UPHOLSTERED FURNITURE:
BURNING BEHAVIOUR - FULL SCALE TEST

Key words: upholstered furniture - fire, full scale fire test, rate of heat release, smoke production, fire test

0. INTRODUCTION

0.1 Users of this test method should observe the following warning:

SAFETY WARNING - IN ORDER THAT SUITABLE PRE-
CAUTIONS MAY BE TAKEN TO SAFEGUARD HEALTH, THE
ATTENTION OF ALL ENGAGED IN FIRE TESTS IS DRAWN
TO THE POSSIBILITY THAT TOXIC OR HARMFUL GASES
MAY BE EVOLVED DURING COMBUSTION OF TEST SPE-
CIMENS.

1. SCOPE AND FIELD OF APPLICATION

1.1 This method is intended to be used for the evaluation of fire behaviour of upholstered furniture in full scale. The specimen is ignited by a specified ignition source and burns freely under well ventilated conditions.

1.2 Data describing the burning behaviour from ignition to complete burn out is obtained.

1.2.1 The rate of heat release of the burning specimen is measured by an oxygen consumption technique.

1.2.2 The production of light obstructing smoke is measured.

1.2.3 The burning behaviour is visually documented by photographic and/or video recordings.

1.2.4 The amount of certain toxic gas species in the combustion gases are analyzed.

2. REFERENCES

1. ISO 3261 Fire tests - Vocabulary.

3. DEFINITIONS

For the purposes of this test method, the definitions given in ISO 3261 apply together with the following:

3.1 Product: The upholstered furniture about which information is required.

3.2 Specimen: A representative item of the product which is to be tested.

4. TEST PRINCIPLES

4.1 A piece of upholstered furniture, such as a sofa or a chair, is placed on a weighing platform. The platform is located under a hood that extracts all the combustion gases. There should be virtually no obstructions to the air supply to the test set-up. Probes for sampling of gas and for measurement of volume flow rate are placed in the exhaust duct leading from the hood. A photocell lamp system for measurement of light obscuration is installed across the exhaust duct.

4.2 The specimen is ignited with a wooden crib. During the test, concentrations of carbon monoxide, carbon dioxide and oxygen, light obscuration by the smoke and volume flow rate are measured in the exhaust duct. Mass loss rate of the burning sample is measured by means of a weight measuring device.

From these measurements the rates of heat release, the production of gas species and light obstructing smoke are calculated.

These values together with visual recordings constitute the results from the test.

The general test set-up is shown in Fig. 1.
5. IGNITION SOURCE

5.1 Standard ignition source

5.1.1 The ignition source is a wooden crib according to British Standard BS 5852: Part 2: 1982, crib ignition source no. 7. [2]

5.1.2 The following are required for the construction and ignition of the crib.

a) Seasoned and planed wood of the softwood Pinus silvestris having a moisture content of maximum 13 %.

b) BPC grade absorbent surgical lint, approximately 200 g m\(^{-2}\), which is cut into squares 40 mm x 40 mm.

c) Polyvinyl acetate (PVAc) or other suitable wood adhesive for gluing together the sticks and lint.

d) Propanol (1.4 ± 0.1 ml per crib).

e) Graduated glass syringe or other suitable measuring instrument capable of measuring 1.4 ± 0.1 ml of propanol.

5.1.3 The crib parameters are specified in Table 1.

Table 1. Parameters of crib ignition source.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main crib stick length</td>
<td>80±2mm</td>
</tr>
<tr>
<td>Main crib stick square section</td>
<td>12.5±0.5 mm</td>
</tr>
<tr>
<td>Number of sticks main crib</td>
<td>18</td>
</tr>
<tr>
<td>Number of layers each of two sticks in main crib</td>
<td>9</td>
</tr>
<tr>
<td>Ignition crib base stick length</td>
<td>80±2mm</td>
</tr>
<tr>
<td>Ignition crib stick length</td>
<td>40±2mm</td>
</tr>
<tr>
<td>Square section of all sticks in the ignition crib</td>
<td>6.5±0.5 mm</td>
</tr>
<tr>
<td>Number of ignition crib base sticks</td>
<td>4</td>
</tr>
<tr>
<td>Number of ignition crib sticks</td>
<td>6</td>
</tr>
<tr>
<td>Number of layers each of two sticks in ignition crib</td>
<td>5</td>
</tr>
<tr>
<td>Total mass of main and ignition crib sticks</td>
<td>126±4g</td>
</tr>
<tr>
<td>Approximate lint dimensions</td>
<td>40 mm x 40 mm</td>
</tr>
</tbody>
</table>

