

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.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises of a front cover, an inside front cover, pages i to iv, pages 1 to 23 and a back cover.

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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.

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 ($\text{mg} \cdot \text{min}^{-1}$) divided by the mass flow rate of oxygen in the primary air introduced into the furnace in milligrams per minute ($\text{mg} \cdot \text{min}^{-1}$) divided by the stoichiometric fuel mass to oxygen mass ratio for the material under test.

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 $\text{g}\cdot\text{m}^{-3}$ [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 $\text{g}\cdot\text{m}^{-3}$ [BS 7899-2:1999, definition 2.21]

3.5**mass loss exposure dose**

mass loss concentration multiplied by the exposure time, expressed in $\text{g}\cdot\text{m}^{-3}\cdot\text{min}$ [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 $(50 \pm 1) \text{ l}\cdot\text{min}^{-1}$ 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.