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BRITISH STANDARD

BS 7990:2003

Tube furnace method for the determination of toxic product yields in fire effluents

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Foreword

This British Standard has been prepared by Technical Committee FSH/16.

It describes a tube furnace method for the determination of toxic product yields in fire effluents.

It has been developed for use in conjunction with BS 7899-1 and BS 7899-2, to provide data on toxic product concentrations and yields in fire effluents from materials and products decomposed under a range of fire conditions. These data are suitable for use in the assessment of toxic and environmental hazards and risks to life and health from fires.

One of the prerequisites for the application of BS 7899 is information on toxic product yields for estimation of the toxic potency and toxic hazards of fire effluents. There are a number of ways in which this information can be obtained and applied, as described in BS 7899-1 and BS 7899-2. One method involves the decomposition of materials or products in a small-scale test apparatus under conditions occurring in different types and stages of full-scale fires. Measurements of toxic product concentrations in the test enable calculations to be made of toxic product yields, and overall toxic potencies, to be expected during relevant types and stages of full-scale fires. These data can then be used in conjunction with other data (including ignitability and fire growth data) and suitable calculation methods, for the assessment of toxic hazard in full-scale fire scenarios. This standard gives a method for such a small-scale test.

Although there are no statutory requirements placing limits on the toxicity of fire effluent from materials and products used in buildings and transport, toxicity test data are often included in specifications. Manufacturers, suppliers, specifiers and regulators of products are often faced with the need to generate and apply data from small-scale toxic potency tests. A requirement for the application of data from small-scale toxic potency tests is that the combustion conditions and data produced have to be related to those in a range of stages of full-scale fires. The method described in this standard has been developed specifically to meet these requirements. It is also extremely important to recognize that toxic potency is only one element in the development of toxic hazard, which is often more dependent on ignitability and fire growth characteristics of materials and products.

It has been assumed in the preparation of this standard that the execution of its provisions will be entrusted to appropriately qualified and competent people for whose use it has been produced.

WARNING. This British Standard calls for the use of substances and/or procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage. In particular, attention is drawn to the following hazards.

a) The test procedure involves combustion processes, and the combustion products can give rise to fire hazards. To avoid accidental leakage of hazardous combustion products the entire test system should be placed in a fume cupboard with an external venting system.

b) The venting system should be checked for proper operation before testing and should discharge into an exhaust system with adequate capacity.

c) As, in unfavourable circumstances, extremely rapid combustion or explosion can occur when the device is in operation, a protective screen between the operator and the tube furnace is recommended and, in addition, care should be taken to ensure that the gas outlet at the end of the furnace tube is as large a diameter as possible.

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Introduction

For any specific material or product the effluent yields in fires depend upon the thermal decomposition conditions. The most important variables are whether the decomposition is non-flaming or flaming, and for flaming decomposition the fuel/oxygen ratio. Based upon these variables it is possible to classify fires into a number of types, as detailed in BS 7899-2:1999, Table 8.

For non-flaming oxidative pyrolysis from externally applied radiation, (BS 7899-2:1999, Table 8 fire type 1b) it is sufficient to heat a specimen of the test material in air. The yields of thermal decomposition products then depend upon the specimen temperature above a minimum at which little or no thermal decomposition occurs up to a maximum above which flaming ignition is likely to occur. Although it is therefore possible to measure effluent yields over a wide range of temperatures it is considered reasonable to specify a fixed temperature for this standard at which the majority of materials will evolve thermal decomposition products, but at an insufficient rate for flaming ignition to occur. The air supply should be sufficient to maintain an oxidative environment in contact with the specimen, but not so much as to encourage glowing combustion.

For flaming decomposition the product yields have been shown to be highly dependent upon the fuel/oxygen ratio, such that the yields of important toxic products such as carbon monoxide can vary by up to a factor of 50 between well ventilated and vitiated conditions (see references [1] to [5]). It is therefore considered vital that for a standard test method the fuel/oxygen ratio should be controlled.

The fuel/oxygen ratio can be expressed in terms of the equivalence ratio (ϕ), the fuel mass to oxygen mass ratio in the test divided by the stoichiometric fuel mass to oxygen mass ratio. The value of ϕ can be calculated as follows:

$$\phi = (F_t/O_t) \times (O_s/F_s)$$

where

F_t/O_t is the fuel mass to oxygen mass ratio in the test;

O_s/F_s is the stoichiometric oxygen mass to fuel mass ratio.

For fuel-lean mixtures [i.e. well ventilated fires (BS 7899-2:1999, Table 8 fire type 2)]:	$\phi < 1$.
For stoichiometric mixtures:	$\phi = 1$.
For fuel-rich mixtures [i.e. vitiated fires (BS 7899-2:1999, Table 8 fire type 3)]:	$\phi > 1$.

In practice it has been found that for well ventilated conditions, product yields are relatively constant at equivalence ratios with values of $\phi < 0.75$. The test conditions in this standard for well ventilated flaming have therefore been set to ensure an equivalence ratio of less than 0.75.

For vitiated flaming conditions, product yields vary considerably with equivalence ratio, increasing up to equivalence ratios of 2, at which a plateau region commonly occurs. For this standard the test conditions for vitiated fires have therefore been set to obtain an equivalence ratio of 2 ± 0.2.

The use of this standard therefore provides data on the range of toxic product yields likely to occur in different types and stages of full-scale fires. More comprehensive data on the relationships between decomposition conditions and product yields can be obtained by using a wider range of apparatus settings. Guidance on choice of additional decomposition conditions is provided in Annex A.

The data on toxic product concentrations and yields obtained using this standard may be used as part of the assessment of toxic potencies, toxic hazards from fires, health and safety assessments of combustion products, and assessments of environmental hazards from fires. Further guidance on these aspects is provided in Annex B, Annex C and Annex D.

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1 Scope

This British Standard describes a tube furnace method for the generation of fire effluent for the identification and measurement of its constituent combustion products. It uses a moving test specimen and a tube furnace at different temperatures and air flow rates as the fire model.

The method can be used to model a wide range of fire conditions by using different combinations of temperature, non-flaming and flaming decomposition conditions and different fuel/oxygen ratios in the tube furnace. These include the following types of fires, as detailed in BS 7899-2:1999, Table 8:

— *Stage 1: Non-flaming:*
  — Stage 1b) Oxidative pyrolysis from externally applied radiation;
— *Stage 2: Well ventilated flaming (representing a flaming developing fire);*
— *Stage 3: Less well ventilated flaming:*
  — Stage 3a) Small vitiated fires in closed or poorly ventilated compartments;
  — Stage 3b) Post-flashover fires in large or open compartments.

For each flaming fire type the minimum conditions of test are specified in terms of the equivalence ratio ϕ as follows:

— Stage 2: $\phi < 0.75$;
— Stages 3a) and 3b) $\phi = 2 \pm 0.2$.

NOTE 1 Guidance on choice of additional decomposition conditions is given in Annex A.

The test method described in this standard can be used solely to measure and describe the properties of materials, products or systems in response to heat or flame under controlled laboratory conditions. It is not suitable to be 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 toxicity can be based.

NOTE 2 Guidance on calculation of lethal toxic potency of combustion products is given in Annex B.

NOTE 3 Guidance on the application of data from the tube furnace test to assessment of toxic hazard in fires, to health and safety assessments of combustion products and to environmental hazard assessment of combustion products is given in Annex C, Annex D and Annex E, respectively.

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.

BS 7899-2:1999*, Code of practice for assessment of hazard to life and health from fire — Part 2: Guidance on methods for the quantification of hazards to life and health and estimation of time to incapacitation and death in fires.*

3 Terms and definitions

For the purposes of this British Standard the terms and definitions given in BS 7899-2 and the following apply.

3.1
combustible load
mass of the components of a test specimen capable of combustion in the furnace

NOTE This usually includes all components of a specimen excluding inert fillers and other non-combustible components such as metal frames.

3.2
equivalence ratio ϕ
fuel mass to oxygen mass ratio in the test divided by the stoichiometric fuel mass to oxygen mass ratio

NOTE For the tube furnace method this is the mass loss rate of combustible effluent from the test specimen in milligrams per minute ($mg \cdot min^{-1}$) divided by the mass flow rate of oxygen in the primary air introduced into the furnace in milligrams per minute ($mg \cdot min^{-1}$) divided by the stoichiometric fuel mass to oxygen mass ratio for the material under test.

