (kW), for the entire test;

v) graph depicting the curves of smoke production rate, expressed in m^2 s^{-1} for the entire test;

w) additional observations 1), such as transitory flaming or flashing;

x) difficulties encountered in testing 1), if any.

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1) Report these items for each specimen.

Annex A
(normative)

Additional calculations

A.1 General

After a test, a series of parameters shall be calculated to evaluate the performance of the product.

The following calculations shall be carried out:

- calculation of total heat release ($\mathrm{THR}_{600\mathrm{s}}$);
- calculation of fire growth-rate index (FIGRA);
- calculation of total smoke production ($\mathrm{TSP}_{600\mathrm{s}}$);
- calculation of the smoke growth-rate index (SMOGRA).

A.2 Heat release and fire index calculations

A.2.1 Calculation for the total heat release of the specimen ($\mathrm{THR}_{600\mathrm{s}}$)

Using the heat release rate results (11.2.2), the total heat release of the specimen in the first 600 s of the exposure period (t = 0 s to t = 600 s) is calculated as follows:

$$\mathrm{THR}_{600\mathrm{s}} = \frac{1}{1\,000} \times \sum_{t=0\mathrm{s}}^{t=600\mathrm{s}} \mathrm{HRR}(t) \times \Delta t$$

where

$\mathrm{HRR}(t)$ is the rate of heat release of the specimen, expressed in kilowatts (kW);

Δt is the scan interval, expressed in seconds (s);

THR_{600} is the total heat release of the specimen during the period from 0 to 600 s.

A.2.2 Calculation of the fire growth-rate index (FIGRA)

Before the FIGRA calculation, the HRR(t) results should be time-averaged over a period of 15 s.

Using the $\mathrm{HRR}_{\mathrm{av}}(t)$ calculation (11.2.2), FIGRA is calculated for all (t) as follows:

$$\mathrm{FIGRA} = 1\,000 \times \max\left(\frac{\mathrm{HRR}_{\mathrm{av}}(t)}{t}\right)$$

A.3 Smoke production and smoke-index calculations

A.3.1 Calculation for the total smoke production of the specimen (TSP$_{600s}$)

Using the smoke production rate (SPR) results (11.4.1.2), the total smoke production of the specimen in the first 600 s of the exposure period (t = 0 s to t = 600 s) is calculated as follows:

$$\text{TSP}_{600\text{s}} = \sum_{t=600\text{s}}^{t=0\text{s}} \text{SPR}(t) \times \Delta t$$

where

SPR(t)	is the rate of heat release of the specimen, expressed in kilowatts (kW);
Δt	is the scan interval, expressed in seconds (s);
THR$_{600s}$	is the total heat release of the specimen during the period from 0 to 600 s, expressed in kilowatts per second (kW/s).

A.3.2 Calculation of the smoke growth-rate index (SMOGRA)

Before the SMOGRA calculation, the SPR(t) results should be time-averaged over a period of 15 s.

Using the SPR$_{av}$(t) calculation in 11.4.1.2, SMOGRA is calculated for all (t) as follows:

$$\text{SMOGRA} = 10\,000 \times \max\left(\frac{\text{SPR}_{\text{av}}(t)}{t}\right)$$

Annex B
(informative)

Simplified version of the apparatus

B.1 General

Factory production control may be performed with a simplified and low-cost version of the test apparatus based on thermal measurements.

B.2 Principle

A set of thermocouples replaces the oxygen-monitoring equipment inside the exhaust duct for the purpose of heat release measurement.

There are no other fundamental changes to the general design of the apparatus (see Figure 1), but a radiation shield [calcium silicate board with an area of 700 mm × 500 mm and a thickness of (11 ± 2) mm] may be settled between the heater and the sample holder.

B.3 Exhaust-gas temperature measurement

The temperature measurement system consists of five 1 mm diameter K-type thermocouples distributed around the measuring tube at a length of (155 ± 5) mm from the hood outlet.

The length of the thermocouple inserted in the measuring tube should be (60 ± 3) mm.

At ambient temperature and without fan activation, the maximum deviation between the hottest and the coldest thermocouple should be within 1,5 °C.

B.4 Thermal response of the apparatus

An experimental coefficient, K_T, that is representative of the thermal response of the apparatus is determined by:

$$K_\mathrm{T} = \left(\frac{Q_{(i)}}{T_{(i)} \times V_{(i)}} \right)$$

where

K_T is the coefficient of thermal response, which is unitless;

$Q_{(i)}$ is the theoretical heat release at time i, expressed in kilowatts (kW);

$T_{(i)}$ is the level of temperature recorded at time i, expressed in kelvin (K);

$V_{(i)}$ is the exhaust flow rate in the duct at time i, expressed in metres cubed per second (m^3/s).