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Recommendations for

The use of the cone calorimeter

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- Association of Building Component Manufacturers
- Association of Roof Light Manufacturers
- Autoclaved Aerated Concrete Products Association
- British Cable Makers Confederation
- British Carpet Manufacturers Association Ltd.
- British Electrical Systems Association (BEAMA Ltd.)
- British Plastics Federation
- British Resilient Flooring Manufacturers' Association
- British Rigid Urethane Foam Manufacturers' Association
- British Wood Preserving and Damp-proofing Association
- Chemical Industries Association
- Chief and Assistant Chief Fire Officers Association
- Department of the Environment, Transport and the Regions — Represented by the Building Research Establishment
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- Specialist Ceilings and Interiors Association Ltd.
- Thermal Insulation Manufacturers and Suppliers Association (TIMSA)
- Timber Research and Development Association
- UK Steel Association
- Wood Panel Industries Federation
- Wood Wool Slab Manufacturers Association

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The following bodies were also represented in the drafting of this Draft for Development, through subcommittees and panels:

- British Railways Board
- Ministry of Defence
- University of Edinburgh
- University of Ulster

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Foreword

This Draft for Development has been prepared by Technical Committee FSH/21.

The cone calorimeter is a fire test instrument in which horizontal specimens are exposed to controlled levels of radiant heating by means of a truncated cone-shaped heater. Continuous spark ignition is provided and the time to ignition is recorded for specimens which ignite. The rate of heat release from the burning specimen is determined from measurements of the amount of oxygen consumed from the air flowing through the apparatus, which has been demonstrated to equate to heat release. The mass of the specimen is also measured throughout the burning period. The specimens are usually tested under well ventilated conditions.

Results are expressed in terms of peak and average rates of heat release as well as total heat released and the effective net heat of combustion. The standard limits the specimen type to building products which are essentially flat. Several other groups are now utilizing the cone calorimeter and a number of new parameters in addition to those defined in BS 476-15:1993 (ISO 5660-1) have been defined and used. Some of these, including smoke measurement, require that measurements are made from the beginning of the test rather than the onset of ignition which is commonly used as the starting point for heat release measurement.

The cone calorimeter is also designed to allow measurement of smoke and gases such as CO and CO₂. Smoke measurement is described in ASTM E 1354 and is the subject of a work item within ISO/TC 92/SC1 which is expected to lead to a dynamic smoke test method to be published as ISO 5660-2. Further work is under way in the same working group to define a quality control tool for measuring burning rates of building products. This will be published as ISO 5660-3 and is based on mass loss measurements using the thermal decomposition model of the cone calorimeter. Both ISO 5660-2 and ISO 5660-3 are being prepared and only exist as draft documents. A similar system which measures the temperature of combustion products generated by this apparatus is also being standardized by ISO/TC 61 as CD 13927. The cone calorimeter fire model has also been for use in a corrosivity standard developed by ASTM (ASTM D 5485). The effect of the evolved gases on the resistance of a printed circuit board target is used to assess corrosivity. This method is also being standardized within ISO TC 61 and is at the DIS stage as DIS 11904-4.

During development of the cone calorimeter it became apparent that there was considerable interest in the development of the use of the instrument for products other than building products. Several national and international application standards have been published and major purchasing agencies such as railways and the US military have specifications based on the cone calorimeter.

This Draft for Development provides recommendations for the testing of products in the cone calorimeter and gives guidance on the presentation of the results. It supplements the guidance given in guidance documents and text books [1], [2].

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature because techniques, applications and software for the use of the cone calorimeter are still being developed. It should be applied on this provisional basis, so that information and experience of its practical application may be obtained.

A review of this Draft for Development will be carried out not later than 2 years after its publication. Notification of the start of the review period, with a request for the submission of comments from users of this Draft for Development, will be made in an announcement in the appropriate issue of *Update Standards*.

According to the replies received, the responsible BSI Committee will judge whether the Draft for Development can be converted into a British Standard or what other action should be taken.

Observations which it is felt should receive attention before the official call for comments will be welcomed.

These should be sent to the Secretary of BSI Technical Committee FSH/21 at 389 Chiswick High Road, London W4 4AL.

Annexes A and B are informative

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 25 and a back cover.

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1 Scope

This Draft for Development examines the limitations of the cone calorimeter as currently used for building products and recommends ways in which some of these may be overcome for other types of products for other application areas. It draws together information from a large body of experience with regard to the use of the instrument into a set of guidelines which will help to standardize the use of the cone calorimeter in this wider scope.