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3.3
mass charge concentration
concentration of fire effluents from a material defined in terms of the mass of material exposed to burning conditions (mass charge) and the volume into which the effluent is dispersed, expressed in $g \cdot m^{-3}$
[BS 7899-2:1999, definition **2.19**]

3.4
mass loss concentration
concentration of fire effluents from a material defined in terms of the mass of material decomposed (mass loss) and the volume into which the effluent is dispersed, expressed in $g \cdot m^{-3}$
[BS 7899-2:1999, definition **2.21**]

3.5
mass loss exposure dose
mass loss concentration multiplied by the exposure time, expressed in $g \cdot m^{-3} \cdot min$
[BS 7899-2:1999, definition **2.22**]

3.6
yield
mass of an effluent component divided by the mass loss of the test specimen associated with the production of that mass of the effluent component

3.7
volume yield
volume of an effluent component at standard temperature and pressure (20 °C and 101.325 kPa) divided by the mass loss of the test specimen associated with the production of that volume of the effluent component

4 Principle

A test specimen, in granular or rod form, is placed in a clear heat resistant quartz boat, and introduced at a constant rate along a clear quartz furnace tube through the hot zone of a fixed tubular furnace. A stream of primary air is passed through the quartz furnace tube and over the test specimen to support combustion. The fire effluent is expelled from the quartz furnace tube into a mixing and measuring chamber, where it is diluted with secondary air to a nominal total air flow rate of $(50 \pm 1)\ l \cdot min^{-1}$ through the chamber and then exhausted to waste. Samples of the effluent mixture are taken from the chamber for analysis.

The decomposition conditions in the furnace are set using different combinations of temperature and primary air flow rate in separate test runs, to model the decomposition condition in a range of fire stages as characterized in BS 7899-2.

For flaming decomposition conditions, different fuel/oxygen ratios and hence different equivalence ratios, are obtained when different primary air flow rates are used in relation to the constant rate of introduction of the fuel.

The aim in each test run is (after an initial settling down period when decomposition conditions and product yields may be variable) to obtain stable, steady state, conditions for at least 5 min during which the concentrations of effluent gases can be measured. The longer the duration of the test run the longer the period during which steady state conditions can exist. The duration of the test run depends upon the length of the specimen (which is limited by the length of the test specimen boat and the quartz furnace tube) and the rate of test specimen advance. The time taken for steady state conditions to be established varies depending upon the nature of the test specimen and the test conditions. The test specimen boat and quartz furnace tube lengths specified are the minimum lengths usable for obtaining 5 min of steady state conditions for all materials under all decomposition conditions.

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5 Apparatus

NOTE The arrangement of the apparatus is shown in Figure 1.

5.1 *Tube furnace,* with a heating zone of length 500 mm to 600 mm and an inside diameter of 40 mm to 70 mm, equipped with an adjustable electric heating system capable of controlling the final temperature to within ±2 % of the nominal temperature. The heating element should preferably be rated at 1 300 °C.

NOTE A furnace as described in IEC 60754-2 is suitable.

5.2 *Quartz furnace tube,* as shown in Figure 2, made of clear heat resistant quartz, resistant to the effects of fire effluent and with a wall thickness of (2 ± 0.5) mm, approximately concentric to the furnace bore. The outside diameter shall be such as to permit a smooth fit within the tube furnace (**5.1**) and to allow expansion at operating temperatures (see Note 1).

The inlet end of the quartz furnace tube shall have a closure with openings in it to allow the primary air inlet and the test specimen boat drive bar to pass through. The outlet end of the quartz furnace tube shall pass through a heat resisting sealed gland (see Note 2) and shall protrude approximately 55 mm into the mixing and measurement chamber (**5.6**). The tube length shall be sufficient to allow this and also to allow the test specimen boat to rest in it, outside of the tube furnace (see Note 3). The quartz furnace tube shall be cleaned after each test (see **5.3**, Note 3).

In addition, a quartz tube of outside diameter approximately 5 mm and inside diameter approximately 3 mm may be introduced 100 mm into the quartz furnace tube along the top edge to sample the atmosphere inside the furnace tube for the measurement of oxygen concentration.

NOTE 1 A quartz furnace tube with an outside diameter of 47.5 mm ± 1 mm has been found to be suitable for use with tube furnaces of 50 mm to 65 mm internal diameter.

NOTE 2 A gland made from glass wool inside a brass collar has been found to be suitable.

NOTE 3 For use with a 600 mm tube furnace and test specimen boats of up to 800 mm a quartz furnace tube length of 1 600 mm has been found to be suitable.

5.3 *Test specimen boat*, as shown in Figure 2, made from clear heat resistant quartz, having the following minimum dimensions:

— diameter of cross-section (41 ± 1) mm (see Note 1);

— length 800 mm (see Note 2);

— wall thickness 2 mm ± 0.5 mm.

The test specimen boat shall be cleaned after each test (see Note 3).

NOTE 1 A convenient method for making a suitable test specimen boat for a 47.5 mm diameter quartz furnace tube is to use an 800 mm length of quartz tubing with a nominal diameter less than that of the furnace tube (a nominal diameter of 41 mm is suitable). This can then be sliced in half lengthways to provide a test specimen boat with a semi-circular cross-section, with nominal dimensions 41 mm diameter of cross-section, 18 mm depth and 800 mm length. Semi-circular quartz end pieces then need to be fused in place. A test specimen boat diameter of just less than the quartz furnace tube internal diameter should be used to provide the maximum specimen capacity.

NOTE 2 A test specimen boat length of less than 800 mm has been found to be insufficient for obtaining 5 min of steady state conditions for many materials under some decomposition conditions. A test specimen boat length of 800 mm has been found suitable for most situations.

NOTE 3 A convenient method of cleaning both the test specimen boat and the quartz furnace tube is to remove obvious residues mechanically, then fire at 1 000 °C, followed by washing in water to remove any inorganic residues.

5.4 *Test specimen boat drive mechanism*, connected to the test specimen boat by a hooked drive bar passing through a gland seal (see Note 1) at the input end of the quartz furnace tube to enable the test specimen boat to be advanced through the quartz furnace tube (see Note 2).

NOTE 1 A polytetrafluoroethylene (PTFE) gland seal has been found to be suitable.

NOTE 2 The test specimen boat drive mechanism should be capable of achieving the default advance rate of 40 $mm \cdot min^{-1}$. It has been found useful to be able to set different advance rates of up to 60 $mm \cdot min^{-1}$ for particular situations.

5.5 *Calibrated thermocouple*, stainless steel sheathed, 1.5 mm in diameter, for measuring the temperature in the quartz furnace tube (see **7.2.2**).

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5.6 *Mixing and measurement chamber*, consisting of an approximately cubic box (see Figure 3). The exact dimensions are not critical, but it should be sufficiently large to accommodate the necessary sampling and measurement equipment (ports for gas sampling lines, bubblers, particle filters and smoke meter) and small enough to ensure that the equilibration time for the test atmosphere is not too long. (The time required for a volume of air equal to that of the chamber volume to pass through the chamber should be not more than 1 min). The front of the chamber has a door providing a seal when shut. The right-hand wall of the chamber and the right-hand portion of the roof are made of stainless steel, so as to be resistant to heat and any flames emanating from the end of the quartz furnace tube.

NOTE 1 A suitable chamber consists of a box made of a plastics material (e.g. polymethyl methacrylate, polyethylene or polycarbonate) which can be made from a commercially available desiccator cabinet with nominal dimensions of 310 mm × 310 mm × 340 mm (see Figure 3). This would have an internal volume of 33 l, so an air volume equal to the chamber volume passes through the chamber in 40 s at a total air flow rate of 50 $l \cdot min^{-1}$. The right-hand wall of the chamber (facing the furnace) should be removed and replaced by a stainless steel plate fitted to the inner surface; the top of the plate extending 140 mm across the chamber roof to provide heat protection for the plastics surfaces.

The roof of the chamber is fitted with a safety blow-out panel 75 mm in diameter made of aluminium foil approximately 0.04 mm thick.

A port fitted with a gland is provided in the right-hand wall of the chamber for insertion of the quartz furnace tube (**5.2**).