5.1.4 The required number and sizes of sticks, conditioned as specified in 5.5, having the required total mass, are selected and assembled into a crib together with the square of lint, fluffy side uppermost when the crib is standing on its base. The sticks in each layer are parallel to one another and at right angles to the sticks in the adjacent layer. The sticks in each layer are placed as far away from each other as possible to form a square-sectioned crib but without any undue overhang at their ends.

5.1.5 The assembly of the crib is shown in figures 2A and 2B.

Glue together 16 of the main crib sticks to form the main crib body to make construction A. Glue together the six ignition crib sticks plus two of the ignition crib base sticks to form the...
ignition crib body: stick one square of lint across the ignition crib square section and then glue on the remaining two ignition crib base sticks to form the ignition crib: glue on the remaining two main crib sticks to make construction B (Fig. 2A). When the adhesive is set, invert construction B and glue it to construction A (Fig. 2B).

5.1.6 Before the test the sticks and the cribs shall be conditioned for 72 h in indoor ambient conditions and then immediately before the test for at least 16 h in an atmosphere having a temperature of 20 ± 5 °C and a relative humidity of (50 ± 20) %.

5.2 Alternative ignition source

5.2.1 The wooden crib corresponds to the burning of sheets of newspaper laying in a sofa, see reference [2]. However, there might be cases were other ignition sources are more relevant to study; for example the paper cushion for fire testing of seats in rail vehicles; UIC Instruction Sheet 564.2 VE, Appendix III, Method A.

5.2.2 For those cases an appropriate ignition source can be chosen. However, this shall be clearly stated in the test report together with a detailed description of the chosen ignition source.

6. WEIGHING PLATFORM

6.1 A weighing platform shall be used to continuously measure the mass loss of the burning sample. The weighing platform shall consist of a slab placed on top of a weight measuring device.

6.2 The slab shall have the dimensions 1.2 m x 2.4 m and be of a noncombustible material, e.g. calcium silicate boards. The boundary shall have a frame of 10 cm height in order to prevent melting or falling material from the tested sample to fall off the slab.

6.3 The weight measuring device, e.g. load cells, shall measure the specimen mass with an accuracy of at least ±150 g up to at least 90 kg of specimen mass. It shall be installed in such a way that the heat from the burning sample and any eccentricity of the load is not affecting the accuracy. Care should be taken to avoid range shifts during measurements. All parts of the weight measuring device should be below the top level of the slab.

6.4 The distance from the upper surface of the slab to floor level shall not exceed 0.5 m. The area between the slab and the floor level shall be shielded in order to avoid lifting forces due to fire endured air flow that could influence the measurement.

7. HOOD AND EXHAUST DUCT

The system for collecting the combustion products shall have a capacity and be designed in such a way that all of the combustion products leaving the burning specimen are collected. There must not be any leakage of flames or smoke. The system shall not disturb the fire endured flow. The exhaust capacity shall be at least 3.5 m³ s⁻¹ at normal pressure and at a temperature of 25 °C. Exhaust system design based on natural convection is not permitted.

A design example of a hood and an exhaust duct is given in Annex A.

8. INSTRUMENTATION IN THE EXHAUST DUCT

The following specifications are minimum requirements. Additional information and technical solutions can be found in Annex B.

8.1 Volume flow rate

8.1.1 Specification

The volume flow rate in the exhaust duct shall be measured with an accuracy of at least ±5 %.

The response time to a stepwise change of the duct flow rate shall be maximum one second at 90 % of the final value.

8.2 Gas analysis

8.2.1 Sampling line

The gas samples shall be taken in the exhaust duct at a position where the combustion products are uniformly mixed. The sampling line tubes shall be made of a material not influencing the concentration of the gas species to be analysed, see Annex B.

8.2.2 Oxygen analyser

The oxygen consumption shall be measured with an accuracy of at least ±0.01 percentage by volume oxygen. A suitable output range is 0-21 percentage by volume. The gas sample shall be taken from the end of the sampling line from where the time delay including the time constant of the instrument shall be maximum 20 seconds. (See Annex B).

