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Reaction to fire tests — Measurement of material properties using a fire propagation apparatus

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National foreword

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Reaction to fire tests — Measurement of material properties using a fire propagation apparatus

Essais de réaction au feu — Mesurage des propriétés des matériaux au moyen d'un appareillage de propagation du feu

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12136 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

Introduction

This International Standard contains four separate test methods[3][4][5][12], which are conducted using a fire propagation apparatus (FPA). The ignition, combustion and pyrolysis test methods involve the use of horizontal specimens subjected to a controlled, external radiant heat flux, which can be set from 0 kW/m^2 to 65 kW/m^2. The fire propagation test method involves the use of vertical specimens subjected to ignition near the base of the specimen from an external radiant heat flux and a pilot flame. The combustion, pyrolysis and fire propagation test methods can be performed using an inlet air supply that is either normal air or other gaseous mixtures, such as air with added nitrogen, 100 % nitrogen or air enriched with up to 40 % oxygen.

The ignition test method is used to determine the time required for ignition, t_{ign}, of horizontal specimens by a pilot flame as a function of the magnitude of a constant, externally applied radiant heat flux. Measurements also are made of time required until initial fuel vaporization. The surface of these specimens is coated with a thin layer of black paint to ensure complete absorption of the radiant heat flux from the infrared heating system (note that the coating does not itself undergo sustained flaming).

The combustion test method is used to determine the chemical and convective heat release rates, and smoke generation rate when the horizontal test specimen is exposed to an external radiant heat flux.

The pyrolysis test method with a flow of 100 % nitrogen and no ignition can be used to measure the mass loss rate as a function of externally applied radiant heat flux for a horizontal specimen. From these measurements, the heat of gasification of the material can be determined.

The fire propagation test method using 40 % oxygen is used to determine the chemical heat release rate of a burning, vertical specimen during upward fire propagation and burning initiated by a heat flux near the base of the specimen. Chemical heat release rate is derived from the release rates of carbon dioxide and carbon monoxide. Observations also are made of the flame height on the vertical specimen during fire propagation. As discussed in B.5 and B.6, the use of enhanced oxygen in small-scale fire tests can better simulate the flame heat flux occurring in large-scale fires[16][18][19][20][21]. Correlation has been developed between the results from small-scale tests with 40 % oxygen and the results from large-scale tests for a class of materials (see B.6).

Distinguishing features of the FPA include:

- tungsten-quartz external, isolated heaters to provide a radiant flux of up to 65 kW/m^2 to the test specimen, which remains constant whether the surface regresses or expands;
- provision for combustion or upward fire propagation in prescribed flows of normal air, air enriched with up to 40 % oxygen, air oxygen vitiated, pure nitrogen or mixtures of gaseous suppression agents with the preceding air mixtures;
- the capability of measuring heat release rates and exhaust product flows generated during upward fire propagation on a vertical test specimen 0,305 m high.

The original FPA uses a vertical exhaust duct configuration[6], which requires laboratories to have available a sufficient ceiling height to accommodate all the system components. Also, the original FPA has the gas sampling and analysis system completely separate from the main apparatus. To reduce this ceiling height constraint and to allow for a more compact arrangement, a horizontal exhaust configuration has been developed as shown in Figures 1 and 2. The FPA with horizontal duct provides equivalent results to those measured using the FPA with vertical duct, as described in Annex C.

The FPA is used to evaluate the flammability of materials and products. It is also designed to obtain the transient response of such materials and products to prescribed heat fluxes in specified inert or oxidizing environments and to obtain laboratory measurements of generation rates of fire products (CO_2, CO, and, if desired, gaseous hydrocarbons) for use in fire safety engineering.

Ignition of the specimen is by means of a pilot flame at a prescribed location with respect to the specimen surface [described in 11.1 e)].

The Fire Propagation test of vertical specimens is not suitable for materials that, on heating, melt sufficiently to form a liquid pool.

This International Standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this International Standard to establish appropriate health and safety practices and to determine the applicability of regulatory limitations prior to use. For specific hazard statements, see Clause 7.

This International Standard specifies small-scale test methods for determining the performance of materials when exposed to fire, which are based on decades of research published in the fire science literature. Parts of this International Standard are based on information contained in ASTM E2058 and NFPA 287.

The following test methods, capable of being performed separately and independently, are included:

1) Ignition test, to determine t_{ign} for a horizontal specimen;

2) Combustion test, to determine Q_{chem}, Q_{c}, $\dot{m}$, ΔH_{eff}, and Y_{s} from burning of a horizontal specimen;

3) Pyrolysis test, to determine $\dot{m}$ and ΔH_{g}; and,

4) Fire propagation test, to determine Q_{chem} from burning of a vertical specimen.

Reaction to fire tests — Measurement of material properties using a fire propagation apparatus

1 Scope

This International Standard determines and quantifies the flammability characteristics of materials, in relation to their propensity to support fire propagation, by means of a fire propagation apparatus (FPA). Material flammability characteristics that are quantified in this International Standard include time to ignition, chemical and convective heat release rates, mass loss rate, effective heat of combustion, heat of gasification and smoke yield. These properties can be used for fire safety engineering and for fire modelling.

2 Normative references

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

ISO 13943, *Fire safety — Vocabulary*

ISO 14934-3, *Fire tests — Calibration and use of heat flux meters — Part 3: Secondary calibration method*

3 Terms and definitions

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

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

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

3.3
ignition
sustained flaming on or over the surface of the specimen for periods of over 10 s

3.4
fire propagation
increase in the exposed surface area of the specimen that is actively involved in flaming combustion

3.5
smoke yield
mass of smoke particulates generated per unit mass of fuel vaporized

4 Symbols

A	Exposed surface area of specimen	m^2
A_d	Cross sectional area of test section duct	m^2
c_p	Specific heat of air at constant pressure	kJ/kg K
D	Optical density per unit length	m^{-1}
$\dot{D}_{\mathrm{o}_2}$	Consumption rate of O_2	kg/s
$\dot{G}_\mathrm{co}$	Mass flow rate of CO in test section duct	kg/s
$\dot{G}_{\mathrm{co}_2}$	Mass flow rate of CO_2 in test section duct	kg/s
$\dot{G}_\mathrm{j}$	Mass flow rate of compound j in test section duct	kg/s
ΔH_co	Heat of complete combustion per unit mass of CO	kJ/kg
ΔH_eff	Effective heat of combustion	kJ/kg
ΔH_g	Heat of gasification	kJ/kg
ΔH_T	Net heat of complete combustion per unit mass of fuel vaporized	kJ/kg
K	Flow coefficient of averaging Pitot tube [duct gas velocity/$(2\,\Delta P_\mathrm{m} / \rho)^{1/2}$]	–
k_{co_2}	Stoichiometric CO_2 to fuel mass ratio, for conversion of all fuel carbon to CO_2	–
k_co	Stoichiometric CO to fuel mass ratio, for conversion of all fuel carbon to CO	–
k_{o_2}	Stoichiometric ratio of mass of oxygen consumed to mass of fuel burned	–
L	Optical path length	m
M_loss	Total mass loss in combustion test method	k
M_s	Total smoke generation in combustion test method	kg
$\dot{m}$	Mass loss rate of test specimen	kg/s
$\dot{m}_\mathrm{s}$	Mass generation rate of smoke	kg/s
$\dot{m}_\mathrm{d}$	Mass flow rate of gaseous mixture in test section duct	kg/s
P_atm	Atmospheric pressure	Pa
ΔP_m	Pressure differential across averaging Pitot tube in test section duct	Pa
Q	Cumulative heat released during combustion test method	kJ

$\dot{Q}_{\text{chem}}$	Chemical heat release rate	kW
$\dot{Q}_{\text{c}}$	Convective heat release rate	kW
T_{a}	Gas temperature in test section duct before ignition	K
T_{d}	Gas temperature in test section duct	K
t	Time	s
t_{ign}	Ignition time	s
$\dot{v}$	Total volumetric flow rate in test section duct	m3/s
W	Width of a flat specimen or the circumference of a cable specimen	m
Y_{s}	Smoke yield	–
X_{co_2}	Mole fraction of carbon dioxide in test section duct	–
X_{co}	Mole fraction of carbon monoxide in test section duct	–
ρ	Gas density in test section duct	kg/m^3

5 Principle

The four test methods given in this International Standard are based on measurements of time to observed ignition, mass loss rate, heat release rate and smoke generation rate. The test methods are performed using a laboratory calorimeter known as fire propagation apparatus whereby the heat source is isolated from the test specimen. The test methods are intended to produce flammability property measurements that will characterize fire behaviour during reference-scale fire tests.

The ignition, combustion or fire propagation test methods, or a combination thereof, have been performed with materials and products containing a wide range of polymer compositions and structures, as described in B.7.

The unique feature of the fire propagation test method is that it produces laboratory measurements of the chemical heat release rate during upward fire propagation and burning (from a material's own flame after initiation by an external radiant flux) on a vertical test specimen in normal air, oxygen-enriched air, or in oxygen-vitiated air.

These test methods are intended for evaluation of specific flammability characteristics of materials. Materials to be analysed consist of specimens from an end-use product or the various components used in the end-use product. Results from the test methods provide input to flame spread and fire growth models, risk analysis studies, building and product designs and materials research and development.

This International Standard can be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products or assemblies under actual fire conditions. The sample size and amount should not exceed the measurement capacity of the apparatus. A sample that is explosive in nature should not be tested in the apparatus.

6 Apparatus

6.1 General

6.1.1 Dimensions

Where dimensions are stated in the text or in figures, they shall be followed within a tolerance of ±0,5 % typical and ±1 % maximum. An exception is the case of components which are intended to fit together, where the joint tolerance shall be appropriate for a sliding fit.

6.1.2 Components

The apparatus (see photograph and schematic in Figures 1 and 2 respectively, and exploded view in Figure 3) shall consist of the following components:

a) an infrared heating system;

b) a load cell system;

c) an ignition pilot flame and timer;

d) a product gas analysis system;

e) a laser smoke measuring system;

f) a combustion air distribution system;

g) a water-cooled shield;

h) an exhaust system;

i) measuring section instruments;

j) calibration instruments;

k) a digital data acquisition system.

6.2 Infrared (IR) heating system

The IR heating system[1)] shall consist of four 240 mm long, 81 mm high and 81 mm wide heaters (see different views in Figures 1 to 3) and a power controller.

Each of the four IR heaters shall contain six tungsten filament tubular quartz lamps (each 500 watts) in a compact reflector body that produces up to 510 kW/m^2 of radiant flux in front of the quartz window that covers the lamps. The reflector body is water cooled and the lamp chamber, between the quartz window and reflector, is air cooled for prolonged life. The emitter of each lamp is a 127 mm long tungsten filament in an argon atmosphere enclosed in a 9,5 mm outer diameter (o.d.) clear quartz tube. The emitter operates at approximately 2 205 °C (4 000 °F) at rated voltage, with a spectral energy peak at 1,15 µm. Wavelength greater than about 3,6 µm is absorbed by the quartz bulb envelope and heater front window, which are air cooled.