NOTE 2 This needs to be of sufficient diameter to accommodate the gland and the quartz furnace tube (approximately 55 mm). The exact position of this port will depend on the furnace used, but it should be in the centre of the right-hand wall, approximately 100 mm up from the chamber base.

Ports for sampling lines are provided in the mixing and measurement chamber for taking samples of the test atmosphere.

NOTE 3 Provided that the test atmosphere is well mixed (see **5.8**) and the sampling points are away from the rising plume and chamber walls, these can be sited in any convenient location. Suitable locations are shown in Figure 3.

The ports are provided with fittings for connection to the sampling lines.

NOTE 4 Stainless steel or polytetrafluoroethylene bulkhead unions [6 mm (or 1/4″)] are suitable.

A port approximately 35 mm in diameter is provided at the base of the rear face of the chamber for the test atmosphere to be exhausted to waste.

Ports are provided in the chamber for the insertion of a light source and a photodetector for the continuous measurement of smoke density.

NOTE 5 Provided that the test atmosphere is well mixed (see **5.8**) and the smoke density measurement points are away from the rising plume or chamber walls, these may be sited in any convenient location. A suitable smoke measurement path length has been found to be approximately 300 mm. A suitable smoke measurement system is described in BS 476-33. A suitable method is to mount the light source and photodetector vertically in tubes, as shown in Figure 3. Tubes with a diameter of 22 mm and a length of 110 mm are suitable. The tube containing the light source at its lower end is inserted through the chamber base and the tube containing the photodetector at its upper end is inserted through the chamber top. The path length can then be adjusted by altering the extent of insertion of the lower tube. An alternative could be to mount the tubes containing the light source and the photodetector horizontally.

Suitable methods for the prevention of the deposition of particles on the surfaces of both the light source and the photodetector shall be used.

NOTE 6 A suitable method is to purge the tubes to containing the light source and the photodetector with part of the chamber diluent (secondary) air through tubes, 6 mm or 1/4″ in diameter, inserted into the sides of the light source and photodetector tubes as shown in Figure 3. A suitable air flow rate through the purge tubes is 500 $ml \cdot min^{-1}$.

5.7 *Thermocouple*, extending approximately 50 mm into the mixing and measurement chamber, located as shown in Figure 3, for monitoring of the temperature in the chamber during the tests.

NOTE This is important for safety reasons.

5.8 *Piping 3 mm to 4 mm internal diameter*, fitted with in-line flow meters, for the delivery of the secondary (diluent) air supply under positive pressure, passing through the wall of the mixing and measurement chamber and ending approximately 70 mm above the end of the quartz furnace tube so that the secondary air supply intercepts the rising plume to facilitate the efficient mixing of the test atmosphere.

NOTE This removes the need for a mechanical stirring device.

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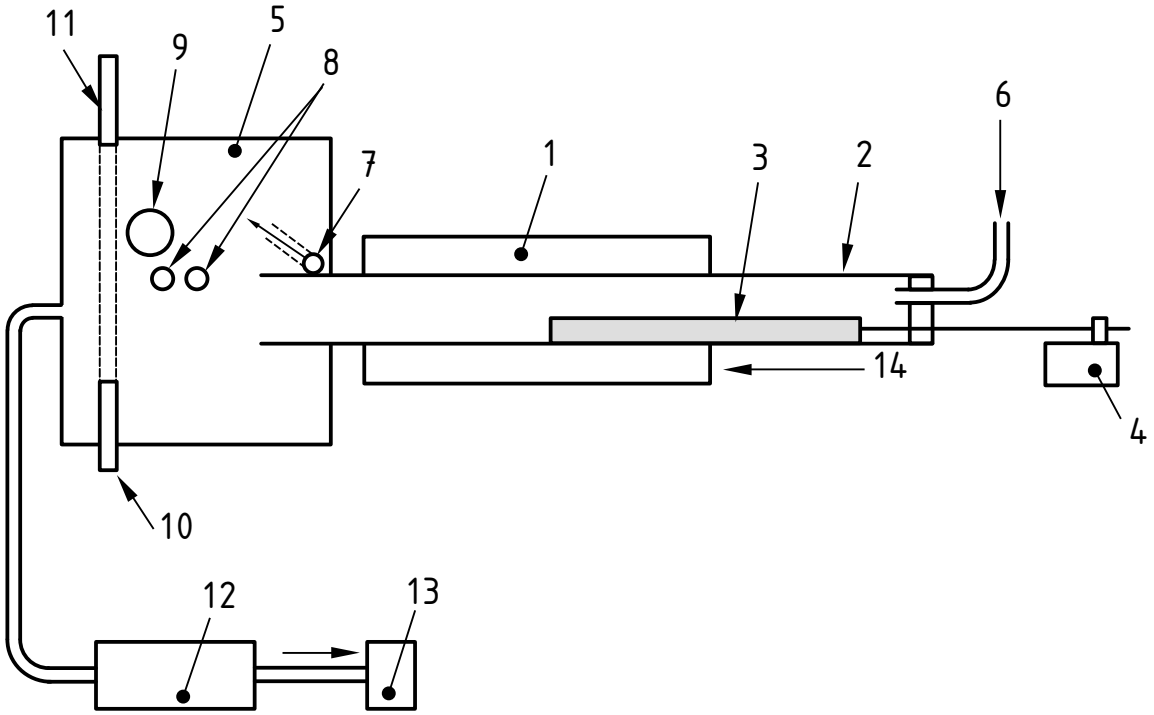

Key

1 Tube furnace
2 Quartz furnace tube
3 Test specimen boat
4 Test specimen boat drive mechanism
5 Mixing and measurement chamber
6 Primary air inlet
7 Secondary air inlet
8 Ports for sampling lines
9 Smoke particle filter
10 Tube containing light source
11 Tube containing photodetector
12 Gas bubblers
13 Pump with flow meter
14 Direction of test specimen boat movement

Figure 1 — Tube furnace decomposition and sampling apparatus

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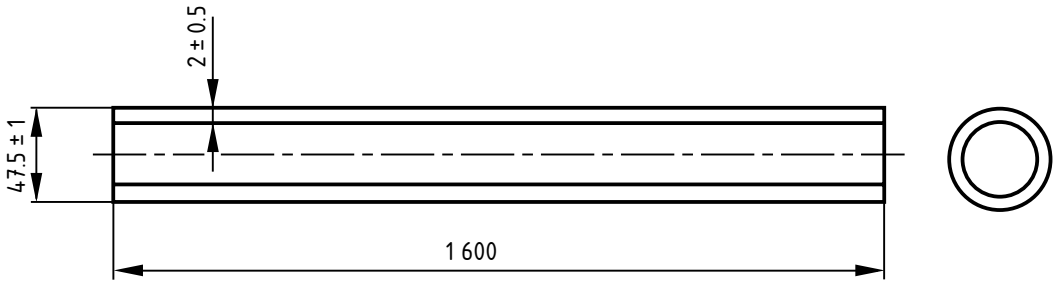
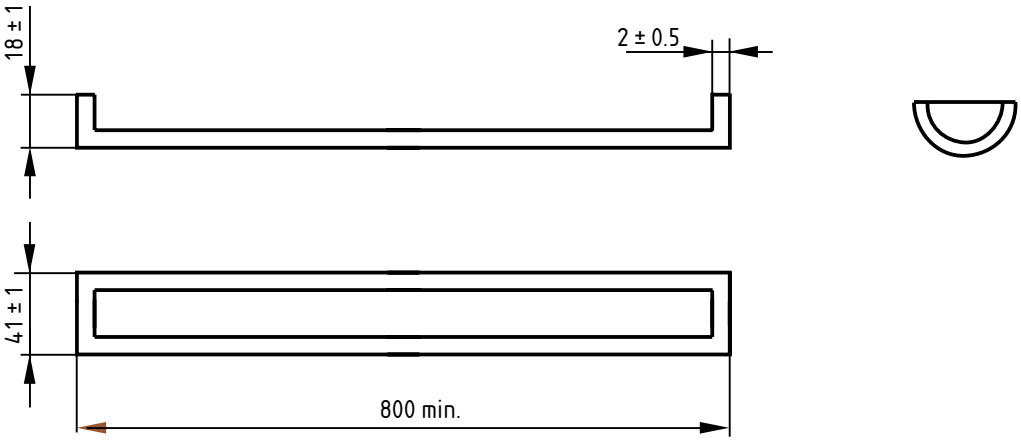
Dimensions in millimetres