Tests may also be performed without measuring carbon monoxide.

8.2.3 Carbon monoxide and carbon dioxide analyser

The gas species shall be measured with an instrument having an accuracy of at least ±0.1 percentage by volume for carbon dioxide and ±0.02 percentage by volume for carbon monoxide. A suitable output range is 0-1 % for carbon monoxide and 0-6 % for carbon dioxide. The gas sample shall be taken from the end of the sampling line from where the time delay, including the time constant of the instrument, shall be maximum 20 seconds. (See Annex B). Tests may also be performed without measuring carbon monoxide.

8.3 Optical density

The optical density of the smoke is determined by measuring the light absorption with a system consisting of a lamp, lenses, an aperture and a photocell, see Fig. 3. The system shall be
constructed so that soot deposits during a test do not reduce the light transmission by more than 5 %. (See Annex B).

8.3.1 Lamp
The lamp shall be of the incandescent filament type and operate at a colour temperature of 2900 ± 100 K. The lamp shall be supplied with stabilized direct current, stable within ±0.2 % (including temperature, short-term and long-term stability).

8.3.2 Lenses
The lens system shall align the light to a parallel beam with a diameter of at least 20 mm.

8.3.3 Aperture
The aperture shall be placed in the focus of the lens L2 according to Fig. 3 and it shall have a diameter, d, chosen with regard to the focal length, f, of L2 so that d/f ≤ 0.04.

8.3.4 Detector
The detector shall have a spectrally distributed responsivity according to the CIE V(λ)-function (the CIE photopic curve). The detector shall be linear within 5 % over an output range of at least 3.5 decades.

9. CALIBRATION

9.1 A calibration test according to paragraphs 9.2 and 9.3 shall be performed prior to each test or continuous test series. Paragraphs 9.4 and 9.5 refer to a basic calibration to be performed on a new system, when modifications are introduced or at any other occasion when required. Equations for calculations are given in Annex C.

9.2 The calibration of the instrumentation in the exhaust duct shall be performed by the burning of propane gas and comparing the heat release rates calculated from the metered gas input and the measured oxygen consumption. A suitable burner is a pipe, which is supplied with gas from beneath. The inner diameter of the pipe should be 100 mm. The burner flame shall not be premixed with air. The propane shall be of at least 95 % purity. The gas flow to the burner shall be measured with an accuracy of at least ±3 %. The burner shall be positioned directly under the hood. The heat output shall be 300 kW.

Measurements are taken at least every 6th second and shall be started one minute prior to ignition of the burner. The difference between the time average value, measured over a period of one minute of the rate of heat release and calculated from the measured oxygen consumption and the rate of heat release calculated from the metered gas input must not exceed 5 %. These measurements should only be made when steady state conditions have been reached.

9.3 Calibration of the weight measuring device shall be performed by loading the weighing platform with known masses corresponding to the measuring range of interest, to ensure that the requirements of accuracy in paragraph 6.3 are fulfilled.

9.4 In order to minimize the errors due to time delays in the gas analysis system the delay times shall be established by the following test sequence:

<table>
<thead>
<tr>
<th>Time</th>
<th>Burner output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2 minutes</td>
<td>0 kW</td>
</tr>
<tr>
<td>2–7 minutes</td>
<td>300 kW</td>
</tr>
<tr>
<td>7–9 minutes</td>
<td>0 kW</td>
</tr>
</tbody>
</table>

The stepwise changes of the burner heat output shall be completed within the same time period as the time period between two scans of the data acquisition system. Measure the time delay from the moment the burner output is changed from 0 kW to 300 kW to when the analysers start to respond. The time delay shall be maximum 20 seconds. Note that the time delay for the oxygen analyser in most cases differ from that of the CO and CO2 analyser. The time delays for the different gas analysers shall be introduced in the heat release calculations as a time shift between volume flow and gas concentrations.

9.5 The precision of the system at various volume flow rates is checked by increasing the volume flow in the exhaust duct in four steps, starting from 2 m³ s⁻¹ (at 0.1 MPa and 25 °C) up to maximum. The heat output from the burner shall be 300 kW. The drift, in rate of heat release, comparing time average values over one minute, shall not be more than 10 % of the actual heat output from the burner.