Particular guidance is given on aspects of specimen preparation and on the behaviour, such as melting, spalling and intumescenting, of specimens exposed to radiant heat. The relevance of specimen thickness and the use of substrate and methods of fixing to substrate is also discussed. Advice is given on approaches to testing a variety of “non-standard” products. Recommendations are made on techniques of calibration of the apparatus, selection of appropriate heat flux levels and ignition protocols.

In addition to the guidance given to operators, the document makes recommendations on presentation of the test results. Correlation of cone calorimeter results with large scale fire behaviour of products is product-dependent. Specific guidance on the modelling of full-scale behaviour from cone calorimeter results is covered by [1], [2] and by standards developed by product committees.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Draft for Development. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 476-15:1993, *Fire tests on building materials and structures — Part 15: Method for measuring the rate of heat release of products* (ISO 5660-1:1993).

IEC 332-3:1992, *Tests on electric cables under fire conditions — Part 3: Tests on bunched wires or cables*.

3 Terms and definitions

For the purposes of this Draft for Development the following terms and definitions 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 periods of less than 1 s

3.3

ignition

onset of sustained flaming

3.4

sustained flaming

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

3.5

irradiance

(at a point of a surface) quotient of the radiant flux incident on an infinitesimal element of surface containing the point, by the area of the element

NOTE Convective heating is negligible in the horizontal specimen orientation. For this reason, the term “irradiance” is used instead of “heat flux” throughout this Draft for Development as it best indicates the essentially radiative mode of heat transfer.

3.6

orientation

plane in which the exposed face of the specimen is located during testing

NOTE This is either vertical or horizontally face upwards.

3.7

oxygen consumption principle

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

3.8

specimen

representative piece of the product which is to be tested together with any substrate or treatment

NOTE For certain types of products, for example products that contain an air gap or joints, it may not be possible to prepare specimens that are representative of the end-use conditions (see clause 8).

4 Symbols

For the purposes of this Draft for Development the following symbols apply.

D'	optical density of calibration filter (dimensionless)
d	cone calorimeter duct diameter, in millimetres (mm)
F	calibration factor = f/d , in reciprocal metres (m^{-1})
f	correction factor = k_2/k_1 (dimensionless)
I_0/I	ratio of incident light intensity to transmitted light intensity (dimensionless)
k	extinction coefficient, in reciprocal metres (m^{-1})
k_m	measured extinction coefficient, in reciprocal metres (m^{-1})
k_1	measured calibration extinction coefficient, in reciprocal metres (m^{-1})

k_2	corrected calibration extinction coefficient, in reciprocal metres (m^{-1})
p_d	differential pressure, in kilopascals (kPa)
T_e	absolute temperature of gas at the orifice meter, expressed in kelvins (K)
t	time, in seconds (s)
t_{end}	end time, in seconds (s)
t_{ignition}	ignition time, in seconds (s)
X_{O_2}	oxygen analyser reading, mole fraction of oxygen (dimensionless)
ΔH_c	heats of combustion, in kilojoules per gram (kJ/g)
ε	emissivity (dimensionless)

5 Capability and limitations of the cone calorimeter

Rate of heat release is one of the fundamental properties of fire and should almost always be taken into account in any assessment of fire hazard. Heat release significantly affects fire growth. Considerable progress has been made in methods of using rate of heat release and ignition time results from the cone calorimeter to predict full scale fire characteristics, such as time to flashover in a small room lined with the tested product and exposed to a high energy fire source such as that used in ISO 9705.

The design of the instrument also provides for measurement of smoke (both gravimetrically and optically) and other gaseous products of pyrolysis or combustion. The instrument may thus be applied to the assessment of real fire hazards such as smoke, and toxic and corrosive gas emission, in addition to heat release. The results are expressed in terms of fundamental physically-based parameters.

When functioning purely as a rate of heat release apparatus the parameter which is measured in the plume from the specimen is the concentration of oxygen. Temperature measurements are made but these are not used to measure the heat output from the specimen in the manner of a conventional calorimeter. This is a crucial point in understanding heat release by oxygen consumption calorimetry. The theory of oxygen consumption calorimetry is discussed in more detail in clause 13.