a) Quartz furnace tube



b) Test specimen boat

Figure 2 — Dimensions of a suitable quartz furnace tube and test specimen boat

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Dimensions in millimetres

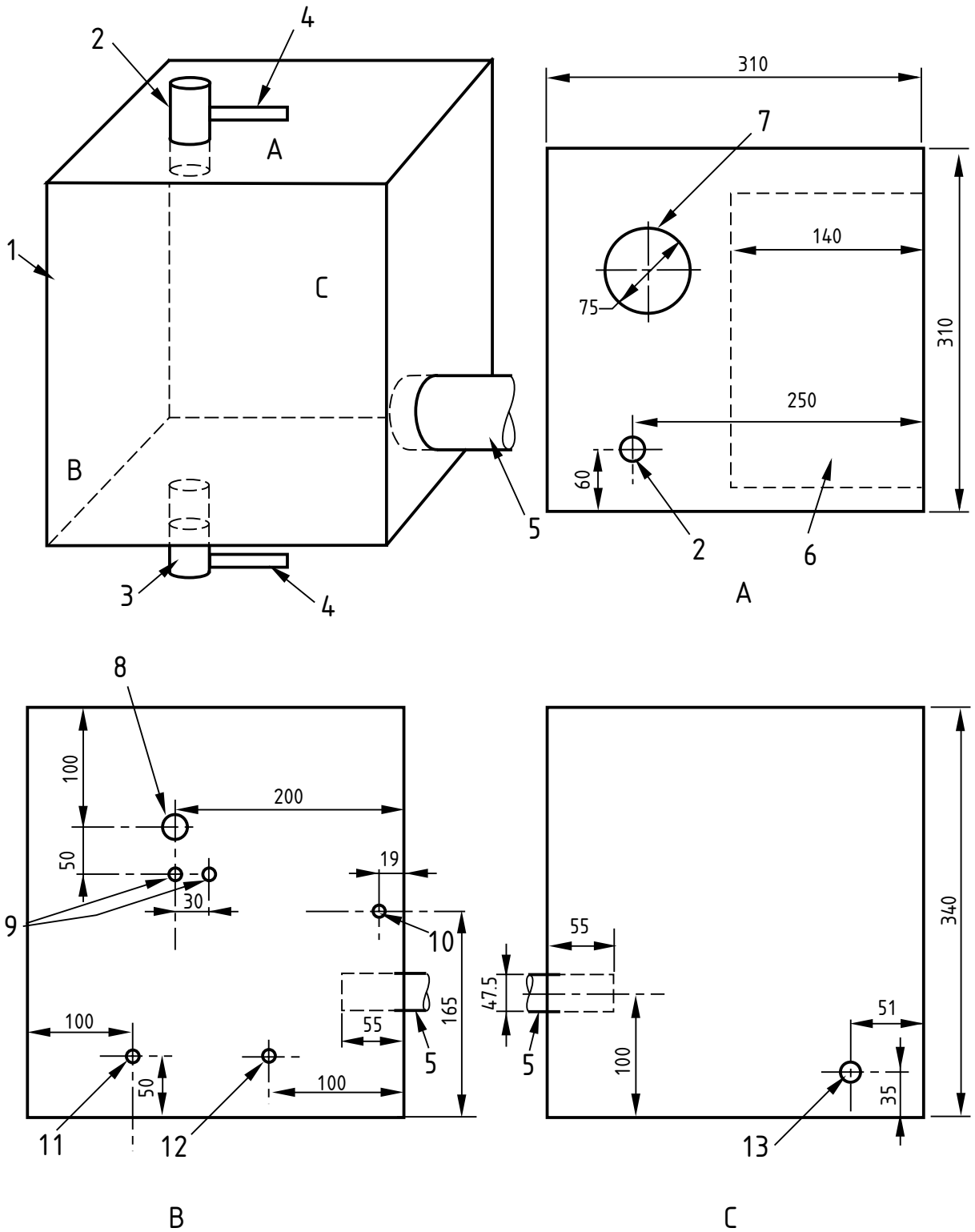

Figure 3 — Dimensions of mixing and measurement chamber

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Key

A	Top
B	Front
C	Back
1	Door
2	Tube containing photodetector
3	Tube containing light source
4	Purge tubes for photodetector and light source
5	Quartz furnace tube
6	Stainless steel plate
7	Safety blow-out panel
8	Smoke particle filter
9	Ports for sampling lines
10	Secondary air inlet
11	Port for thermocouple
12	Port for tube to sample atmosphere in furnace tube for measurement of oxygen concentration
13	Exhaust port

Figure 3 — Dimensions of mixing and measurement chamber (*continued*)

6 Air supplies

The primary and secondary air supplies to the apparatus shall be clean and free from excessive moisture that could interfere with burning characteristics or combustion product analysis.

NOTE 1 Oil free compressed air passed through a carbon trap and silica gel, or bottled air, have been found to be suitable.

Air flow rates shall be calibrated at the point of entry to the quartz furnace tube and the mixing and measurement chamber.

NOTE 2 A correction for back pressure at the in-line flow meters may be necessary.

7 Establishment of furnace temperature profile and setting of furnace temperature

7.1 General

It is necessary to standardize the temperature to which the test specimen and the combustion products released from the test specimen are subjected as they pass through the quartz furnace tube.

There are two stages to the temperature standardization. The first stage is to establish that the temperature profile (change of temperature with distance through the quartz furnace tube) of the particular furnace to be used is suitable; the second stage is to determine the temperature setting needed for the particular experimental run condition to be used.

7.2 Establishing furnace temperature profile to determine furnace suitability

7.2.1 *General*

The main problem with differences in furnace temperature profiles is that if the hot zone of the furnace is too short then the test specimen and decomposition products might not be heated for a sufficient time. If the hot zone is longer than the 600 mm specified, this is less likely to present problems, but it is possible that the longer period for which the test specimen and decomposition products are heated could result in small differences in the combustion product yields. The procedure given in **7.2.2** shall be used to determine whether the temperature profile of any particular furnace is within an acceptable range to be used for testing in accordance with this standard.

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7.2.2 *Temperature profile measurement procedure*

Set up the furnace, with an empty quartz furnace tube in place, under static conditions (i.e. with no air flow through the quartz furnace tube). Close the quartz furnace tube at one end with a bung to prevent air flow through the quartz furnace tube and set the furnace temperature controller at 680 °C.

Introduce the calibrated thermocouple (**5.5**) into the quartz furnace tube with the tip of the thermocouple in air within a 10 mm radius of the centre of the quartz furnace tube. Allow the furnace to reach equilibrium. Then measure the temperature profile along the furnace tube by taking measurements at intervals of no greater than 25 mm to find the point of maximum temperature. This should be near the centre of the furnace and the maximum temperature should be (650 ± 10) °C. If the maximum temperature is outside this range adjust the furnace temperature controller to bring the maximum temperature into this range.

From the results obtained determine the location of the point of maximum temperature and record the temperature at that point. Make further measurements also at intervals of no greater than 25 mm on each side of the location of the point of maximum temperature until points are reached at which the temperature decrease relative to the maximum temperature exceeds 100 °C. For the furnace to be acceptable these points have to lie between 125 mm and 250 mm from the location of the point of maximum temperature.

7.3 Setting the temperature for an individual experimental run condition

Once it has been determined that the furnace temperature profile is suitable, the only temperature setting necessary for an experimental run is the maximum temperature under air flow conditions (T_{run}). In order to set the maximum temperature for an experimental run, set up the furnace with the quartz furnace tube in place and set up the appropriate primary air flow through the quartz furnace tube. Introduce the calibrated thermocouple (**5.5**) into the quartz furnace tube as described in **7.2.2** and allow it to reach equilibrium. Once a primary air flow has been established, the point of maximum temperature moves downstream relative to its location under static conditions. In order to compensate for this shift, position the thermocouple tip (75 ± 10) mm downstream of the point of maximum temperature established under static conditions (see **7.2.2**). This position introduces a minimum error for flow rates of up to 20 $l \cdot min^{-1}$. Then adjust the furnace temperature controller until a temperature within ±5 °C of the desired value for T_{run} is obtained.