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1) Hi-Temp 5208-05 high density infrared heaters with model 500T3/CL/HT lamps and 664 SCR power controller; or Hi-Temp 5209-05 with QIH240-1000R12 lamps and 3629B power controller, supplied by Research, Inc., http://www.researchinc.com, are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

6.3 Load cell system

The load cell system, shown in Figures 2 and 3, shall consist of a load cell with a suitable load cell signal conditioning load cell controller, which shall have:

a) an accuracy of 0,1 g and a measuring range of 0 g to1 000 g; a 6,35 mm diameter stainless steel shaft, at least 330 mm long, resting on the load cell support point;

b) a 100 mm diameter, 1,5 mm thick aluminium load platform connected to the upper end of the stainless steel shaft by a collar;

c) two low friction, ball-bushing bearings that guide the shaft as it passes through the top and bottom, respectively, of the air distribution chamber.

The stainless steel shaft shall incorporate, at the lower end, a threaded adjustment rod to compensate for horizontal test specimens of different thicknesses.

6.4 Ignition pilot flame

The ignition pilot shall consist of an ethylene/air (60/40 by volume) flame adjusted for a 10 mm length. The pilot flame is anchored at the 50 mm long, horizontal end of a stainless steel tube with an outer diameter of 6,35 mm and an inner diameter of 4,70 mm. In the horizontal tube section, use a four-hole ceramic insert to produce a stable flame and prevent flashback. The pilot flame tube shall be able to be rotated and elevated to position the horizontal flame at specified locations near the specimen [described in 11.1 e)], as shown in Figures 2 and 3.

6.5 Ignition timer

The device for measuring time to sustained flaming shall be capable of recording elapsed time to the nearest 0,1 s and have an accuracy of better than 1 s/h.

6.6 Gas analysis system

6.6.1 Gas sampling

The gas analysis system shall consist of a gas sampling system and gas analysis instruments. The gas sampling arrangement is shown in Figure 4. This arrangement consists of:

a) a sampling probe in the test section duct;

b) primary and secondary plastic filters (5 µm pore size) to prevent entry of soot;

c) a condenser operating at temperatures in the range –5 °C to 0 °C to remove liquids;

d) a tube containing an indicating desiccant (10 to 20 mesh) to remove most of the remaining moisture;

e) a filter to prevent soot from entering the analysers, if not already removed;

f) a sampling pump that transports the flow through the sampling line, system flow meters, needle valves and manifolds to direct the flow to individual analysers (CO, CO_2, O_2, and hydrocarbon gas).

The sampling probe, made of stainless steel tubing (6,35 mm o.d.) with 14 holes, inserted through a test section port, shall be positioned such that the open end of the tube is at the centre of the test section. The sampling probe is connected to a tee fitting that allows either sample or calibration gas to flow to the analyser, and the excess to waste.

6.6.2 Carbon dioxide/carbon monoxide analysers

The carbon dioxide analyser shall enable measurements from 0 % to 1,5 vol % (15 000 µl/l) and the carbon monoxide analyser shall enable measurements from 0 % to 0,05 vol % (500 µl/l) levels. Drift shall be not more than ±1 % of full scale over a 24 h period. Precision shall be 1 % of full-scale and the 10 % to 90 % of full-scale response time shall be 10 s or less (typically 5 s for the ranges specified). The time delay of the system shall not exceed 25 s (measured from sampling probe to the analyser, as shown in Figure 4).

6.6.3 Inlet air oxygen analyser

This analyser shall have a 10 % to 90 % of full-scale response time of 10 s or less, an accuracy of 0,05 % of full-scale, a noise and drift of not more than ±0,005 vol % (50 µl/l) O_2 over a 30 min period and a 0 % to 100 % range. The time delay of the system shall not exceed 25 s (measured from the sampling probe to the analyser, as shown in Figure 4).

6.6.4 Optional product analysers for the combustion test

An additional oxygen analyser can be used to measure the depletion of oxygen in the combustion products. This analyser should have the same specifications as the inlet air analyser but should have a concentration range of 19 % to 21 %. A hydrocarbon gas analyser employing the flame ionization method of detection can be used to determine the total gaseous hydrocarbon concentration. This analyser should have a 10 % to 90 % of full-scale response time of 1 s or less and multiple ranges to permit measurements from a full-scale of 0,001 vol % (10 µl/l) methane equivalent to 0,1 vol % (1 000 µl/l). The time delay of the system shall not exceed 25 s (measured from the sampling probe to the analyser, as shown in Figure 4).

6.7 Combustion air distribution system

6.7.1 General

This system shall consist of an air distribution chamber, shown in Figure 5, and air supply pipes, shown in Figures 6 and 7.

6.7.2 Air distribution chamber

This aluminium chamber, shown in Figure 5, shall contain eight discharge tubes arranged in a circle, the inside diameter of which shall be 165 mm. Each tube shall be aluminium and built to distribute inlet gases (air, O_2, N_2, etc.) to three sets of screens (stainless steel woven wire cloth of 10, 20, and 30 mesh from bottom to top, respectively), for producing a uniform air flow. Inlet air flows downward through the eight discharge tubes, disperses on the bottom plate, then rises through the mesh screens towards the aluminium support cylinder.

6.7.3 Air supply pipes

These pipes shall consist of an aluminium cylinder, shown in Figures 3 and 6, extending from the air distribution chamber up to the load platform. This cylinder shall contain a step (see Figures 6 and 7) to support a quartz pipe (165,0 ± 5,0 mm inner diameter and 3,0 ± 0,5 mm thickness). Above the load platform elevation, the quartz pipe (see Figures 6 and 7) shall supply oxidant to the specimen flame while enabling radiant energy from the IR heating system to reach the specimen surface. The aluminium support cylinder shall be rigidly attached to the distribution chamber; the quartz pipe shall be removable.

6.8 Water-cooled shield

To prevent the specimen from being exposed to the IR heaters during the 1 min heater stabilization period, there shall be a shield (see Figure 8) consisting of two aluminium cylinders welded together with an inlet and outlet for water circulation. An electrically-actuated, pneumatic piston shall raise the shield to cover the specimen during test preparation and shall lower the shield within 1 s to expose the specimen at the start of a test.

6.9 Exhaust system

The exhaust system (see Figure 3) shall consist of the following main components:

a) an intake funnel;

b) a mixing section;

c) a measuring section;

d) duct flanges;

e) a high temperature blower fan to draw gases through the intake funnel, mixing section and measurement section at flow rates from 0,1 m^3/s to 0,25 m^3/s.

The intake funnel, mixing section and measurement section shall be coated internally with fluorinated ethylene propylene (FEP) resin enamel and finish layers over a suitable primer to form a three layer coating that shall withstand temperatures of at least 200 °C.

6.10 Measuring section instruments

6.10.1 Measuring section thermocouple probe

A thermocouple probe, inserted through a measuring section port, shall be positioned such that the exposed, type K measurement bead is at the centre of the measuring section, at the axial position of the gas sampling port. Fabricate the thermocouple probe of wire no larger than 0,254 mm ± 0,5 % diameter for measurement of gas temperature with a time response [in the specified exhaust flow, see 11.2 h)] of no more than 1 s and an accuracy of 1,0 °C.

6.10.2 Averaging Pitot probe and pressure transducer

An averaging Pitot probe, inserted through a measuring section port downstream of the thermocouple port, shall measure the mass flow rate of the gas stream using at least four sets of flow sensing openings. One set of flow sensing openings shall be facing upstream and the second set shall be facing downstream. The flow sensing openings shall be designed for compatibility with the measuring section diameter. Measure the differential pressure generated by the probe with an electronic pressure transducer (electronic manometer).

NOTE The measured differential pressure is proportional to the square of the flow rate. Experience has shown that the averaging Pitot probe in this application is reliable (not susceptible to plugging), while minimizing pressure losses in the exhaust system.

6.11 Heat flux gauge

For calibration of the IR heating system, use a Gardon-type, or equivalent, total heat-flux gauge which has a nominal range of 0 kW/m^2 to 100 kW/m^2 and a flat, 6 mm to 8 mm diameter sensing surface coated with a durable, flat-black finish. The body of the gauge shall be cooled by water above the dew point of the gauge environment. The gauge shall be rugged and maintain an accuracy of within ±9 % (in accordance with ISO 14934-3) and repeatability within 0,5 % between calibrations. Check the calibration of the heat-flux gauge monthly through the use of a black-body oven calibration facility that compares the gauge response to that of an optical pyrometer. Alternatively, compare the gauge output to that of a reference standard.

6.12 Digital data acquisition system

Digitally record the output from the CO, CO_2, hydrocarbon gas, O_2 combustion and O_2 inlet air analysers, the load cell, the measuring section duct thermocouple, and the electronic pressure transducer at 1 s intervals. Time shift the data for the gas concentrations to account for delays within the gas sampling lines and respective instrument response times. The data collection system shall be accurate to within ±1 °C for temperature measurement and ±0,01 % of full-scale instrument output for all other channels. The system shall be capable of recording data for at least 1 h at 1 s intervals, although test duration typically is between 8 min and 15 min.

7 Hazards

7.1 Laboratory safety

All normal laboratory safety precautions should be followed since the test procedures involve high temperatures and combustion reactions, as well as the use of electric radiant heaters, laboratory glassware, and different types of compressed gases.

7.2 Safety precautions

Hazardous conditions leading to e.g. burns, ignition of extraneous objects or clothing, and inhalation of combustion products, might exist. During the operation of the apparatus, the operator should use hearing protection and at least Shade 5 welding goggles or glasses. The operator should use protective gloves for insertion and removal of test specimens. Specimens should be removed to a fume hood. Neither the heaters nor the associated fixtures can be touched while hot, except with protective gloves.

7.3 Exhaust system operation

The exhaust system should be checked for proper operation before testing and should be discharged away from intakes for the building ventilation system. Provision should be made for collecting and venting any combustion products that the exhaust system fails to collect.

8 Test specimen

8.1 Specimen holders

Four types of specimen holder are used: horizontal square, horizontal circular (Figure 9), vertical (Figure 10), and vertical cable (Figure 11). The horizontal square holder consists of two layers of 0,05 mm thickness aluminium foil moulded to the sides and bottom of a square specimen. The horizontal circular holder is a 0,114 m diameter aluminium dish (see Figure 9 and 8.2.1). The vertical specimen holder is a 0,485 m high × 0,133 m wide ladder rack (see Figure 10). The vertical cable holder is 0,825 m high (see Figure 11) and can support a cable specimen of 0,81 m length and up to 51 mm diameter.