The instrument is limited to bench-scale specimens and it uses a simple fire model which provides continuous free ventilation and removal of the products of partial and complete combustion. Specimen behaviour during the experiment such as shrinking and swelling can be tolerated if this happens within small margins, but if the specimen intumesces such that it touches the igniter or the cone or if it exhibits spalling this behaviour will invalidate the results generated.

6 Calibration of the cone calorimeter

6.1 General

Regular and accurate calibration of several measuring devices is essential in order for valid results to be obtained from the cone calorimeter. The calibration procedure described in the following subclauses of BS 476-15:1993 should be followed:

- 6.11 Heat flux meter (paragraphs 2 and 3)
- 10.1 Heater calibration
- 10.2 Oxygen analyser calibration
 - 10.2.1 Preliminary
 - 10.2.2 Operating
- 10.3 Heat release rate calibration
- 10.4 Mass measuring system calibration

Table 1 details the major calibration recommendations.

Calibration procedures are to some extent apparatus-controlled and the comments in the rest of clause 6 may not apply to all makes of cone calorimeter.

Some guidelines are given on actual operating experiences with these calibrations and follow the clause headings in the standard. In addition there are some additional comments on low orifice calibration factors and the cause thereof.

6.2 Heat flux meter calibration

Early work on cross-calibration of the heat flux meters showed some differences in the calibration constant as given by the supplying company. It is therefore very wise to attempt some cross-calibration with another cone calorimeter user.

Great care should be taken of the heat flux meter which is in regular use and care should be taken always to use this with water cooling. It should be checked regularly against a primary meter as set out in BS 476-15:1993, annex E to ensure its continued correct working. It is false economy to omit this regular check.

6.3 Heater calibration

The setting of the required heat flux is set out in the manuals of the different instruments. Once a steady state value has been obtained (small fluctuations of the order of ± 0.1 K may occur) this value should be noted for future reference and act as an early warning of some change. In particular users should ensure that the control thermocouples which should be situated behind and touching the heater helix (i.e. the face remote from the specimen) do not penetrate the heater helix and experience the temperature of the flame rather than that of the heater winding.

Table 1 — Frequency of various calibration procedures

Equipment item	Prior to run	Daily	Weekly	Monthly	Six-monthly
Drying/CO ₂ removal columns	Check unused portion is sufficient ^a				
Oxygen analyser	Span	Pressure/zero			Check analyser flow rates
Main filter	Replace				
Load cell	Check loading is acceptable Tare and weight	Calibrate			Damping adjustment
Irradiance	Check temperature	Check heat flux level ^b		Check heat flux-temperature relationship Calibrate marking heat flux meter versus reference heat flux meter	
CO/CO ₂		Set zero, calibrate span			
Methane		Calibrate using 5 kW burn		Calibrate using 10 kW burn	
Laser smoke photometer	Check adjustment	Check response with filter		Set zero	
Differential pressure transducer		Set zero			Check calibration
PMMA burn			Burn reference PMMA and compare performance against library data		

^a Always before spanning the oxygen analyser.
^b Also when required to change irradiance level.

6.4 Oxygen analyser calibration

Few problems should be encountered when carrying out the calibration of the oxygen analyser. When running the “zero” check using pure nitrogen with analysers equipped to measure pressure in the sensor cell, it has been found easier to set the nitrogen flow using the analyser pressure reading. The nitrogen flow is adjusted until the pressure reading is the same as when the analyser is pulling from the atmosphere.

The oxygen analyser delay time should be determined from time to time (recommended frequency, once every three months) as set out in BS 476-15:1993, 10.2.2. It should be remembered that because of the time offset, the amount of valid data collected will be less than the total test time by the extent of the delay time. Thus testing should continue for at least 2 min after the last point of interest.

6.5 Determining orifice plate calibration factor

6.5.1 Calibration using methane

It is recommended that the methane burn is carried out when the heater has been set at the required heat flux. This allows the differential pressure transducer (DPT) to warm up. The fan is shut down and the DPT is re-adjusted to zero. The fan is then set to the required air flow and the methane burn is carried out.

BS 476-15:1993 requires one 5 kW burn at the start of each day. An orifice constant between 0.040 and 0.046 should be obtained with 99.9 % or 99.5 % methane at a flow rate of 8.45 l/min 6 g/s. Daily calibration factors should agree within approximately ± 1 % accuracy. If daily calibration factors disagree by more than 5 %, the calorimeter should not be used and a full recalibration should be carried out.