8 Test specimen preparation

This depends to some extent upon the nature of the material to be tested. The test specimen shall be uniformly distributed along the length of the sample boat so that a constant flow of decomposition products is produced as the test specimen passes through the furnace.

The test specimen preferably should be in the form of a rod of uniform cross-sectional area. The test specimen loading should be approximately 25 $mg \cdot mm^{-1}$ (10 g spread over 400 mm). To give this loading, a specimen rod with a density of 1 $g \cdot ml^{-1}$ would have to have a cross-sectional area of 25 mm^2.

NOTE Test specimens may be in a granular form or in other forms depending upon the nature of the material. In the case of materials that are subject to rapid flame spread or that might distort or shrink on introduction into the furnace the test specimens may be divided into short lengths. These test specimen forms are acceptable providing the material is uniformly distributed along the length of the test specimen boat such that the test specimen loading per unit length is known and so that the rate of decomposition can be determined. Test specimens having densities below approximately 0.05 $g \cdot ml^{-1}$ can be so large that they interfere with the air flow through the quartz furnace tube at a test specimen loading of 25 $mg \cdot mm^{-1}$. To overcome this problem it is acceptable to reduce the test specimen loading and increase the advance rate of the test specimen boat to compensate (see **5.4**). For materials that contain an inert matrix or fillers which do not form part of the combustible mass, the test specimen mass loading should be increased to compensate.

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9 Test decomposition conditions

9.1 General

In order to obtain fire stages 1b) and 2 (ϕ <0.75) and fire stages 3a) and 3b) ($\phi = 2 \pm 0.2$), as given in BS 7899-2:1999, Table 8, the decomposition conditions specified in **9.2**, **9.3**, **9.4** and **9.5**, respectively, shall be used.

NOTE For well ventilated and vitiated flaming conditions it is important that the test specimen burns with a steady flame throughout the dynamic steady state period. For the majority of materials, a primary air flow rate of 10 $l \cdot min^{-1}$ will produce a well ventilated condition at a value of ϕ of <0.75. For test specimens with a high hydrocarbon fuel content [carbon >60 % or stoichiometric oxygen demand (stoichiometric oxygen mass to fuel mass ratio) >2.0], it will be necessary to use a primary air flow rate of 15 $l \cdot min^{-1}$ to achieve a well ventilated condition. For a vitiated flaming condition at a value of ϕ of 2.0 ± 0.1, the required primary air flow rate depends upon the stoichiometric oxygen demand of the test specimen. In practice, it is possible to determine the required primary air flow rate from the oxygen concentration in the mixing and measurement chamber obtained from a well ventilated flaming test run as described in **10.2** and **10.3**.

Depending upon the nature of the test specimen, or where high primary air flow rates present other difficulties, it is permissible to use different primary air flow rates, provided the test specimen mass/air flow ratio is maintained constant (e.g. 25 $mg \cdot mm^{-1}$ specimen loading at an air flow rate of 20 $l \cdot min^{-1}$ corresponds to 12.5 $mg \cdot mm^{-1}$ specimen loading at an air flow rate of 10 $l \cdot min^{-1}$).

Where difficulties are encountered in obtaining steady flaming conditions, these can often be overcome by varying the test specimen loading or the decomposition temperature. If flaming combustion cannot be obtained, or where only intermittent flaming occurs, these should be reported.

9.2 Stage 1b) oxidative pyrolysis from externally applied radiation

Place a test specimen loading of 25 $mg \cdot mm^{-1}$ in the test specimen boat. Set the furnace temperature to obtain a T_{run} of 350 °C. Set the primary air flow rate to 2 $l \cdot min^{-1}$. If flaming decomposition occurs during the run, repeat at temperatures progressively 25 °C lower until a non-flaming decomposition run is obtained.

9.3 Stage 2 well ventilated flaming

Place a test specimen loading of 25 $mg \cdot mm^{-1}$ in the test specimen boat (or a combustible loading of 25 $mg \cdot mm^{-1}$ if the test specimen material contains a known amount of inert filler). Set the furnace temperature to obtain a T_{run} of 650 °C. Set the primary air flow rate to 10 $l \cdot min^{-1}$ and the secondary air flow rate to 40 $l \cdot min^{-1}$.

Complete a test run as described in **10.1**.

From the mean oxygen concentration in the mixing and measurement chamber, M_{O2}, as a percentage by volume of the atmosphere in the mixing and measurement chamber, calculated to 2 decimal places, calculate the oxygen depletion, D_{O2}, as a percentage by volume, from the following equation:

$$D_{O2} = 20.95 - M_{O2}$$

If D_{O2} <3.14 % and >1.80 % then ϕ <0.75 and the run is acceptable.

If D_{O2} >3.14 % then ϕ >0.75 and the run is unacceptable. Repeat with a primary air flow rate of 15 $l \cdot min^{-1}$. Under these conditions ϕ <0.75 and the run is acceptable.

If D_{O2} >1.50 % and <1.80 % then ϕ <0.75 but the combustible material content of the test specimen is too low to obtain reliable data. Repeat the run with a test specimen loading of 1.5 times the mass of the original test specimen loading.

If D_{O2} <1.5 % then ϕ <0.75 but the combustible material content of the test specimen is too low to obtain reliable data. Repeat the run with a test specimen loading of twice the mass of the original test specimen loading.

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9.4 Stage 3a) small vitiated fires in closed or poorly ventilated compartments

Place a test specimen loading of 25 $mg \cdot mm^{-1}$ in the test specimen boat (or a combustible loading of 25 $mg \cdot mm^{-1}$ if the test specimen material contains a known amount of inert filler).

Set the furnace temperature to obtain a T_{run} of 650 °C.

Complete a test run as described in **10.1**.

Calculate D_{O2} in accordance with **9.3** and calculate the required primary air flow rate, P, in litres per minute ($l \cdot min^{-1}$) from the following equation:

$$P = D_{O2} \times 1.1933$$

This will provide a ϕ of 2.0 ± 0.2.

9.5 Stage 3b) post-flashover fires in large or open compartments

Carry out the procedure given in **9.4** but set the furnace temperature to obtain a T_{run} of 825 °C.

10 Procedure

10.1 Decomposition of the test specimen

Bring the tube furnace to the required temperature at the required primary air flow rate in accordance with **9.2**, **9.3**, **9.4** or **9.5**, as applicable. Set the secondary air flow rate to provide a total air flow rate through the mixing and measurement chamber of 50 $l \cdot min^{-1}$. Calibrate the sampling and measurement equipment. Introduce the test specimen boat containing a test specimen of known mass, prepared in accordance with Clause **8**, into the quartz furnace tube with the front end of the test specimen boat just outside the air inlet end of the tube furnace entrance.

Start the experimental run by switching on the test specimen boat drive mechanism (**5.4**) to introduce the test specimen boat containing the test specimen into the furnace at a rate of 40 $mm \cdot min^{-1}$.

NOTE A test specimen boat advance rate of 40 $mm \cdot min^{-1}$ has been found suitable for most materials under most decomposition conditions. For some fast burning and low density materials it has been found necessary to use advance rates of up to 60 $mm \cdot min^{-1}$. In this case it may be necessary to change the test specimen mass and air flow rate to maintain a constant test specimen mass/air flow ratio.

When the back end of the test specimen boat enters the quartz furnace tube the run is completed. Switch off the test specimen boat drive.

10.2 Observations to be made during the run

Look down the furnace tube to determine the presence or absence of flaming, to determine when ignition occurs and that flaming is continuous during flaming decomposition runs, also to confirm that flaming does not occur during non-flaming decomposition runs. The fire condition can also be verified from the gas analysis and smoke density measurements (see **10.3.2** and **10.3.6**). Observe the recordings from the gas analysers and the smoke density monitor during the early stages of the run. When these have reached approximately constant levels, then dynamic steady state conditions have been achieved. The decomposition conditions need to remain approximately steady for a minimum of 5 min, to enable the test specimen decomposition behaviour and toxic product yields to be characterized (see Note). Data for all measured parameters shall be averaged over this period.

Where difficulties are encountered in obtaining steady flaming conditions, these can often be overcome by varying the test specimen loading or decomposition temperature. If flaming combustion cannot be obtained, or where only intermittent flaming occurs, this should be reported.