10. PREPARATION OF TEST SPECIMENS

10.1 Full size items of upholstered furniture for seating (sofas, chairs) shall be tested as they appear in reality. Sofas shall normally be tested in a version having three seats.
10.2 If comparative testing of only cushion material (filling covered with fabric) is required, then a sofa mock-up consisting of a metal frame, three seat cushions, three back cushions and two arm rest cushions shall be used. Details of the sofa mock-up is given in Annex D.

10.3 Prior to testing, the product shall be conditioned for at least two weeks in an atmosphere having a temperature of 20 ± 5 °C and a relative humidity of (50 ± 5) %.

11. TESTING

11.1 Initial conditions

11.1.1 The ambient temperature shall be 20 ± 5 °C.

11.1.2 The horizontal wind draught measured at a distance of 0.5 m from the boundary of the weighing platform in level with the slab shall not exceed 0.5 m s⁻¹.

11.1.3 The product to be tested shall be positioned centrally on the weighing platform.

11.1.4 The product shall be photographed before testing.

11.1.5 Means for extinguishing a fully developed fire shall be available.

11.2 Procedure

11.2.1 All recording and measuring devices shall be started and data taken at least two minutes prior to the test. Measurements are taken at least every 5th second.

11.2.2 Slowly add 1.4 ± 0.1 ml of propanol to the centre of the lint in the wood crib.

11.2.3 Place the wood crib at one end of the tested item on the seat cushion and in contact with the back cushion and the arm rest cushion.

11.2.4 If the product lacks arm rest cushions, then place the wood crib on the centerline of the middle seat cushion in contact with the back cushion.

11.2.5 If the conditions of 11.2.3 and 11.2.4 cannot be fulfilled, then place the wood crib at the center of the middle seat cushion.

11.2.6 Within two minutes of adding the alcohol, ignite it from the front and above the lint using a small flame.

11.2.7 The test starts and the clock shall be started when the crib is ignited. The exhaust capacity shall always be adjusted in order to collect all the combustion products, but may not be too high as that would decrease the level of accuracy of the measurements.

11.2.8 A photographic and/or a video recording shall be performed during a test. A clock shall appear in all photographic records, giving time to the nearest one second. During a test records of the following events including times when they occur shall be taken:

- ignition of the product
- position of flame front
- melting and dripping
- occurrence of pool fire under the product
- general description of the burning behaviour
- any other event of special interest

11.2.9 The test is terminated after the burning has ceased.

11.2.10 When appropriate, the extent of damage to the product is noted after the test.

12. TEST REPORT

The test report shall contain the following information:

a) Name and address of the testing laboratory
b) Date and identification number of the report
c) Name and address of the client
d) Purpose of the test
e) Method of sampling
f) Name of manufacturer or supplier of the product
g) Name or other identification marks and description of the product
h) Density or weight per square unit and thickness of the main components in the product
i) Description of the specimens
j) Conditioning of the specimens
k) Date of test
l) Test method
m) Test results (see also Annex C)
   m:1 Time - mass burning rate
   m:2 Time - total rate of heat release
   m:3 Time - production rate of carbon monoxide
   m:4 Time - production rate of carbon dioxide
   m:5 Time - production rate of light obstructing smoke
   m:6 Time - massflow in the exhaust duct
   m:7 Description of the fire development (photographs)
   m:8 Calibration results according to paragraph 9.2

When appropriate also:

m:9 Effective heat of combustion determined from the quotient between the measured rate of heat release and the mass burning rate
m:10 The production rates given in m:3 - m:5 normalized versus measured rate of heat release and measured mass burning rate

n) When appropriate: designation of the product according to criteria expressed in official standards or regulations

o) Deviations from the test method, if any
p) When not identified in the test method, equipment and instruments used.
DESIGN OF EXHAUST SYSTEM

A.1 Hood and exhaust duct, recommended design

A.1.1 The combustion gases from the burning specimen are collected by a hood. Below, a system is described which has been tested in practice and proved to fulfill the requirement specifications given in the method.

A.1.2 The hood is located centrally above the weighing platform. The bottom dimensions of the hood are 3 m x 3 m and the height 1.0 m, see Fig. A:1 and Fig. A:2. On four sides, steel sheets are extended 1.0 m downwards. The effective height of the hood will thus be 2 m, and the distance between the lower edge of the hood and the weighing platform should be 1.5-2 m. The hood feeds into a plenum having a cross section area of 0.9 m x 0.9 m and a height of 0.9 m.