8.2 Specimen size and preparation

8.2.1 Ignition, pyrolysis and combustion tests of horizontal specimens

Cut specimen from essentially planar materials or product so that it is 102 mm × 102 mm in area for a horizontal square holder. For a horizontal circular holder, cut specimens from essentially planar materials or products to be (96,5 ± 2) mm in diameter. Specimens shall have a thickness of no less than 3 mm and no more than 25,4 mm and be representative of the end-use material or product.

Expose composite specimens in a manner typical of the end-use condition. Horizontal specimens with a diameter of (96,5 ± 2) mm shall be sealed (both rear and side) with (0,075 ± 0,002) mm thick fibreglass adhesive aluminium tape and then mounted in a well-insulated aluminium dish (62,6 ± 2) g. The side of specimen in the specimen holder shall be insulated with 3 layers of (3 ± 0,2) mm thick ceramic paper (density 190 kg/m^3 to 200 kg/m^3). The bottom of the specimen in the specimen holder shall be insulated with layers of (3 ±0,2) mm thick ceramic paper [8].

Maintain the top surface of each specimen flush with the top of the ceramic insulation, as shown in Figure 9. In case of cable specimens, cut the cable (each end sealed with fibreglass adhesive aluminium tape) to cover the centre and at least 20 mm on each side of the centre of the aluminium dish. Spray the exposed top surface of the specimen with a single coat of non-combustible flat black paint2) that is designed to withstand temperatures of (540 ± 10) °C (this paint did not ignite when applied on a thin metal foil[8]). Prior to testing, cure the paint coating by conditioning the specimen at a temperature of (23 ± 3) °C and a relative humidity of (50 ± 5) % for 48 h. The mass per unit area of this coating shall not exceed (50 ± 5 %) g/m^2. This coating is applied to ensure surface absorption of the imposed radiant heat flux. Where applicable, 50/50 mixture of carbon black and activated carbon charcoal3) can be used for surface coating. The mass per unit area for this coating shall not exceed (160 ± 5 %) g/m^2. Just before a test is to be performed, place the holder containing the specimen on a 13 mm thick, calcium silicate board (density 700 kg/m^3 to 750 kg/m^3, thermal conductivity 0,11 W/m K to 0,13 W/m K) which has the same dimensions as the holder.

8.2.2 Fire propagation test of vertical, rectangular specimens

Cut specimens from essentially planar materials or products so that they are 102 mm in width and 305 mm in height. Specimens shall have a thickness of no less than 3 mm and no more than 13 mm and shall be representative of the end-use material or product.

Place ceramic paper (density 190 kg/m^3 to 200 kg/m^3) of (3 ± 0,2) mm thickness to cover the sides and back surface of the specimen and then wrap the specimen, with the ceramic paper, in two layers of aluminium foil of 0,05 mm thickness to expose only the front surface to be tested.

Wrap the covered and exposed width of the specimen securely with one turn of (0,5 ± 0,1) mm diameter nickel/chromium wire at distances of 50 mm from each end and at the midpoint of the 305 mm length of the specimen.

Place the bottom of the specimen on the metal base-plate (see Figure 10) of the vertical holder with the covered (back) surface of the specimen against the ladder rack.

Wrap one turn of (0,5 ± 0,1) mm diameter nickel/chromium wire securely around the specimen, the ladder rack and the threaded rods at distances of 100 mm and 200 mm from the bottom of the specimen to keep the specimen firmly in contact with the vertical specimen holder.

8.2.3 Fire propagation test of vertical, cable specimens

Mount cable specimens as shown in Figure 11.

9 Calibration

9.1 Radiant-flux heater

9.1.1 Routine calibration

Calibrate IR heaters at the start of the test day. Clean the quartz windows, lamps, and back reflective surfaces of the heaters to keep them free of any impurity build-up or scratches. Position the heat-flux gauge-sensing surface to be horizontal, at a location equivalent to the centre of the top surface of a horizontal specimen. If

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2) Thurmalox® Solar Collector Coating, No. 250 Selective Black spray paint, packaged for the Dampney Company, http://www.dampney.com, is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

3) Carbon Black, CAS Reg. No. 1333-86-4 supplied by Cabot Black Pearl, http://www.cabot-corp.com, and Fisherbrand Activated Carbon Charcoal 50-200 mesh, Catalog No. 05-690B supplied by Fisher Scientific, http://www.fishersci.com, are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

forced air flow is required for the test, place the quartz pipe, which has an inner diameter of (165,0 ± 5,0) mm and a thickness of (3,0 ± 0,5) mm, in position. Record IR heater RMS voltage settings from the power controller and measured radiant flux levels for planned tests.

9.1.2 Positioning of radiant-flux heaters

At least annually, check the position of the IR heaters. Set the heater voltage at 90 % of the maximum value. Position the heat-flux gauge sensing surface so that it is horizontal; measure the heat flux at each of five locations, corresponding to each corner and the centre of a square horizontal specimen, at an elevation equivalent to that of the specimen top surface. Adjust the position of each IR heater symmetrically and repeat these heat flux measurements, if necessary, until there is at most a 5 % mean deviation of the five readings from the average value. Then position the heat-flux gauge to locations equivalent to the vertical axis at the centre of a square specimen. Measure the heat flux at elevations of 10 mm and 20 mm above and below that equivalent to the specimen top surface. Check that the heat flux at these four elevations is within 5 % of the value at the elevation of the specimen face.

9.2 Gas-analyser calibration

9.2.1 Carbon dioxide/carbon monoxide analysers

Calibrate the carbon dioxide/carbon monoxide analysers before the first combustion or fire propagation test of the day. Calibrate the CO_2 and CO analysers for measurement of combustion gases by establishing a downscale calibration point and an upscale calibration point. Perform the upscale calibration with a “span gas” at the upper end of the range that will be used during actual sample analysis and use a “zero gas” for the down-scale calibration point at the lower end of the analyser range. Use nitrogen as the “zero gas” reference source by turning on a grade 5 nitrogen cylinder at 0,8 L/min. Zero the CO and CO_2 analysers. Span each analyser with its appropriate gas for the corresponding range.

9.2.2 Oxygen analyser

Calibrate the oxygen analysers before the first combustion or fire propagation test of the day. Calibrate the oxygen analyser for measurement of inlet oxygen concentration (and the optional oxygen analyser for combustion gases) by establishing a downscale calibration point and an upscale calibration point. Perform the upscale calibration with a “span gas” at the upper end of the range that will be used during actual sample analysis and use a “zero gas” for the down-scale calibration point at the lower end of the analyser range. To calibrate the analyser, open the span gas at 1,0 L/min, set the analyser span, close the span gas, and open the zero gas at the same flow rate, and then set the lower end of the analyser range. Re-span and re-zero several times, if necessary.

9.2.3 Optional hydrocarbon gas analyser

Calibrate the total hydrocarbon analyser before the first combustion or fire propagation test. Adjust the zero control of the analyser by using ultra pure nitrogen flowing at 3 L/min as the “zero gas.” As the “span gas,” use methane at a concentration that matches the operating range of the analyser.

9.3 Load cell

Calibrate the load cell each time it is used. Set the output voltage to zero by adjusting the tare, with the appropriate empty specimen holder in position. Then, place a weight corresponding to the weight of the specimen to be tested on the empty holder and measure the output voltage. Check linearity by repeating this procedure with three other weights so as to cover the entire specimen weight range.

9.4 Heat release calibration

Calibrate the heat release rate measurement process at least weekly to ensure the proper functioning of the FPA. Check that the measured effective heat of combustion of acetone is within ±5 % of the reference value of 27 900 kJ/kg[8] and that the measured total delay (or lag) time of the gas analysers is less than 15 s. Use ΔH_T, k_co, k_co2 and k_o2 values 29,7 kJ/g, 10,5 kJ/g, 13,1 kJ/g and 13,4 kJ/g, respectively[8].

a) Do not use the IR heaters or the pilot.

b) Perform the rest of the required calibration procedures as described in 9.2 and 9.3.

c) Check that inlet air flow is set at $3{,}3 \times 10^{-3}$ $\mathrm{m^3/s}$.

d) Turn on the exhaust blower and set an exhaust flow rate of 0,15 $\mathrm{m^3/s}$.

e) Start data acquisition program.

f) Place 100 mL of acetone in a specimen dish (100 ± 5) mm inner diameter on the load cell.

g) Install the quartz pipe on the mounting step in the aluminium oxidant supply pipe.

h) Ignite the acetone using a match 30 s after the start of data acquisition.

i) End data acquisition 2 min after the end of visible flaming.

j) Determine the effective heat of combustion following the calculation procedure in Clause 12.

k) Determine the delay time for the gas analysers by computing the difference between the time when the test section duct gas temperature reaches 50 % of its steady-state value and the time when the reading of each analyser reaches 50 % of its steady-state value.

10 Specimen conditioning

Condition specimens to moisture equilibrium (constant weight) at an ambient temperature of (23 ± 3) °C and a relative humidity of (50 ± 5) % for 24 h.

11 Procedure

11.1 Procedure 1 — Ignition test method

The ignition test is performed to determine the time required from the application of an externally applied heat flux to a horizontal test specimen until ignition of that specimen.

a) Verify that nitrogen for flame extinguishment is available for flow at $1{,}67 \times 10^{-3}$ $\mathrm{m^3/s} \pm 0{,}0167 \times 10^{-3}$ $\mathrm{m^3/s}$ and that pilot flame gases (ethylene to air ratio 60:40) are regulated to give specified flame length of 10 mm.

b) Place the 13 mm thick calcium silicate board supporting the appropriate horizontal specimen holder in position (centred) on the aluminium load platform (to ensure natural air flow, confirm that there is no quartz pipe in place).

c) Turn on the exhaust blower and set an exhaust flow rate of 0,15 $\mathrm{m^3/s}$.

d) Light the pilot flame and adjust for a 10 mm flame length.

e) Move the lighted pilot flame to a position 10 mm above the specimen surface and 10 mm from the perimeter of the specimen.

f) Turn on air and water to cool the infrared radiant heaters.

g) Raise the water-cooled shield surrounding the specimen holder to prevent specimen exposure to external heat flux.

h) Set the IR heater voltage to produce the desired heat flux and leave for 1 min of stabilization.

i) Lower the water-cooled shield to expose the sample to the external heat flux. Simultaneously start a timer.

j) Record the time when vapours are first observed coming from the test specimen.

k) Record the time to ignition as the time duration from exposure to the external heat flux until sustained flaming (existence of flame on or over most of the specimen surface for at least a 10 s duration). If there is no ignition after a 15 min heat flux exposure time, turn off the IR heater voltage and stop the test.

l) If there is sustained flaming, turn off the IR heater voltage and introduce nitrogen to extinguish flames.

m) Using a protective glove, remove the specimen to a ventilated environment.

n) Repeat this procedure for additional infrared heater settings, as required.