NOTE During dynamic steady state conditions the concentrations of carbon dioxide and oxygen in the mixing and measurement chamber should remain approximately constant, without any long-term trend (greater than ±10 %) or short-term fluctuations (greater than ±20 %). Carbon monoxide concentration and smoke density may be somewhat more variable in some cases. If larger fluctuations occur then this should be reported. If steady state conditions are not maintained for at least 5 min then it may be necessary to use a longer test specimen boat or reduce the rate of introduction of the test specimen boat into the quartz furnace tube to increase the duration of the run. A standard 20 min run has been found to provide a steady state period of at least 10 min duration in most cases.

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10.3 Sampling and analysis of fire effluent and measurement of smoke density

10.3.1 *General*

10.3.1.1 The effluent components to be sampled and analysed or measured directly in the mixing and measurement chamber shall consist of the following base set which shall be measured in all cases:

— carbon monoxide;
— carbon dioxide;
— oxygen;
— total particulates;
— total organic content;
— smoke optical density.

10.3.1.2 Further components shall be sampled and analysed depending upon the elemental composition of the test specimen and to some extent on the purpose of the investigation. These shall include the following, as applicable:

— hydrogen cyanide (if the presence of nitrogen is suspected);
— NO_x (if the presence of nitrogen is suspected);
— hydrogen chloride (or other hydrogen halides if present);
— sulfur dioxide (if the presence of sulfur is suspected);
— phosphoric acid (if the presence of phosphorus is suspected).

10.3.1.3 The concentrations of permanent gases (see **10.3.2**), and the smoke density (see **10.3.6**), which are continuously measured, shall be averaged over the period during which dynamic steady state conditions are maintained. The concentrations of acid gases (see **10.3.3**) and the total organic content of the fire effluent (see **10.3.5**) shall be averaged over the period sampled within the dynamic steady state decomposition period.

10.3.2 ***Permanent gases*** *(CO, CO_2 and O_2)*

Sample the fire effluent in the mixing and measurement chamber continuously at an appropriate flow rate.

NOTE A flow rate of approximately 2 $l \cdot min^{-1}$ has been found to be suitable.

Pass the sample continuously through a drying agent and a smoke filtration system, and then through gas analysers to measure CO, CO_2 and O_2, connected to a continuous recording system.

10.3.3 ***Acid gases***

If acid gases as listed in **10.3.1.2** are to be determined, pass a continuous sample of the fire effluent at an appropriate flow rate through two gas bubblers placed in series, each containing an appropriate volume of 0.1 M sodium hydroxide solution. Calibrate the flow rate using a bubble meter. This sampling shall be carried out within the period during which dynamic steady state decomposition conditions are maintained.

NOTE A flow of 1 $l \cdot min^{-1}$ for 5 min through two 250 ml bubblers fitted with sintered glass heads of grade P250 conforming to BS 1752, each containing 150 ml of sodium hydroxide solution, has been found to be suitable. For effluent with a high particulate content it is advisable to use a coarse pre-filter consisting of a loose plug of glass wool placed before the bubblers to trap large particles. Before use the glass wool should be washed in several changes of distilled water to remove any soluble salts and then dried. Immediately after the end of the sampling period the pre-filter should be placed into the sodium hydroxide solution so that alkali soluble salts attached to the particles pass into solution.

10.3.4 ***Total particulates***

Sample the fire effluent in the mixing and measurement chamber continuously through a particle filter at an appropriate flow rate. Calibrate the flow rate using a bubble meter. This sampling shall be carried out within the period during which dynamic steady state decomposition conditions are maintained. Weight the filter before and within 10 min after sampling to enable calculation of the mass of particulates deposited.

NOTE A glass microfibre filter 0.26 mm thick with a 1.6 μm particle retention characteristic and a diameter of 37 mm has been found to be suitable.

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10.3.5 *Organic content*

NOTE Since the organic fraction of the effluent contains many irritant species it is important to obtain some indication of the organic fraction of the effluent and, if appropriate, the concentrations and yields of individual organic compounds. The minimum requirement is for an estimate of the total organic content of the effluent (see **10.3.1.1**).

One of the following methods shall be used to measure the organic content of the effluent.

a) A total hydrocarbon analyser shall be used to obtain an approximate estimate of the total hydrocarbon content of the effluent.

NOTE A limitation of this method is that since the identities of the organic compounds in the effluent are unknown, the appropriate response factors are also unknown.

b) The fraction of carbon in the effluent in the form of organic carbon shall be determined by oxidizing a sample of the effluent from the mixing and measurement chamber and measuring the CO_2 concentration. The organic fraction shall then be determined by comparing the CO_2 concentration in the oxidized sample with the concentrations of CO_2, CO and soot particulates in the mixing and measurement chamber, in accordance with **11.4**.

c) For test specimens with a known composition, the organic fraction shall be estimated approximately from the CO_2, CO and soot particulates in the mixing and measurement chamber and the estimated carbon mass loss concentration from the test specimen.

d) Direct measurements shall be made of a range of individual organic species. This shall include irritants (e.g. acrolein and formaldehyde), and may also include other toxic organic species (e.g. benzene) or environmental pollutants (e.g. dibenzodioxins or dibenzofurans).

10.3.6 *Measurement of smoke density*

Make a continuous record of the output from the photodetector in the mixing and measurement chamber.

10.3.7 *Determination of the mass of the test specimen residue*

At the end of the run withdraw the test specimen boat to its starting location in the quartz furnace tube and extinguish any flame by temporarily interrupting the primary air flow. When the test specimen boat has cooled sufficiently, remove it from the quartz furnace tube. Inspect the test specimen residue and measure the length of the uniformly decomposed region from the front end of the boat.

NOTE This represents the part of the test specimen that has been decomposed and has evolved the products measured in **10.3.2**, **10.3.3**, **10.3.4**, **10.3.5** and **10.3.6**.

Remove the uniformly decomposed portion of the residue, weigh it and calculate the mass of residue per millimetre.

10.4 Validity of test run

A test run is only valid if the selected steady state conditions (see **9.1** and **10.2**) are maintained for a period of at least 5 min during the test. If ignition occurs during a non-flaming run, or fails to occur during a flaming run, then the furnace temperature shall be raised or lowered in 25 °C steps until the required behaviour is obtained. A new test run shall then be carried out with a fresh test specimen. For flaming behaviour it is also necessary to ensure that the primary air flow rates are correct, as specified in **9.3**, **9.4** and **9.5**.

11 Calculations

11.1 Mass charge concentration and mass loss concentration

11.1.1 *Mass charge concentration*

Calculate the mass charge concentration, $C_{\text{m.charge}}$, in grams per cubic metre ($g \cdot m^{-3}$), from the following equation:

$$C_{\text{m.charge}} = \frac{\dot{m}}{\dot{a}}$$

where

$\dot{m}$ is the rate of introduction of the test specimen mass into the furnace in milligrams per minute $(mg \cdot min)^{-1}$;

$\dot{a}$ is the total air flow rate through the mixing and measurement chamber in litres per minute ($l \cdot min^{-1}$) (i.e. 50 $l \cdot min^{-1}$).

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11.1.2 *Mass loss concentration*

Calculate the mass loss concentration as follows.

a) Calculate the mass loss per unit length, m_{loss}, in milligrams per millimetre ($mg \cdot mm^{-1}$), from the following equation:

$$m_{loss} = m_{load} - m_{res}$$

where

m_{load} is the test specimen mass loading in milligrams per millimetre ($mg \cdot mm^{-1}$);

m_{res} is the test specimen residue mass in milligrams per millimetre ($mg \cdot mm^{-1}$).

b) Calculate the mass loss rate, $\dot{m}_{loss}$, in milligrams per minute ($mg \cdot min^{-1}$) from the following equation:

$$\dot{m}_{loss} = m_{loss} \times \dot{b}$$

where

$\dot{b}$ is the test specimen boat advance rate in millimetres per minute ($mm \cdot min^{-1}$).

c) Calculate the mass loss concentration, $C_{m.loss}$, in grams per cubic metre ($g \cdot m^{-3}$), from the following equation:

$$C_{m.loss} = \frac{\dot{m}_{loss}}{\dot{a}}$$

where

$\dot{a}$ is as given in **11.1.1**.

11.2 Smoke density

The smoke density is reported as the smoke extinction coefficient, k, and the smoke specific extinction area, σ_f, which are calculated as follows.