It is to be clearly understood that the methane burn does not constitute an absolute calibration of the instrument, but rather that it checks the orifice plate constant, which appears in the calculations [see equations (1) and (3) in BS 476-15:1993, 12.1]. It is not a direct measurement of heat release.

Black polymethylmethacrylate (PMMA), with a thickness of 6 mm or greater can also be used within each laboratory to check repeatability of the cone calorimeter performance.

For zeroing the DPT it should be ensured that the duct fan and any “decoupled” extractor system are switched off. Air should be prevented from flowing over the open end of the stack and across the orifice plate. If necessary a plastic bag or equivalent should be used to block the open end of the stack.

It is important to keep records of those values of X_{O_2} , T_e and p_d that lead to good calibration factors, which should also be noted every time the calibration is carried out. In this way any discrepancy is immediately identified and early correction can be carried out. These are a valuable guide to problem-solving.

6.5.2 Calibration using liquids

WARNING. When calibrating using liquids that have low fire points, it is essential that calibrations are done on a cold system (i.e. the cone heater is not powered). The liquid should be held in a stable vessel, and the vessel should be stably located under the cone before ignition of the liquid. The burning liquid should not be disturbed until it is all burnt.

In addition to the methane burn, users have used a variety of materials such as alcohol. The heats of combustion of ethanol and propan-2-ol are 26.8 kJ/g and 30.2 kJ/g, respectively. It is desirable to use propan-2-ol with a purity of 99.5 % or better.

6.6 Load cell calibration

The load cell calibration is simple and generally problem free. The manufacturer’s instructions or recommendations on tarring, calibrating and setting the damping of the load cell should be followed.

6.7 Additional comments on the orifice calibration factor

Some variation of the orifice plate calibration factor (also known as the methane calibration factor) may be observed for various reasons. However, any large ($\pm 5\%$) changes in values is indicative of malfunction in the system. In the majority of cases the problem is caused by leaks in the sampling lines, in which case the recorded factor will be higher than usual. Other items that can cause problems are: blockages in the gas sampling line, the connections between the orifice plate and the differential pressure transducer, leaks at the methane supply line, a faulty differential pressure transducer or a faulty methane flow meter. The most common cause for this is some leakage in the system. However, in one instance a user encountered low values of the order of -5% and, after extensive testing which indicated that no leaks

were present in the system and that everything else was functioning correctly, the refrigeration system was suspected as causing the fault. The refrigeration system was flushed with propanone and, since the effluent was heavily discoloured, it was thought that the instability was related to a severely clogged refrigeration column. Subsequent recalibration gave a satisfactory calibration factor.

6.8 Calibration of smoke measurement system

Calibration using filters assumes that the system used to calibrate the filter is superior to the optical system in the cone calorimeter. The photodiodes used in the cone calorimeter specify a high degree of linearity. The optical density quoted for a commercially supplied filter is usually the average over a range of wavelengths, and the value at the frequency of the monochromatic laser used in the cone may not be this average value. Therefore the use of the filter is better confined to use as a daily checking routine for the functionality of the system rather than as a primary calibration method.

The user may therefore calibrate by checking zero and 100 % values and utilizing the linearity of the photodiode.

If filters calibrated at the correct wavelength are used, the following routine may be followed. The smoke measurement system should be checked weekly using neutral density glass filters of 0.3 nominal optical density. This procedure assumes that the smoke system is the conventional split beam laser described in ASTM E 1354.

Place the filter in the beam between the duct and the detector. Collect data for a period of 60 s. The measured calibration extinction coefficient, k_1 , is obtained from the equation:

$$k_1 = \ln(I_0/I)/d \quad (1)$$

The correct k value, k_2 , is given by the equation:

$$k_2 = (2.303D')/d \quad (2)$$

A correction factor, f , is calculated from these two k values and is used to correct all subsequent measured k values:

$$f = k_2/k_1 \quad (3)$$

thus

$$k = k_m f \quad (4)$$

where

k is the corrected value;

k_m is the measured value.

Where a calibration factor, F , is used it is calculated as follows:

$$F = f/d \quad (5)$$

and subsequent k values are calculated using the equation:

$$k = \{\ln(I_0/I)\}F \quad (6)$$

The filter used should be of the doped type because coated filters can give rise to interference effects with laser light and can deteriorate with time. The filter should have a reliable calibration covering the wavelength of the measurement.