11.2 Procedure 2 — Combustion test method

The combustion test is conducted to measure the chemical and convective heat release rates ($\dot{Q}_{\text{chem}}$ and $\dot{Q}_{\text{c}}$), mass loss rate ($\dot{m}$) and to determine the ΔH_{eff} of a horizontal specimen.

a) Place the 13 mm thick calcium silicate board supporting the appropriate horizontal specimen holder in position (centred) on the aluminium load platform.

b) Verify that the gas sampling system is removing all water vapour and similarly condensable combustion products. If the sampling system flow meter indicates less than 0,167 × 10–3 m^3/s, then replace sampling system filter elements.

c) Install fresh indicating desiccant and soot filter in the gas sampling line.

d) Ignite the flame in the hydrocarbon gas analyser and check the flame out indicator on the front panel to ensure that there is flame ignition.

e) Verify that nitrogen for flame extinguishment is available for flow at 1,67 × 10–3 ± 0,0167 × 10–3 m^3/s into the inlet air supply line and that pilot flame gases (ethylene to air ratio 60:40) are regulated to give specified flame length when needed.

f) Turn on gas sampling pump and set correct sampling flow rate for each gas analyser (gas analysers, the electronic pressure transducer, and load cell are powered on at all times to maintain constant internal temperatures).

g) Perform required calibration procedures as specified in Clause 9.

h) Turn on the exhaust blowers and set an exhaust flow rate of 0,15 m^3/s.

i) Light the pilot flame and adjust for a 10 mm flame length.

j) Move the lighted pilot flame to a position 10 mm above the specimen surface and 10 mm from the perimeter of the specimen.

k) Turn on air and water to cool the infrared radiant heaters.

l) Install the quartz pipe on the mounting step in the aluminium oxidant supply pipe.

m) Raise the water-cooled shield to cover the specimen.

n) Set an inlet air supply rate of 3,3 × 10–3 m^3/s into the air distribution chamber. To change oxygen content of inlet air supply from that of normal air, introduce oxygen or nitrogen (from grade 2,6 and 4,8 cylinders, respectively) into the inlet air supply line and check oxygen concentration with inlet air oxygen analyser (maximum oxygen concentration shall be 40 % by volume).

o) Set the IR heater voltage to produce the desired radiant exposure of the specimen surface and allow the IR heaters to stabilize for 1 min.

p) Start the digital data collection system to record at 1 s intervals.

q) At 30 s, lower the cooling shield to expose specimen to infrared radiant heaters.

r) Record the time when vapours are first observed coming from the test specimen, the time at ignition, flame height, flame colour/smokiness, any unusual flame or specimen behaviour and flame extinction time.

s) Maintain the position of the pilot flame to be at a height of (10 ± 5) mm above the exposed surface of any specimen that regresses or expands during the test period.

t) Turn off the IR heaters and introduce nitrogen 2 min after the end of visible flaming, or if flames reach (35 ± 10) mm above the rim of the collection funnel for more than 30 s.

u) Using a protective glove, remove the specimen from the specimen holder, weigh the residue and record the result.

v) Repeat the above procedures to give a total of three chemical heat release rate and mass loss rate determinations.

11.3 Procedure 3 — Pyrolysis test method

The pyrolysis test is conducted to measure the mass loss rate ($\dot{m}$) as a function of external radiant heat flux and to determine the heat of gasification ΔH_g of a horizontal specimen (see Annex D). Conduct tests using at least five values of external radiant heat fluxes.

a) Place the 13 mm thick calcium silicate board supporting the appropriate horizontal specimen holder in position (centred) on the aluminium load platform.

b) Verify that the gas sampling system is removing all water vapour and similarly condensable combustion products. If the sampling system flow meter indicates less than 0,167 × 10^{-3} m^3/s, then replace sampling system filter elements.

c) Install fresh indicating desiccant and soot filter in the gas sampling line.

d) Turn on gas sampling pump and set correct sampling flow rate for each gas analyser (gas analysers, the electronic pressure transducer, and load cell are powered on at all times to maintain constant internal temperatures).

e) Perform calibration procedures as specified in Clause 9.

f) Turn on the exhaust blowers and set an exhaust flow rate of 0,15 m^3/s.

g) Turn on air and water to cool the infrared radiant heaters.

h) Install the quartz pipe on the mounting step in the aluminium oxidant supply pipe.

i) Raise the water-cooled shield to cover the specimen.

j) Set an inlet air supply rate of $3{,}3 \times 10^{-3}$ m^3/s into the air distribution chamber. To change oxygen content of inlet air supply from that of normal air, introduce 100 % by volume nitrogen (from grade 4,8 cylinders) into the inlet air supply line.

k) Set the IR heater voltage to produce the desired radiant exposure of the specimen surface and enable the IR heaters to stabilize for 1 min.

l) Start the digital data collection system to record at 1 s intervals.

m) At 30 s, lower the cooling shield to expose specimen to infrared radiant heaters.

n) Record the time when vapours are first observed coming from the test specimen.

o) Turn off the IR heaters when no visible vapours are observed at the end of the test.

p) Using a protective glove, remove the specimen from the specimen holder, weigh the residue and record the result.

11.4 Procedure 4 — Fire propagation test method

The fire propagation test is performed to determine the chemical heat release rate ($\dot{Q}_{\text{chem}}$) of a vertical specimen during upward fire propagation and burning.

a) Repeat the necessary steps for measurement of heat release rate in 11.2, with the exception of the load cell calibration.

b) Remove the stainless steel load cell shaft and the ball-bushing bearings from the air distribution chamber and replace with the appropriate vertical specimen holder.

c) Install the specimen so that the bottom edge of the vertical specimen that is to be exposed to IR heating is at an elevation equivalent to that of the top surface of a horizontal specimen.

d) Light the pilot flame and adjust for a 10 mm flame length.

e) Turn on air and water to cool the infrared radiant heaters.

f) Install the quartz pipe on the mounting step in the aluminium oxidant supply pipe.

g) Raise the water-cooled shield surrounding the specimen holder to prevent pre-exposure to external heat flux.

h) Move the pilot flame to a position 75 mm from the bottom of the specimen and 10 mm away from the specimen surface.

i) Set an inlet air supply rate of $3{,}3 \times 10^{-3}$ m^3/s into the air distribution chamber. To change oxygen content of inlet air supply from that of normal air, introduce oxygen or nitrogen (from grade 2,6 and 4,8 cylinders, respectively) into the inlet air supply line and check oxygen concentration with inlet air oxygen analyser (maximum oxygen concentration shall be 40 % by volume).

j) Turn on the exhaust blowers and set an exhaust flow rate of 0,15 m^3/s.

k) Set the IR heater voltage to produce 50 kW/m^2 and leave to stabilize for 1 min.

l) Start the digital data collection system to record at 1 s intervals.

m) At 30 s, lower the water-cooled shield to expose the lower portion of the vertical sample to the external heat flux from the infrared radiant heaters. Simultaneously start a timer.

n) After preheating the base area of the specimen for 1 min, move the pilot flame into contact with the specimen surface to initiate fire propagation, if ignition and fire propagation has not already occurred, and then move the pilot flame away from the specimen.

o) Measure the chemical heat release rate as a function of time during fire propagation, using the combustion test procedures.

p) Record the time when vapours are first observed coming from the test specimen, the time at ignition, flame height at 1 min intervals, flame characteristics, such as colour, and the time at flame extinction.

q) Turn off the IR heaters and introduce nitrogen 2 min after the end of visible flaming, or if flames reach (35 ± 10) mm above the rim of the collection funnel for more than 30 s, or if the specimen undergoes noticeable structural deformation.

r) Repeat the above procedures to give a total of three heat release rate determinations.

12 Calculation

Determine the chemical heat release rate, $\dot{Q}_{\mathrm{chem}}$ from the following equation, derived from B.3 (Annex B):

$$\dot{Q}_{\mathrm{chem}} = 13\,300\left(\dot{G}_{\mathrm{CO_2}} - \dot{G}_{\mathrm{CO_2}}{}^{0}\right) + 11\,100\left(\dot{G}_{\mathrm{CO}} - \dot{G}_{\mathrm{CO}}{}^{0}\right) \tag{1}$$

where

$\dot{G}_{\mathrm{CO_2}}$ and $\dot{G}_{\mathrm{CO}}$ are the generation rates, (kg/s) of CO_2 and CO, respectively, and

$\dot{G}_{\mathrm{CO_2}}{}^{0}$ and $\dot{G}_{\mathrm{CO}}{}^{0}$ are the corresponding measurements before ignition of the specimen.

From the consumption rate of O_2, the $\dot{Q}_{\mathrm{chem}}$ can also be determined:

$$\dot{Q}_{\mathrm{chem}} = \left(\Delta H_{\mathrm{T}} / k_{\mathrm{O_2}}\right)\dot{D}_{\mathrm{O_2}} \tag{2}$$

Determine the generation rates of CO_2 and CO from the following equations, derived from B.3 (Annex B).

$$\dot{G}_{\mathrm{CO_2}} = A_{\mathrm{d}}\, K\left(P_{\mathrm{atm}}/101\,000\right)^{1/2} \times \left(2 \times 353\, \Delta_{P\mathrm{m}}/T_{\mathrm{d}}\right)^{1/2} \times 1{,}52\, X_{\mathrm{CO_2}} \tag{3}$$

$$\dot{G}_{\mathrm{CO}} = A_{\mathrm{d}}\, K\left(P_{\mathrm{atm}}/101\,000\right)^{1/2} \times \left(2 \times 353\, \Delta_{P\mathrm{m}}/T_{\mathrm{d}}\right)^{1/2} \times 0{,}966\, X_{\mathrm{CO}} \tag{4}$$

The convective heat release rate $\dot{Q}_{\mathrm{c}}$ is obtained as follows:

$$\dot{Q}_{\mathrm{c}} = \dot{m}_{\mathrm{d}} c_{\mathrm{p}} (T_{\mathrm{d}} - T_{\mathrm{a}}) \tag{5}$$

where

$\dot{m}_{\mathrm{d}}$ is the mass flow rate of combustion products (kg/s) in the test section duct (a formula for which can be found in B.3),

c_{p} is the specific heat of air, (kJ/kg·K),

T_d is the gas temperature in the test section duct, (K), and

T_a is the gas temperature in the test section duct, (K), just before pilot flame ignition occurs.

Correct the specific heat, c_p, for temperature, T_d, as follows:

$$c_p = 1{,}00 + 1{,}34 \times 10^{-4} \times T_d - 2590 / T_d{}^2 \tag{6}$$

such that the convective heat release rate is determined from the following equation:

$$\begin{aligned}\dot{Q}_c = {} & A_d K (P_{atm} / 10\ 1000)^{1/2} (706 \Delta_{pm} / T_d)^{1/2} \times [1{,}00 + 1{,}34 \times 10^{-4} \times T_d - 2590 / T_d{}^2) T_d \\ & - (1{,}00 + 1{,}34 \times 10^{-4} \times T_a - 2\ 590 / T_a{}^2) T_a]\end{aligned} \tag{7}$$

Determine specimen mass loss rate, $\dot{m}$, from the slope of five-point, straight-line regression fits to the data on mass loss versus time. Compute the slope each time using mass loss data from the current time record, from the two preceding time records and from the two succeeding time records.