Calculate the smoke extinction coefficient, k, in reciprocal metres (m^{-1}) from the following equation:

$$k = \frac{1}{L}\ln\left(\frac{I_o}{I}\right)$$

where

I_o is the intensity of a beam of parallel light rays, in candelas (cd) measured in a smoke free environment with a photodetector having the same spectral sensitivity as the human eye;

I is the intensity of the same beam of parallel light rays, in candelas (cd), measured after traversing the environment containing the smoke;

L is the length of the beam of light that has traversed the environment containing the smoke, in metres (m).

Calculate the smoke specific extinction area, σ_f, in metres squared per gram ($m^2 \cdot g^{-1}$) from the following equation:

$$\sigma_f = \frac{k}{C_{m.loss}}$$

where

k is the smoke extinction coefficient, in reciprocal metres (m^{-1});

$C_{m.loss}$ is the mass loss concentration of the test specimen calculated in accordance with **11.1.2**, in grams per cubic metre ($g \cdot m^{-3}$).

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11.3 Yield

Calculate the yield of each effluent component, Y, (dimensionless) from the following the equation:

$$Y = (M/V_m) \times (F_v/C_{m.loss}) \times 10$$

M is the molar mass of the component, in grams per mole ($g \cdot mol^{-1}$);

V_m is the molar volume of the component at 20 °C and 101.325 kPa atmospheric pressure, assuming that it behaves as an ideal gas, in litres per mole ($l \cdot mol^{-1}$), i.e. 24.055 $l \cdot mol^{-1}$;

F_v is the measured volume fraction of the component in the mixing and measurement chamber as a percentage;

$C_{m.loss}$ is the mass loss concentration, calculated in accordance with **11.1.2**, in grams per cubic metre ($g \cdot m^{-3}$).

To aid calculations, values of the molar mass factor (M/V_m) are given in Table 1 for a number of effluent components.

Table 1 — Values of (M/V_m)

Component	Molar mass $g \cdot mol^{-1}$	(M/V_m) $g \cdot l^{-1}$
CO_2	44.01	1.830
CO	28.01	1.164
HCN	27.03	1.124
NO_2	46.01	1.913
NO	30.01	1.248
HCl	36.46	1.516
HBr	80.91	3.364
HF	20.01	0.832
H_2S	34.08	1.417
SO_2	64.06	2.663
H_3PO_4	98.00	4.074
Acrolein (C_3H_4O)	56.06	2.331
Formaldehyde (CH_2O)	30.03	1.248

NOTE Another yield concept that may be used is that of the "volume yield". The volume yield of an effluent component is the volume of the component (at 20 °C and 101.325 kPa pressure) divided by the mass loss concentration of the test specimen associated with the production of that volume of the component. The volume yield, X, in litres per gram ($l \cdot g^{-1}$) can be calculated from the following equation:

$$X = (F_v \times 10^{-3})/C_{m.loss}$$

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11.4 Organic fraction

Where the fraction of carbon in the effluent in the form of organic carbon, $F_{C.org}$, is to be determined [see **10.3.5**b)], this shall be calculated using the following equation:

$$F_{C.org} = \frac{\left[CO_2\right]_{oxidized} - \left(\left[CO_2\right]_{chamber} + \left[CO\right]_{chamber} + \left[soot\right]_{chamber}\right)}{\left[CO_2\right]_{oxidized}}$$

where

$F_{C.org}$ is the fraction of the effluent carbon in the form of organic carbon;

$[CO_2]_{oxidized}$ is the volume fraction of CO_2, as a percentage, in the oxidized sample;

$[CO_2]_{chamber}$ is the volume fraction of CO_2, as a percentage, in the mixing and measurement chamber;

$[CO]_{chamber}$ is the volume fraction of CO, as a percentage, in the mixing and measurement chamber;

$[soot]_{chamber}$ is the soot concentration [measured in grams per cubic metre ($g \cdot m^{-3}$)] expressed as an equivalent volume fraction of CO_2, as a percentage, in the mixing and measurement chamber (assuming soot is 100 % carbon).

NOTE Where the carbon content of the mass loss can be estimated from the known composition of the test specimen it is possible to make an approximation of the fraction of effluent carbon in the form of organic carbon by calculating the theoretical CO_2 concentration that would be formed in the mixing and measurement chamber if all the specimen mass loss was oxidized to CO_2. This can then be substituted for $[CO_2]_{oxidized}$ in the equation.

12 Test report

The test report shall give at least the following information for data obtained during the steady state decomposition period:

a) the decomposition conditions [fire stage 1, 2, 3a) or 3b)];

b) the run temperature (T_{run}) in degrees centigrade (°C);

c) the primary air flow rate in litres per minute ($l \cdot min^{-1}$);

d) the burning behaviour (flaming/non-flaming) and stability (see **10.2**);

e) the mass charge concentration and mass loss concentration of the test specimen;

f) the mean concentration of each component of the effluent (as listed in **10.3.1**);

g) the mean yield of each component of the effluent, calculated in accordance with **11.3**;

h) the mean smoke extinction coefficient and the smoke specific extinction area of the smoke in the mixing and measurement chamber.

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Annex A (informative)
Guidance on choice of additional decomposition conditions

Since the yields of products in fires depend upon the decomposition conditions (see references [1] to [5]), it is possible to examine the relationships between product yield and a range of variables affecting the decomposition conditions using the apparatus and the methodology described in the present standard. The test conditions specified represent a minimum set designed to obtain data for oxidative pyrolysis under non-flaming conditions, for well ventilated flaming conditions at an equivalence ratio of less than 0.75 and for vitiated flaming conditions at an equivalence ratio of 2.

For a more comprehensive analysis of yields under non-flaming conditions it is possible to vary the furnace temperature in separate runs over a range from low temperatures at which little or no thermal decomposition occurs, to a temperature at which flaming ignition occurs. By this means, product yields can be measured throughout the temperature range over which non-flaming oxidative decomposition is possible for a particular material.

For flaming decomposition conditions the product yields for any specific material are affected mainly by the fuel/oxygen ratio under which the test is carried out (from which the equivalence ratio is calculated, see below). For any material it is therefore possible to map the relationship between equivalence ratio and product yields. This then enables comparison of the behaviour of materials over the entire range of equivalence ratios over which flaming decomposition can be obtained.

In full-scale fires, the equivalence ratios, and hence the product yields and concentrations in the fire compartment, change as the fire develops. Data on the effects of equivalence ratio on product yields for materials can therefore be useful in calculations of time-concentration curves for products from those materials involved in full-scale fires.

For any tube furnace test run, the equivalence ratio ϕ is given by the mass loss rate of combustible effluent from the material under test in milligrams per minute ($mg \cdot min^{-1}$) divided by the mass flow rate of oxygen in the primary air introduced into the furnace in milligrams per minute ($mg \cdot min^{-1}$) relative to the stoichiometric fuel mass to oxygen mass ratio for the material under test, i.e.:

$$\phi = \frac{\dot{m}_{loss} \times \Psi_O}{O}$$

where

$\dot{m}_{loss}$ is the mass loss rate of the test specimen, in milligrams per minute ($mg \cdot min^{-1}$) calculated in accordance with **11.1.2**b);

Ψ_O is the stoichiometric oxygen mass to fuel mass ratio;

O is the oxygen supply rate in milligrams per minute ($mg \cdot min^{-1}$) given by the following equation:

$$O = P \times 0.2095 \times 1330$$

where

P is the primary air flow rate in litres per minute ($l \cdot min^{-1}$);

1330 is a factor to convert volume of oxygen to mass of oxygen at 20 °C.

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The stoichiometric oxygen mass to fuel mass ratio, Ψ_O (also known as the stoichiometric oxygen demand of the material) can be obtained in one of three ways depending upon the information available on the test material, as follows:

a) from the elemental composition or empirical formula for the test material;

b) from the net heat of complete combustion for the test material (ΔH_T);

It has been empirically determined that when a material burns, for every gram of oxygen consumed, the heat released is approximately 13.1 kJ. Thus, if the net heat of complete combustion for the test material (ΔH_T) is known (e.g. as measured by bomb calorimetry), the stoichiometric oxygen mass to fuel mass ratio, Ψ_O, for the particular test material can be calculated from the following equation:

$$\Psi_O = (\Delta H_T)/13.1$$

c) from the oxygen depletion in the mixing and measurement chamber and the mass loss concentration of the test specimen during a well ventilated tube furnace test run, the stoichiometric oxygen mass to fuel mass ratio, Ψ_O, can be calculated from the following equation:

$$\Psi_O = \frac{D_{O2} \times 1330}{C_{m.loss}}$$

where

D_{O2} is the oxygen depletion in the mixing and measurement chamber as a volume fraction (see **9.3**);

$C_{m.loss}$ is the mass loss concentration of the test specimen in grams per cubic metre ($g \cdot m^{-3}$) calculated in accordance with **11.1.2**c).