In the plenum chamber two plates approximately 0.5 m x 0.9 m are located, see Fig. A:2, to increase mixing of the combustion gases.

A.1.3 An exhaust duct is connected with the plenum chamber. The rectilinear part of the exhaust duct must have such a length that a fully-developed flow profile is established at the point of measurement. For a 400 mm diameter exhaust duct the rectilinear part must be at least 4.8 m. The exhaust duct is connected to an evacuation system.

A.1.4 The capacity of the evacuation system shall be designed to exhaust minimally all combustion gases leaving the specimen. This requires an exhaust capacity of at least 4.0 kg s\(^{-1}\) (about 12000 m\(^3\) h\(^{-1}\) at standard atmospheric conditions) corresponding to a driving underpressure of about 2 kPa at the end of the duct. It shall be possible to control the exhaust flow from about 0.5 kg s\(^{-1}\) up to maximum flow as stated above during the test process. If the air flow is not decreased during the initial part of the test, the measurement precision will be too low.

A.1.5 An alternative exhaust system design may be used if it has been shown to produce equivalent results. Equivalency may be demonstrated by meeting the requirements under paragraph 9.

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Fig. A: 1. Design of hood and exhaust duct.
Fig. A:2. Details of exhaust system.
INSTRUMENTATION IN EXHAUST DUCT

B.0 Suitable locations for the probes described below are shown in Fig. B:1.

B.1 Volume flow
B.1.1 The flow may be measured by a bidirectional probe located at the centre line of the duct. The probe shown in Fig. B.2 consists of a stainless steel cylinder, 32 mm long and with an inner diameter of 14 mm. The cylinder has a massive wall in the centre, dividing it into two chambers. The pressure difference between the two chambers is measured by a pressure transducer.

B.1.2 The pressure transducer shall have an accuracy of at least ±5 Pa and be of the capacitance type. A suitable range of measurement is 0-2000 Pa.

B.1.3 Gas temperature in the immediate vicinity of the probe is measured by a thermocouple with a diameter of maximum 0.25 mm. The thermocouple shall not be allowed to disturb the flow pattern around the bidirectional probe.

B.2 Sampling line
B.2.1 The sampling probe shall be located where the exhaust duct flow is well mixed, see Fig. B:1. The probe shall have a cylindrical form so that disturbance of flow is minimized. The gas samples shall be taken along the whole diameter of the exhaust duct. The intake of the sampling probe is turned downstream in order to avoid soot clogging in the probe. A suitable sampling probe is shown in Fig. B:3.

B.2.2 The sampling line, see Fig. B:4, shall be manufactured from noncorrosive material. The combustion gases shall be filtered with inert filters to protect the gas analysis equipment from soot, etc. The filtering procedure should be carried out in more than one step. The gas mixture shall be cooled to trap out the water vapour and the gas samples taken to each analyzer shall be completely dried.

B.2.3 The combustion gas is transported by a pump which does not emit oil, grease or similar products, which can contaminate the gas mixture. A membrane pump is suitable.

B.2.4 The sampling line may end in an open container with atmospheric pressure. The volume of the container shall not be so large that concentration gradients or time lags are generated. Transport time in the sampling line shall be ≤5 s.

B.2.5 A suitable pump shall have the capacity of 10-50 I min⁻¹, as each gas analysis instrument consumes about 1 I min⁻¹. The pump shall generate a pressure differential of at least 10 kPa to reduce the risk of smoke clogging of the filters.

B.3 Combustion gas analysis
B.3.1 Oxygen concentration
An oxygen analyser, corresponding to the specifications under paragraph 8.2.2, should preferably be of the paramagnetic type, e.g. Siemens Oxymat 2. In case a high temperature cell is chosen, the combustion gases must be very carefully filtered, as afterburning in the cell can affect the measurements. The result of the analysis will therefore depend on the degree of filtration.

B.3.2 Carbon monoxide and dioxide concentration
Suitable analysers are of the type IR-spectrometers.

B.3.3 Other gases
For special purposes other gases may be analysed, e.g. total hydrocarbon or nitrogen oxide concentrations.

B.4 Optical density
A suitable light measuring system may have the following components:

Lenses: Plane convex: diameter 40 mm, focal length 50 mm.

Lamp: Osram halo stars: 64410: 6 V, 10 W.