Determine the effective heat of combustion, ΔH_{eff}, from the following equation:

$$\Delta H_{eff} = Q / M_{loss} \tag{8}$$

where

Q is the cumulative heat generated during the combustion test, based on a summation over all data scans of the product of $\dot{Q}_{chem}$, from Equation (1), and Δt, the time between scans; and,

M_{loss} is the change in measured specimen mass (by laboratory balance) resulting from the combustion test.

13 Test report

13.1 Procedure 1 — Ignition test method

Report the following information:

a) Specimen identification code or number.

b) Manufacturer or name of organization submitting specimen.

c) Date of test.

d) Operator and location of apparatus.

e) Composition or generic identification of specimen.

f) Specimen thickness and dimensions of specimen surface exposed to IR heaters (mm).

g) Specimen mass (kg).

h) Details of specimen preparation.

i) Specimen orientation, specimen holder and description of special mounting procedures.

j) Room temperature (°C) and relative humidity (%).

k) Exhaust system flow rate (L/min).

l) Radiant flux from IR heating system applied to test specimen (kW/m^2).

m) Time (s) when vapours are first observed coming from the test specimen.

n) Time (s) at which there is ignition (sustained flaming).

o) Additional observations (including times of transitory flaming, flashing, or melting).

13.2 Procedure 2 — Combustion test method

In addition to a) to l) in 13.1, report the following information:

a) Chemical and convective heat release rates per unit exposed specimen area (kW/m^2).

b) Generation rates of carbon monoxide, and carbon dioxide (kg/s).

c) Specimen mass loss rate (kg/s).

d) Effective heat of combustion, ΔH_eff (kJ/kg).

e) Specimen mass remaining after test (kg).

f) Number of replicate specimens tested under the same conditions.

13.3 Procedure 3 — Pyrolysis test method

In addition to a) to k) in 13.1, report the following information:

a) Specimen mass loss rate (kg/s).

b) Radiant flux from IR heating system applied to test specimen (kW/m^2).

c) Heat of gasification, ΔH_g (kJ/kg).

d) Specimen mass remaining after test (kg).

e) Number of replicate specimens tested under the same conditions.

13.4 Procedure 4 — Fire propagation test method

In addition to a) to l) in 13.1, report the following information:

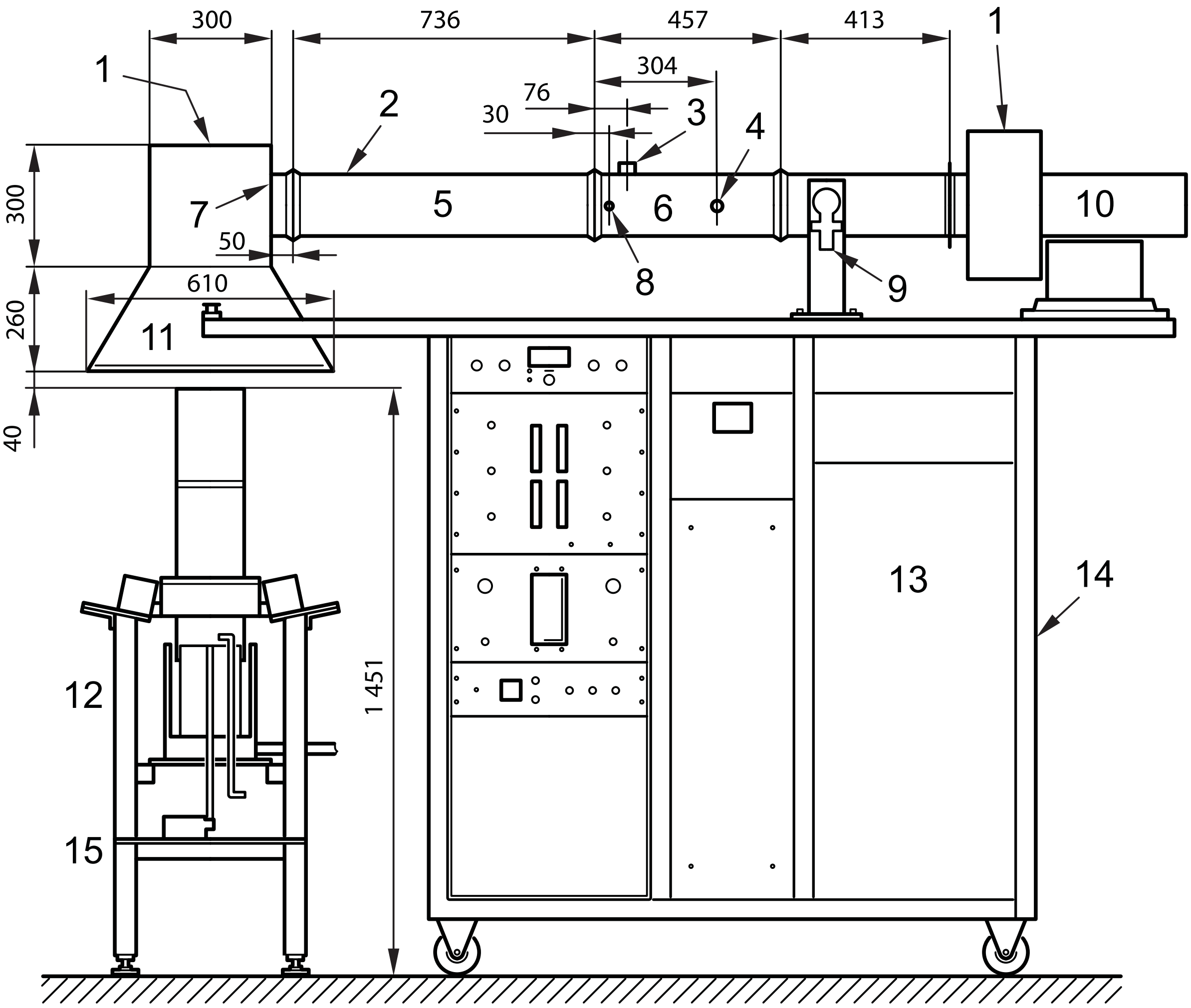
a) Chemical and convective heat release rates per unit exposed specimen area (kW/m^2).

b) Flame height at 1 min interval (m).

c) Number of replicate specimens tested under the same conditions.

Figure 1 — Photograph of fire propagation apparatus

Dimensions in millimetres

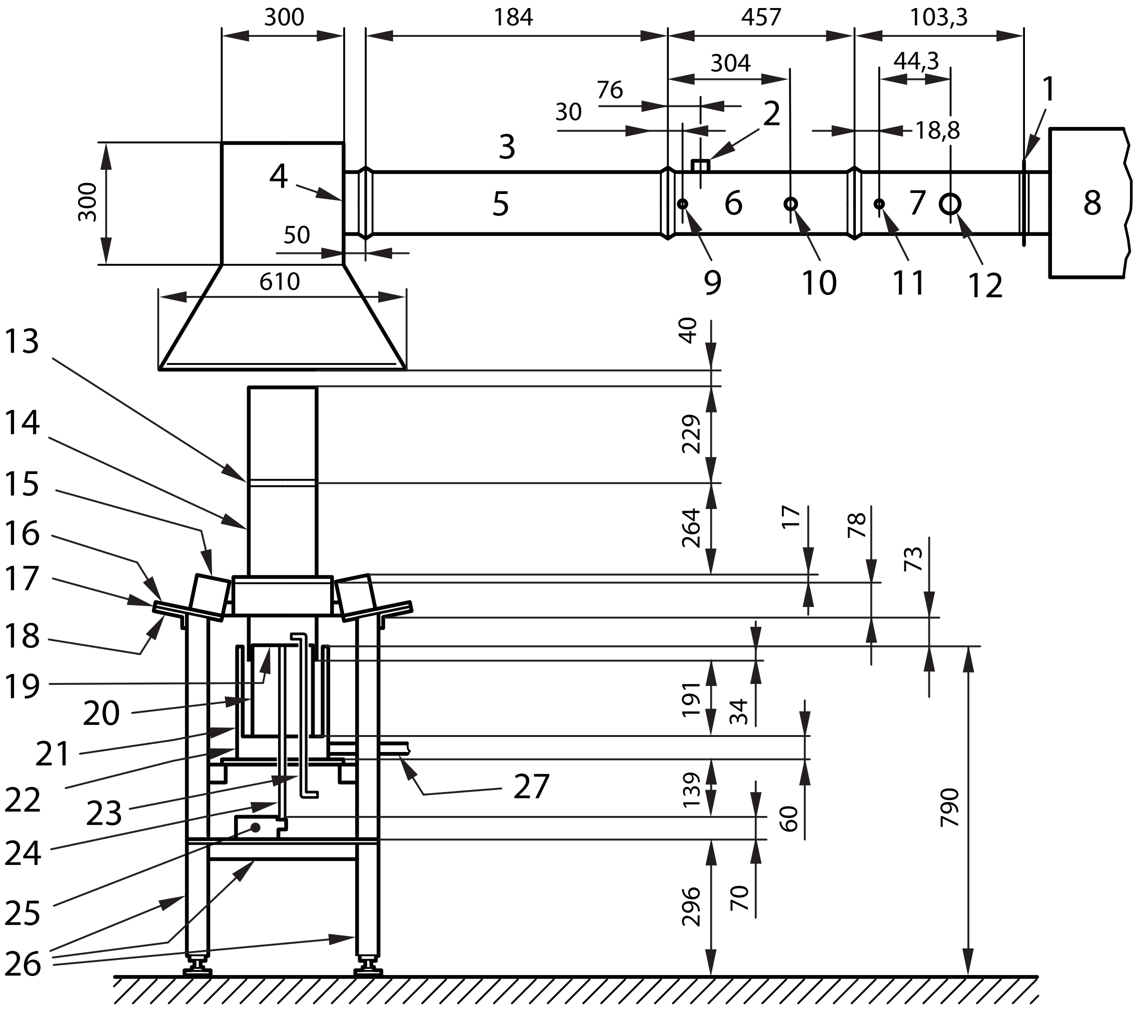


Key

1	exhaust system
2	stainless steel tubing, 152 mm inner diameter, 1,57 mm thickness
3	air velocity port, vertical across duct
4	gas sample port, horizontal across duct
5	mixing duct
6	test section duct
7	orifice plate, 91,5 mm diameter orifice, 1,6 mm thickness
8	thermocouple port
9	laser smoke measuring system
10	blower
11	intake funnel
12	IR heating system and specimen area of FPA
13	instrumentation
14	cart
15	load cell