Annex B (informative)
Guidance on calculation of lethal toxic potency of combustion products

The concept of lethal toxic potency was derived originally from experiments on rats, on the assumption that an exposure dose of effluent lethal to rats is likely to be equally lethal to humans. The lethal toxic potency is expressed in terms of the exposure dose of effluent lethal to 50 % of exposed rats (LCt_{50}), which depends upon the concentration of toxic fire effluent to which the animals are exposed, multiplied by the exposure time (including a 14 day post-exposure period during which any additional deaths are scored). The concentration of toxic fire effluent can be expressed in a number of ways, but the most commonly used parameters are related to the material under test in terms of the mass charge or mass loss concentrations and the yields of individual toxic products. Exposure dose can be expressed in terms of the mass loss exposure dose.

Although estimates of toxic potency have been made primarily using animal exposures it is now considered that, for most test specimens, reasonable estimates of toxic potency can be made based upon chemical analytical measurements of the composition of fire effluent atmospheres. Therefore, the method described in the present standard is intended for use with chemical analysis measurements.

In order to estimate toxic potency in this way it is therefore necessary to have:

a) a method for decomposing test specimens under a range of conditions known to occur in different stages of fires, with measurement of the concentrations and yields of selected components (as described in the present standard); and

b) a method for calculating the lethal toxic potency of the effluent, based upon the concentrations and yields of those selected components (see BS 7899-2:1999, Clause **6**).

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Lethal toxic potency estimates for the combustion products from materials provide one set of data sometimes used as part of the information needed for the assessment of toxic hazard in fires. It is possible to estimate the lethal toxic potency from the concentrations and yields of toxic effluent obtained from materials using the tube furnace method. The basis for this is presented in BS 7899-2:1999, **6.4**. Guidance can also be obtained from BS ISO 13344. BS 7899-2:1999, Equation 13 enables calculation of an estimated fractional effective dose (FED) of effluent obtained from decomposition of a material specimen in the tube furnace. This represents the fraction of an LC_{50} concentration of an effluent mixture for a 30 min exposure period. The input data for the calculations are the concentrations of toxic gases in an effluent atmosphere measured in the tube furnace test. The following procedure can be used to calculate estimated LC_{50} and LCt_{50} concentrations for a material tested in the tube furnace under a specified thermal decomposition condition.

a) Measure toxic gas concentrations and material mass loss concentrations during a tube furnace test run as described in the present standard.

b) Calculate the FED according to BS 7899-2:1999, Equation 13. This then represents the FED for the mass loss concentration of the material specimen tested.

c) If the calculated FED is less than (or greater than) 1, calculate toxic gas concentrations for a correspondingly greater (or smaller) material mass loss concentration (for example, the gas concentrations for a mass loss concentration double that used for the test would be twice the original).

d) Recalculate the FED for the new toxic gas mixture.

e) When the calculated FED equals 1 then the mass loss concentration represents the estimated LC_{50} concentration for the material under test. The estimated LCt_{50} concentration is given by the following equation:

$$LCt_{50} = LC_{50} \times 30.$$

Toxic potency values are only of use in toxic hazard estimations, and it is essential that they are not used for the direct ranking or exclusion of products or materials. The direct use of toxic potency data to rank order materials for potential toxic hazard in fire has been criticised in ISO and IEC guidance documents as likely to be counterproductive to life safety. These data can be properly used only as inputs to toxic hazard calculations. Reference should also be made to BS 7899-1 and BS 7899-2 and to PD 6503-1 and BS ISO/TR 9122.

Because the material based toxic potency value has to be multiplied by the mass loss rate of the product when exposed to heat or fire, it is not possible to infer that a material with a high toxic potency equates to a higher toxic hazard, or vice versa.

For example, it is quite possible that a product made from a material with a low toxic potency could pose a greater toxic hazard than the same product made from a material of higher toxic potency, if the latter is more resistant to ignition, and/or when ignited, burns (i.e. loses mass) more slowly than the former.

In light of this, requirements for toxic potency based on data generated by the test method given in the present standard, or any other test method, should not be included in specifications for materials or end-products, unless it is supported by complementary tests to measure the mass loss rate under an appropriate scenario, or unless it is part of a documented hazard assessment that considers mass loss, exposure concentrations, time to escape and time to tenability etc.

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Annex C (informative)
Guidance on application of data from the tube furnace test to assessment of toxic hazard in fires

The data from the tube furnace test may be used as part of the information needed for assessment of toxic hazard in a fire. Toxic hazard assessments include the following considerations:

a) the point in time during a fire by which a person will have been exposed to a concentration of smoke and irritants capable of impairing the efficiency of escape or causing incapacitation;

b) the point in time during a fire by which a person will have been exposed to dose of asphyxiants capable of causing incapacitation and/or significant post-exposure health effects;

c) the point in time during a fire by which a person will have been exposed to a dose of lung irritants capable of causing post-exposure lung inflammation capable of causing long-term health effects or death.

There are a number of ways in which such assessments can be made, as described in BS 7899-2:1999, Clauses **3** and **4**. Part of the data required for these assessments includes either:

1) the lethal toxic potencies [mass loss LCt_{50} values (see Annex B)] for materials involved in the fire; or

2) the yields of individual toxic gases from materials involved in the fire.

For the first method, mass loss LCt_{50} data obtained from the tube furnace test can be combined with mass loss time-concentration curves for the fire to calculate the point in time by which an exposed person can be predicted to have received a lethal exposure dose.

For the second method, the yield of toxic gases measured using the tube furnace test can be combined with mass loss time-concentration curves for the fire to provide estimates of the time-concentration curves for individual toxic gases in the fire. These data can then be used with the fractional effective concentration (FEC), fractional effective dose (FED) and fractional lethal dose (FLD) methods described in BS 7899-2:1999, Clause **5** to estimate times to different incapacitation and lethal endpoints for exposed persons.

Annex D (informative)
Guidance on application of data from the tube furnace test to health and safety assessments of combustion products

The data from the tube furnace test may be used in health and safety assessments of exposures to combustion products. For this application it is necessary first to identify the material being decomposed and the decomposition conditions (i.e. the fire type, according to BS 7899-2:1999, Table 8). The material is then decomposed using the tube furnace method and the yields of toxic products are measured. Health and safety assessments usually involve situations in which long-term exposures or repeated short-term exposures occur. The range of combustion products for which measurements are required will be considerably wider than that required for assessment of acute toxic hazards involved in fire survival.

From measurements of the yields of individual toxic combustion products from the material (or materials) and data on the expected mass loss concentration in the workplace it is possible to estimate potential workplace concentrations. Since combustion product atmospheres always consist of mixtures of large numbers of toxic products it is necessary to consider the overall toxicity of the mixed combustion products.

Guidance on occupational exposure limits for individual toxic substances is provided in *Occupational exposure limits* [6]. Clauses 38 to 49 of that document provide guidance on the assessment of the overall toxic effects of mixtures.

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Annex E (informative)
Guidance on application of data from the tube furnace test to assessment of environmental hazards from combustion products from fires

Fires produce a range of pollutants capable of contaminating the indoor and outdoor environment including both air contamination during the fire and contamination of water and solid surfaces by deposition. These pollutants include many of the substances of concern with regard to direct exposure during a fire, but also a further range of substances which may present a continued health hazard from effects on indoor air quality or from oral ingestion. The latter include substances such as polyaromatic hydrocarbons, polyhalogenated biphenyls and halogenated dibenzodioxins and dibenzofurans (see BS 7982). As with other substances produced during fires, the yields of these substances can vary considerably with the combustion conditions [5]. The tube furnace method can therefore be used to identify and measure the yields of these substances for application to estimates of the production of environmental contaminants from fires.

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