Photocell: United Detector Technology: PIN 10 AP.

Voltage supply: Gresham Lion Ltd: GX 012.

The photocell shall give a minimum resolution of 3.5 decades. Lenses, lamp and photocell are mounted inside two housings, located on the exhaust duct diametrically opposite each other. The system shall be self-cleansing from soot deposits, which may be achieved by having holes in the periphery of the two housings.
Fig. B.1. Location of the sampling probe for gas analysis, the temperature and pressure meters and the photocell system in the exhaust duct.

Fig. B.2. Bidirectional probe for measuring the differential pressure in the exhaust duct (From Combustion and Flame 26, pp. 125-127 (1976) McCaffrey and Heskestad).

Fig. B.3. The sampling probe.

Fig. B.4. Principle of the sampling line with gas analysis equipment.
CALCULATION EQUATIONS

C.1 Volume flow

For the instrumentation described under paragraph B.1 the volume flow \( \dot{V}_{298} \) (m\(^3\) s\(^{-1}\)) in the exhaust duct, related to atmospheric pressure and an ambient temperature of 25 °C is given by the relation

\[
\dot{V}_{298} = \frac{A_k}{k_p} \cdot \frac{1}{\rho_{298}} \cdot \sqrt{\frac{2\Delta p T_0 p_0}{T_s}} = 22.4 \frac{A_k}{k_p} \cdot \sqrt{\frac{\Delta p}{T_s}}
\]

where

- \( T_s \) = gas temperature in the exhaust duct, K.
- \( \Delta p \) = pressure difference measured by the bidirectional probe, Pa.
- \( A \) = cross section area of exhaust duct.
- \( k_t \) = ratio of the average mass flow per unit area to mass flow per unit area in the centre of the exhaust duct.
- \( k_p \) = calibration constant of bidirectional probe (= 1.08).

The equation assumes that density changes in the combustion gases (related to air) are caused solely by the temperature increase. Corrections due to a changed chemical composition or humidity content may be neglected except in studies of an extinguishment process with water. The calibration constant \( k_t \) is determined by measuring the temperature and flow profile inside the exhaust duct along a cross sectional diameter. Several series of measurements are to be made with representative mass flows and with both warm and cold gas flows. The \( k_t \) factor is to be determined with a maximum error of ±3 %.

C.2 Generated heat effect, calibration and test process

C.2.1 During the calibration process the rate of heat release from the ignition source is calculated from the consumption of propane gas according to the relation

\[
\dot{Q}_b = m_l \Delta h_{c,eff}
\]

where

- \( \dot{Q}_b \) = rate of heat release from the burner, kW.
- \( m_l \) = rate of gas consumption, g s\(^{-1}\).
- \( \Delta h_{c,eff} \) = effective heat of combustion of propane ~46.4 kJ g\(^{-1}\).

C.2.2 The rate of heat release is calculated according to the equation

\[
\dot{Q} = E \dot{V}_{298} \frac{X_{O_2}^a (1 - X_{CO_2}) - X_{O_2} (1 - X_{CO_2})}{X_{O_2}^a (1 - X_{O_2} - X_{O_2})}
\]

\( \Phi \) is the oxygen depletion factor:

\[
\Phi = \frac{X_{O_2}^a (1 - X_{CO_2}) - X_{O_2} (1 - X_{CO_2})}{X_{O_2}^a (1 - X_{O_2} - X_{O_2})}
\]

The ambient mole fraction of oxygen is:

\[
X_{O_2}^a = X_{O_2} (1 - X_{H_2}O)
\]

\( X_{O_2}^a \) should be measured prior to test without trapping of water.

Symbols:

- \( \dot{Q} \) = rate of heat release for complete combustion, kW.
- \( E \) = heat release per volume of oxygen consumed.
- \( E = 17.2 \cdot 10^3 \text{ kJ m}^{-3} (25 \text{ °C}) \) for combustion of tested product.
- \( E_{C_3H_8} = 16.8 \cdot 10^3 \text{ kJ m}^{-3} (25 \text{ °C}) \) for combustion of propane. This value is used for calibration.
- \( \dot{V}_{298} \) = rate of volume flow in exhaust duct at atmospheric pressure and 25 °C according to paragraph C.1, m\(^3\) s\(^{-1}\).
- \( \alpha \) = expansion factor due to chemical reaction of the air that is depleted of its oxygen.
- \( \alpha = 1 .105 \) for combustion of tested product.
- \( X_{O_2}^a \) = ambient mole fraction of oxygen including water vapour.
- \( X_{O_2}^i \) = initial value of oxygen analyser reading, mole fraction.
- \( X_{O_2} \) = oxygen analyser reading during test, mole fraction.
- \( X_{CO_2}^i \) = initial value of carbon dioxide analyser reading including ambient air content, mole fraction.
- \( X_{CO_2} \) = carbon dioxide analyser reading during test, mole fraction.
- \( X_{H_2}O \) = ambient mole fraction of water vapour.

C.2.3 The relations above are based on certain approximations leading to the following limitations.

- No reference is made to the amount CO generated. Normally, the error is negligible. As concentration of CO is measured, corrections can be calculated in those cases where the influence of incomplete combustion may have to be quantified.
- The influence of water vapour on measurements of flow and gas analysis is only partially taken into consideration. A better correction for this error can only be obtained by a continuous measurement of partial pressure of water vapour.
- The factor \( E = 17.2 \text{ MJ m}^{-3} \) (or 13.1 kJ g\(^{-1}\)) is an average value for a large number of products and gives an acceptable accuracy in most cases. It should be used unless a
more accurate value is known. As demonstrated in Fig. C:1 there are certain exceptions.

The accumulated corrections of the error sources enumerated above should normally be less than 10%.

C.3 Combustion gases

By measuring the partial pressure of a specified gas it is possible to calculate the instantaneous rate of gas production \( V_{\text{gas}} \) (m\(^3\) s\(^{-1}\)) and the total amount of gas production \( V_{\text{gas}} \) (m\(^3\)).

\[
\dot{V}_{\text{gas}} = \dot{V}_{298} X^A
\]

\[
V_{\text{gas}} = \int_0^t \dot{V}_{\text{gas}} dt
\]

where

\( V_{\text{gas}} \) = rate of gas production (m\(^3\) s\(^{-1}\) at standard conditions)

\( V_{\text{gas}} \) = total volume of gas production (m\(^3\) at standard conditions).

\( \dot{V}_{298} \) = rate of volume flow in exhaust duct (m\(^3\) s\(^{-1}\) at standard conditions).

\( X^A \) = mole fraction of specified gas in the analyser.

\( t \) = time from ignition.

C.4 Light obscuration

Optical density is defined according to

\[
D = (10/L) \log (I_0/I)
\]

where

\( D \) = optical density, dB m\(^{-1}\).

\( I_0 \) = the light intensity of a beam of parallel light rays measured in a smoke free environment with a detector having the same spectral sensitivity as the human eye.

\( I \) = the light intensity of a parallel light beam having traversed a certain length of smoky environment.

\( L \) = length of beam through smoky environment, m.

From this equation, the instantaneous rate of smoke production \( R_{\text{inst}} \) (m\(^2\) s\(^{-1}\)) and total amount of smoke production \( R_{\text{tot}} \) (m\(^2\)) are calculated.

\[
R_{\text{inst}} = D_I \dot{V}_S
\]

\[
R_{\text{tot}} = \int_0^t D_I \dot{V}_S dt
\]

where

\( \dot{V}_S \) = volume flow in exhaust duct at actual temperature, m\(^3\) s\(^{-1}\).

\( t \) = time from ignition, seconds.

---

Table 2. Heats of combustion and heats of combustion per gram of oxygen consumed for typical synthetic polymers