Figure 2 — Schematic of fire propagation apparatus

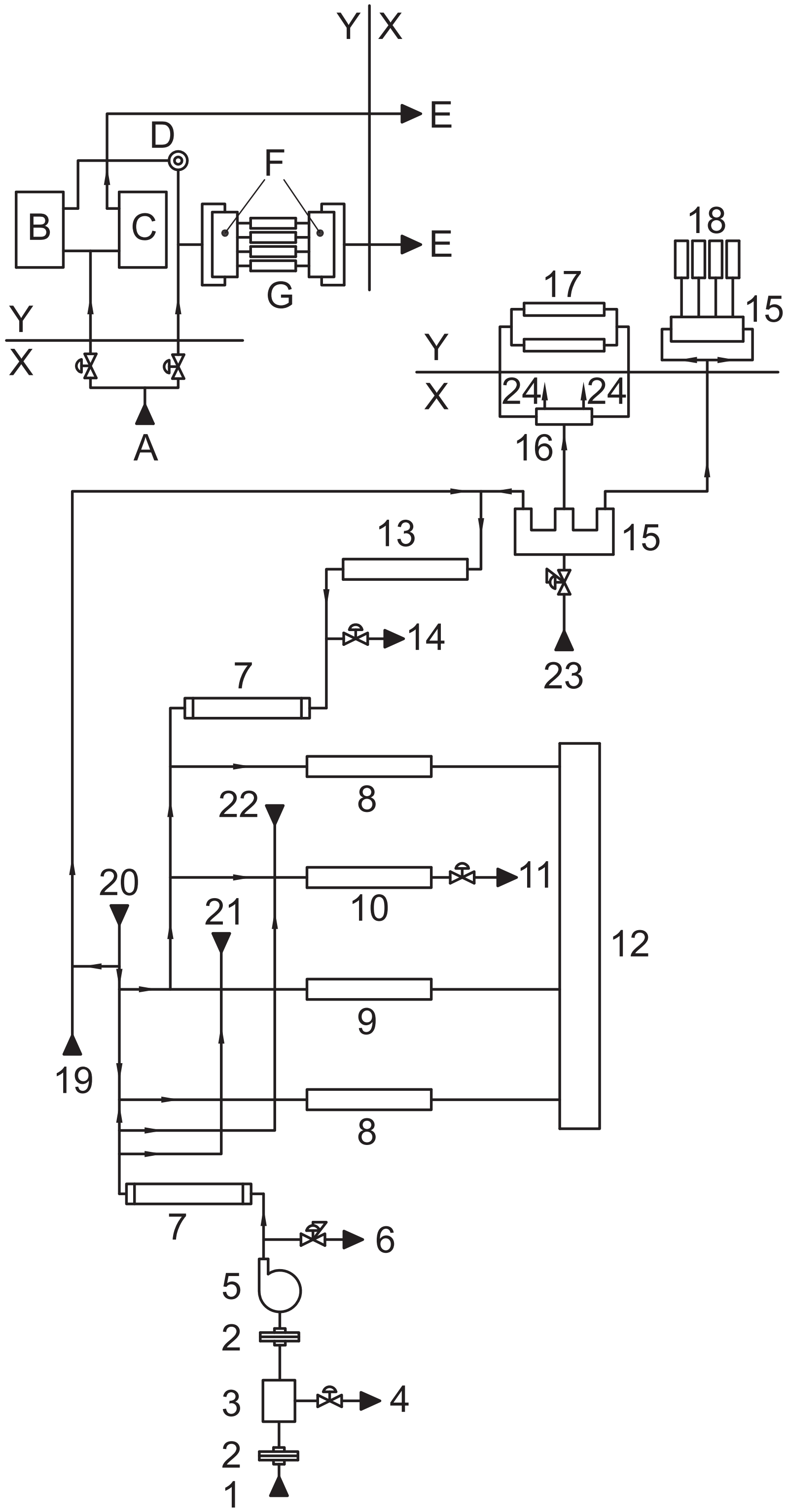
Dimensions in millimetres



Key

1 duct flanges
2 air velocity port, vertical across duct
3 alternative position for thermocouple
4 orifice plate welded into position, sharp edge away from plenum
5 mixing section
6 measuring section
7 laser section
8 fan unit
9 thermocouple port
10 gas sample port, horizontal across duct
11 laser port, horizontal across duct
12 corrosion probe port
13 stainless steel connection
14 quartz pipe, 172 mm diameter
15 four infrared heaters, 241 mm × 81 mm × 81 mm, each with 152 to 203 mm, 500 W lamps
16 aluminium plate, 292 mm length, 165 mm width, 3 mm thickness
17 aluminium mounting plate, 464 mm length, 51 mm width, 6 mm thickness
18 adjustable steel angle bracket, 6 mm
19 aluminium load platform, 100 mm diameter
20 aluminium cylinder, 186 mm diameter
21 water cooled shield with pneumatic piston, 225 mm diameter
22 aluminium air distribution box, 216 mm diameter
23 stainless steel pilot flame tube, 6 mm diameter
24 stainless steel shaft, 6 mm diameter
25 load cell
26 steel frame members
27 jet air supply

Figure 3 — IR heating system and specimen area with horizontal duct



Key

X rack

Y fire model

Figure 4 — Flow diagram of gas sampling system

Key for flow diagram of gas sampling system in Figure 4

KEY FOR GASES P&I

PART	DESCRIPTION	PART	DESCRIPTION
1	from sampling probe	13	air flowmeter
2	soot filter	14	air distribution chamber
3	cold trap	15	manifold block
4	drain	16	solenoid block
5	pump	17	pneumatic cylinders (water cooled shield)
6	extraction	18	lamps
7	drying columns	19	oxygen inlet
8	02 flowmeter	20	nitrogen inlet
9	carbon dioxide/monoxide flowmeter	21	carbon dioxide/carbon monoxide inlet
10	hydrocarbon flowmeter	22	1 000 ppm CH4/nitrogen inlet
11	hydrocarbon analyser (optional)	23	pressure regulated clean air
12	02, C02, C0, 02 analyser	24	vent

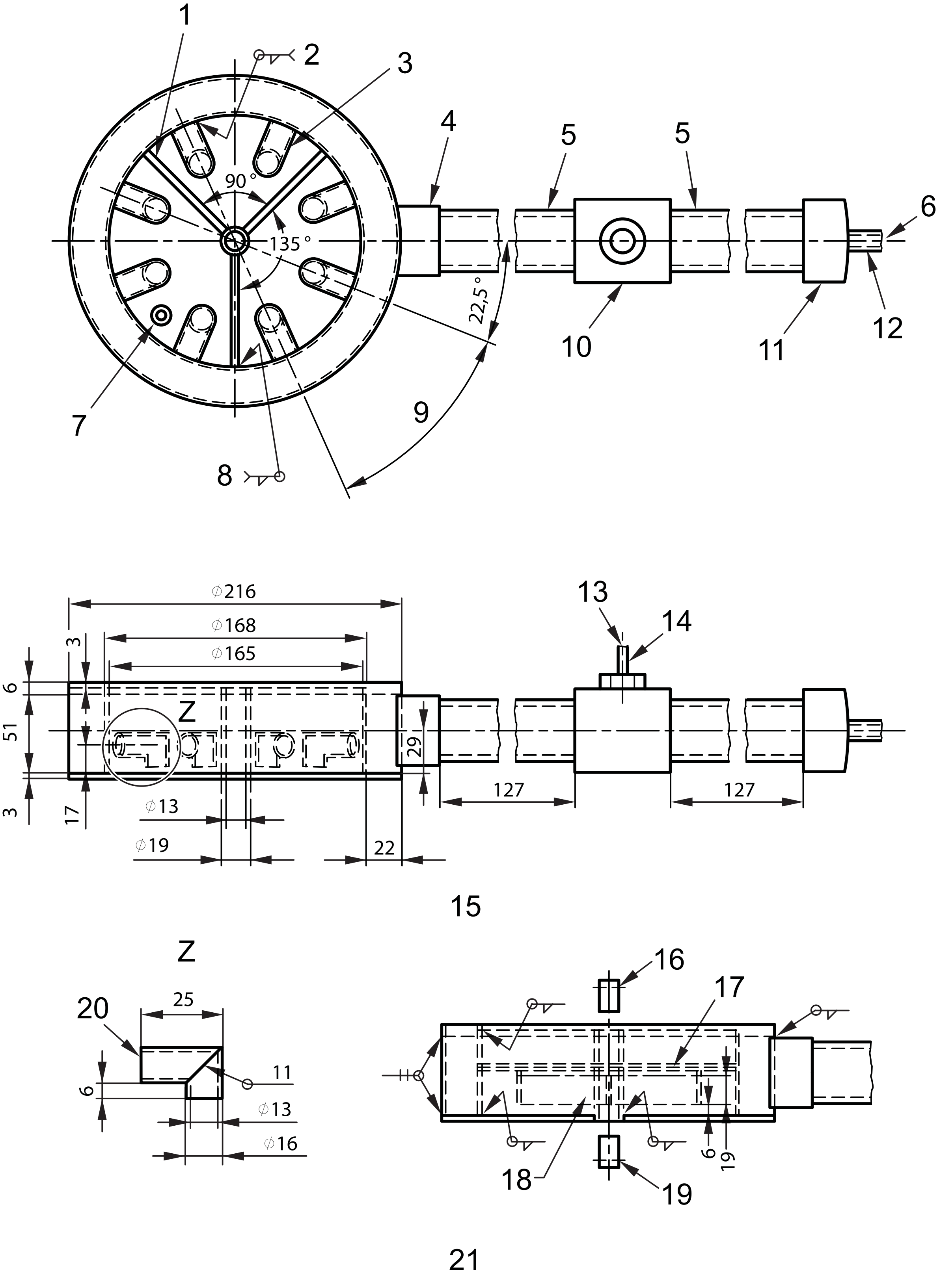
KEY FOR WATER P&I

PART	DESCRIPTION	PART	DESCRIPTION
A	pressure regulated clean water	B	water cooled shield
C	water cooled support	D	heat flux sensor
E	waste	F	manifold
G	lamps		

SYMBOLS FOR ARMATURES AND PARTS

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
	flow control valve		regular

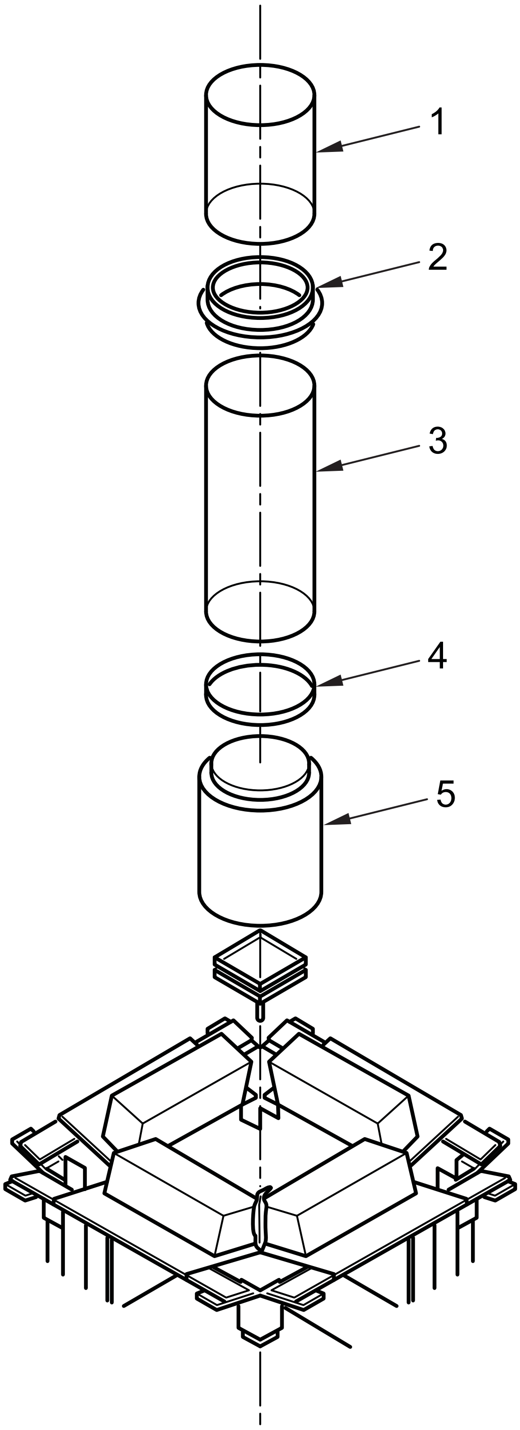
Dimensions in millimetres



Key

1	flat bar, 19 mm length × 3 mm width
2	same angle for each
3	discharge tube
4	threaded socket, aluminium, 33 mm
5	copper pipe, 32 mm
6	forced ventilation inlet air
7	stainless steel tube, 6 mm
8	top and two sides, same in each place
9	same angle for each
10	threaded brass tee, 32 mm × 32 mm × 13 mm
11	threaded brass pipe cap, 32 mm
12	plastic tubing, 13 mm
13	sampling port to measure oxygen concentration
14	copper tubing, 6 mm
15	view showing discharge tubes
16	retaining ring on the ball bushing bearing
17	screens
18	flat bar aluminium (× 3), 19 mm length × 3 mm width
19	low friction ball bushing bearings (one in top of chamber and one in the bottom)
20	detail of discharge tube
21	partial view showing flat bars

Figure 5 — Air distribution chamber

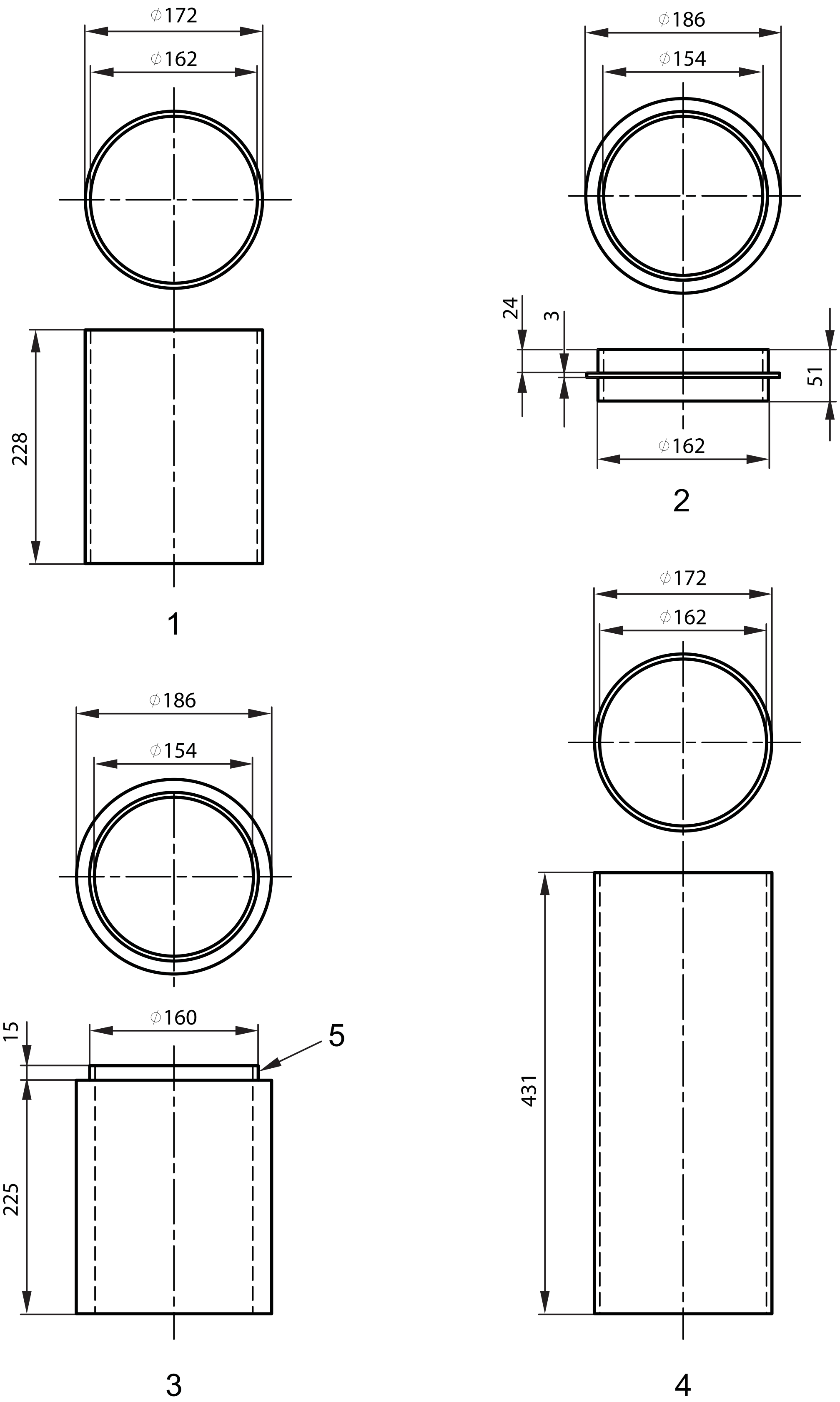


Key

1 quartz pipe extension
2 stainless steel connector
3 quartz pipe
4 ceramic paper gasket seal
5 aluminium support cylinder

Figure 6 — Exploded view of quartz pipe assembly

Dimensions in millimetres



Key

1 quartz pipe extension

2 stainless steel connector

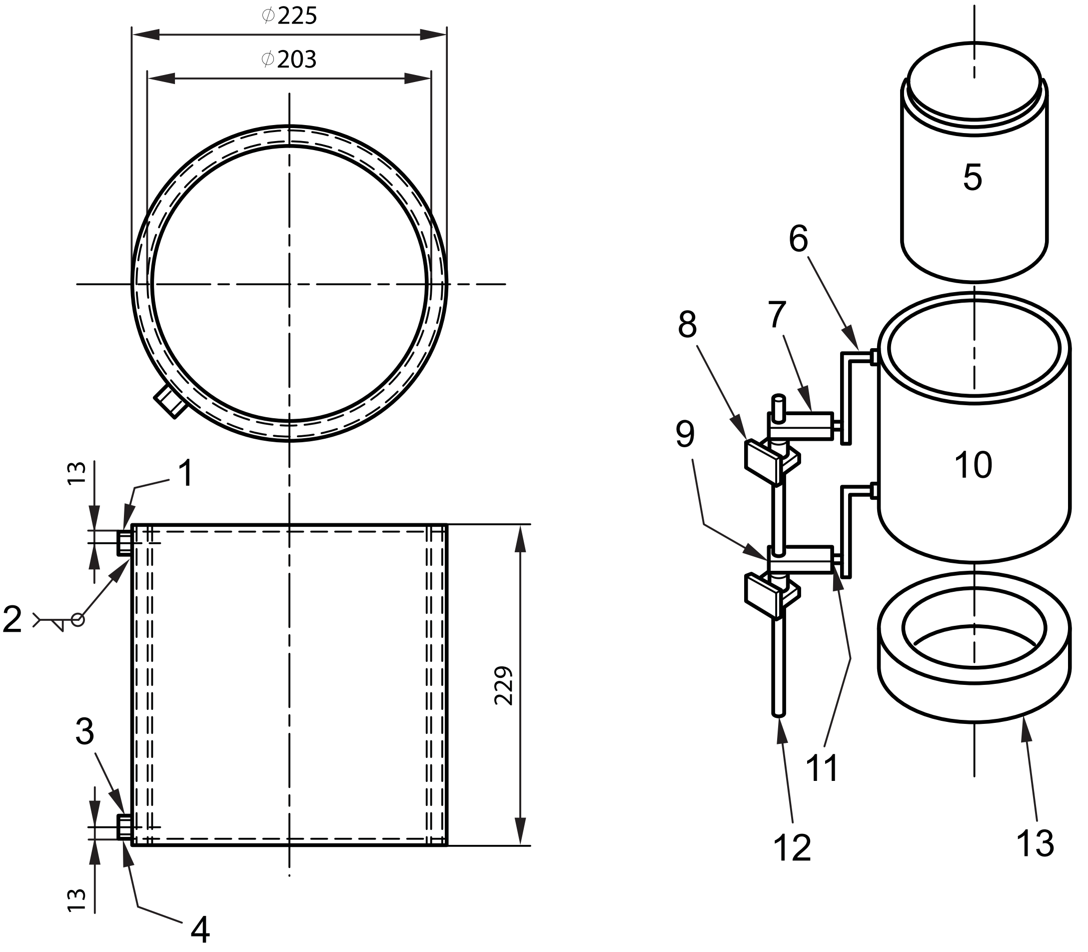
3 aluminium cylinder to support pipe

4 quartz pipe

5 ceramic paper (3 mm), added to provide airtight seal with quartz tube

Figure 7 — Combustion enclosure

Dimensions in millimetres unless otherwise specified



Detail of welded aluminium shield

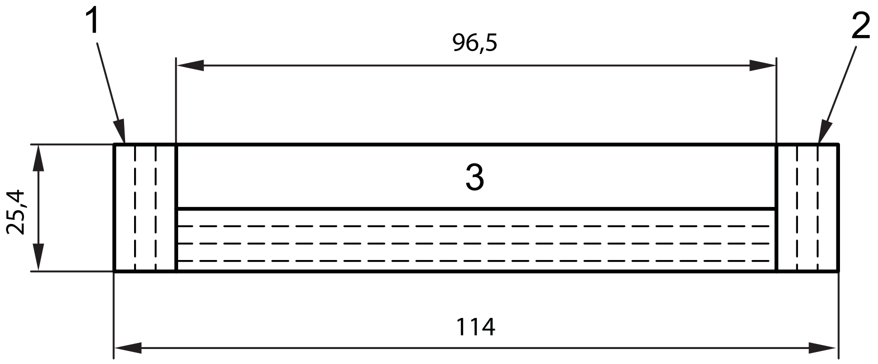
Key

1	cooling water outlet
2	welded threaded attachment (×2)
3	threaded socket, 13 mm × 2 mm
4	cooling water inlet
5	aluminium cylinder
6	copper pipe and fittings (×2), 12,7 mm diameter
7	shaft clamp (×2)
8	low friction pillow block bearing bolt to 50 mm × 50 mm × 4,5 mm angle (×2)
9	clamp to pneumatic cylinder via attaching bracket, forming part of installation
10	water cooled shield
11	soldered connection
12	shaft, 12,7 mm diameter
13	air distribution chamber (internal plates, discharge tube and inlet line omitted for clarity)

NOTE 1 View rotated 45° for clarity.