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Formula</th>
<th>kJ g(^{-1})</th>
<th>kJ g(^{-1}) O(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>((-C_2H_4-)) n</td>
<td>-43.28</td>
<td>-12.65</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>((-C_3H_6-)) n</td>
<td>-43.31</td>
<td>-12.66</td>
</tr>
<tr>
<td>Polysaccharide</td>
<td>((-C_4H_8-)) n</td>
<td>-43.71</td>
<td>-12.77</td>
</tr>
<tr>
<td>Polybutadiene</td>
<td>((-C_5H_10-)) n</td>
<td>-42.75</td>
<td>-13.14</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>((-C_6H_10-)) n</td>
<td>-39.85</td>
<td>-12.97</td>
</tr>
<tr>
<td>Polymethylchloride</td>
<td>((-C_7H_14Cl-) n</td>
<td>-16.43</td>
<td>-12.94</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>((-C_7H_14Cl-) n</td>
<td>-8.99</td>
<td>-13.61</td>
</tr>
<tr>
<td>Polymethylchloride</td>
<td>((-C_8H_18Cl-) n</td>
<td>-13.32</td>
<td>-13.32</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>((-C_9H_18O_2-) n</td>
<td>-24.89</td>
<td>-12.98</td>
</tr>
<tr>
<td>Polycrylonitrile</td>
<td>((-C_9H_9N-) n</td>
<td>-30.80</td>
<td>-13.61</td>
</tr>
<tr>
<td>Polycrylonitrile</td>
<td>((-C_9H_9N-) n</td>
<td>-15.46</td>
<td>-14.50</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>((-C_9H_9O_2-) n</td>
<td>-22.00</td>
<td>-13.21</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>((-C_8H_16O_2-) n</td>
<td>-29.72</td>
<td>-13.12</td>
</tr>
<tr>
<td>Cellulose tricarboxylic acid</td>
<td>((-C_9H_9O_2-) n</td>
<td>-17.62</td>
<td>-13.23</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>((-C_9H_9O_2-) n</td>
<td>-29.58</td>
<td>-12.67</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>((-C_9H_9O_2-) n</td>
<td>-20.12</td>
<td>-12.59</td>
</tr>
</tbody>
</table>

Unweighted average -13.02

Thermodynamic data from Refs. 3, 4 and 5. Reactants and products at 25 °C. Fuels are solids, all products are gaseous.

a Omitted from average.

Table 3. Heats of combustion and heats of combustion per gram of oxygen consumed for selected natural fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>kJ g(^{-1})</th>
<th>kJ g(^{-1}) O(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>-16.09</td>
<td>-13.59</td>
</tr>
<tr>
<td>Cotton</td>
<td>-15.55</td>
<td>-13.61</td>
</tr>
<tr>
<td>Newsprint</td>
<td>-18.40</td>
<td>-13.40</td>
</tr>
<tr>
<td>Corrugated box</td>
<td>-16.04</td>
<td>-13.70</td>
</tr>
<tr>
<td>Leaves, hardwood</td>
<td>-19.30</td>
<td>-12.28</td>
</tr>
<tr>
<td>Wood, maple</td>
<td>-17.76</td>
<td>-12.51</td>
</tr>
<tr>
<td>Lignite</td>
<td>-24.78</td>
<td>-13.12</td>
</tr>
<tr>
<td>Coal, bituminous</td>
<td>-35.17</td>
<td>-13.51</td>
</tr>
</tbody>
</table>

Unweighted average -13.21

Thermodynamic data from Ref. 6. Reactants and products at 25 °C, fuels solid, all products gaseous.

Fig. C:1. (From Huggett, C: 'Estimation of Rate of Heat Release by Means of Oxygen Consumption Measurements', Fire and Materials, Vol. 4, No. 2, 1980).
DESIGN OF SOFA MOCK-UP

D.1 The sofa mock-up shall consist of a metal frame on which three seat cushions, three back cushions and two arm rest cushions are placed.

D.2 The frame shall have a total length of 1.9 m, a width of 0.5 m and an over-all height of 0.8 m, see Fig. D:1 a-e.

The frame should be made of square steel bars. The bottom of the frame shall be covered with a wire net having 45 ± 5 mm mesh size.

D.3 The cushions shall consist of filling material, interliner, if any, and fabric.

The material properties of the cushions will determine the burning behaviour of the mock-up. The way of making them will, however, have a significant effect and they shall therefore as far as possible be made up as they appear in practice.

D.4 The seat cushions shall be 650 mm x 550 mm, the back cushions 420 mm x 550 mm and the arm rest cushions 650 mm x 250 mm. The thickness of the cushions may vary due to type of filling, presence of interliner and type of fabric, but is normally 10-15 cm.

The given cushion sizes are nominal for 10 mm foam thickness and may have to be slightly adjusted to fit a given test set-up. The locations of the cushions are shown in Fig. D:2, a-b.

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c) Arm rests.

d) Side view of assembled sofa frame.

e) Front view of assembled sofa frame.
a) Front view.

b) Side view (the arm rest of the steel frame not shown).

Fig. D.2 a-b. Position of cushions.