NOTE 2 Assembly is mechanically fastened except as specified.

Figure 8 — Water cooled shield



Key

1 aluminium pan, (62,6 ± 1) g

2 layers of 3 mm thick ceramic paper insulation

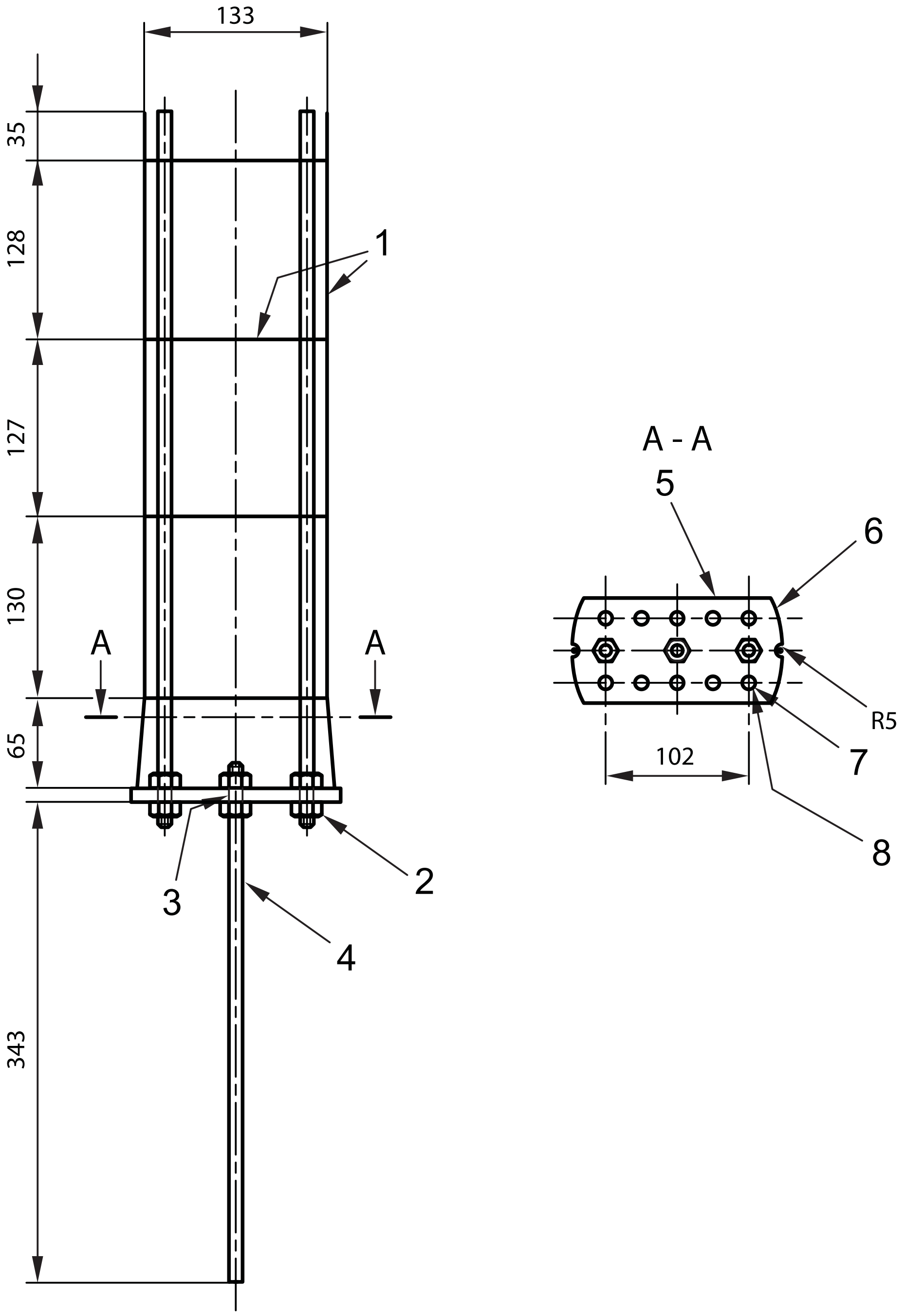
3 sample

NOTE 1 This holder is used to hold charring and non-melting materials as well as powdered specimen. All dimensions are expressed in millimetres unless otherwise specified.

NOTE 2 See Reference [8].

Figure 9 — Horizontal circular specimen holder

Dimensions in millimetres unless otherwise specified



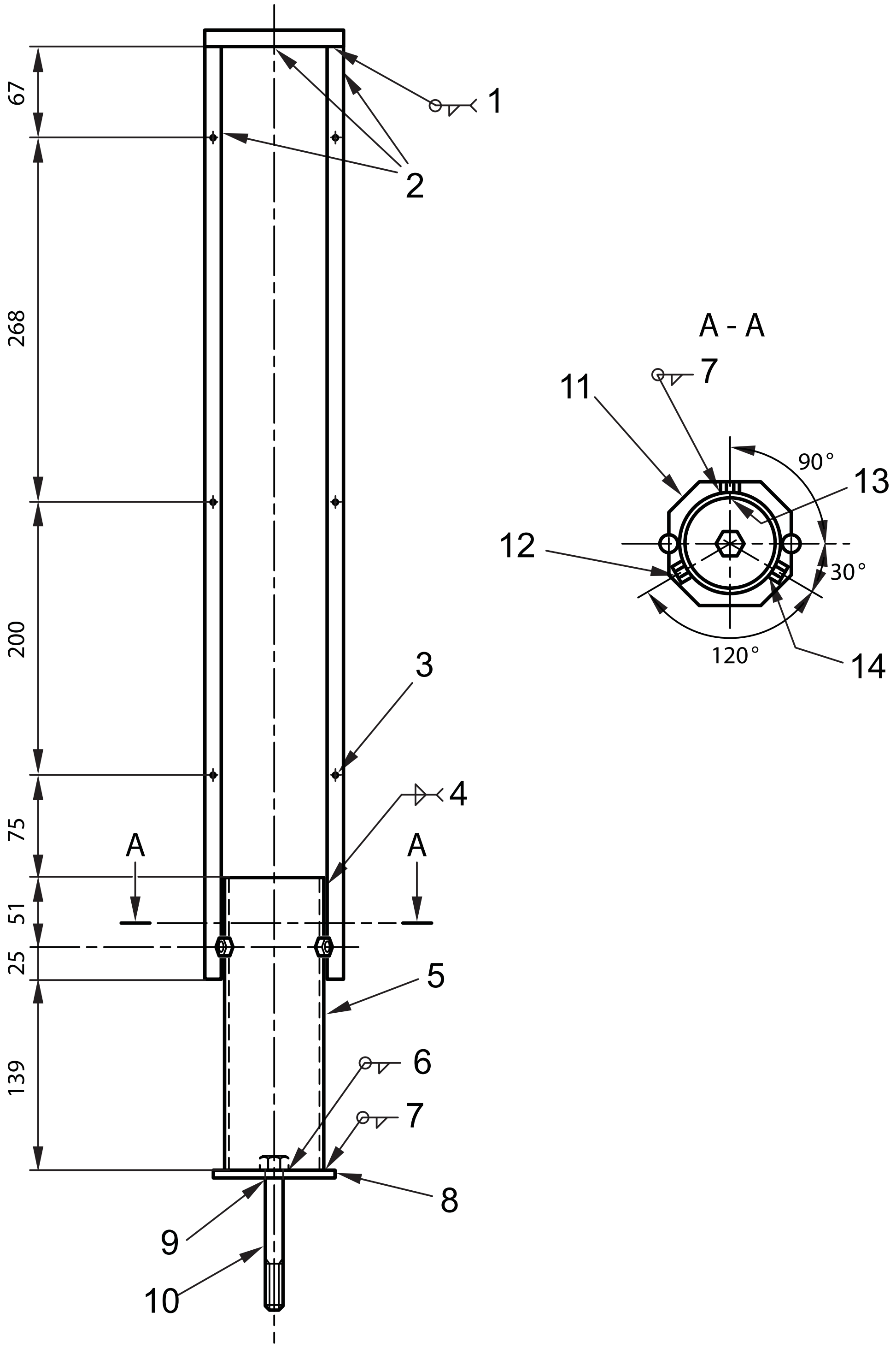
Flat specimen is secured to the ladder frame using 24-gauge wire.

Key

1	stainless steel wire ladder frame, 3 mm diameter, secured to rods with 24 gauge wire
2	hexagon nut (×6), 10 mm diameter
3	drilled hole (×3), 10 mm diameter
4	all through rod (×3), 10 mm diameter
5	steel plate, 76 mm × 150 mm × 5 mm
6	corners (required to be rounded to fit inside (×4)
7	drilled hole to provide air flow (×10), 10 mm diameter
8	holes for air flow not shown in main view for clarity

Figure 10 — Vertical specimen holder

Dimensions in millimetres unless otherwise specified



Key

1	welded joint (×2), 5 mm
2	round steel sock, 13 mm diameter
3	hole for wire to secure cable (×6), 3 mm
4	welded joints, both sides, 1,6 mm
5	steel tube, 75 mm outer diameter, 2 mm thick wall
6	welded joint, 5 mm
7	welded joint (×3), 3 mm
8	steel plate, 92 mm × 92 mm × 6 mm
9	drilled hole, 13 mm diameter
10	bolt, 13 mm diameter, 102 mm length
11	part of installation, cut off 22 mm × 45 degrees (typically 4 corners)
12	bolt (x3), 8 mm diameter, 50 mm length
13	hole drilled before welding hexagon nut to tube (×3), 10 mm diameter
14	hexagon nut spaced at 120 degrees (×3), 8 mm

NOTE Cable specimen is placed in the centre of the holder with lower end on the steel plate. It is secured by three tie wires and is centred by tightening the three bolts in the steel tube.

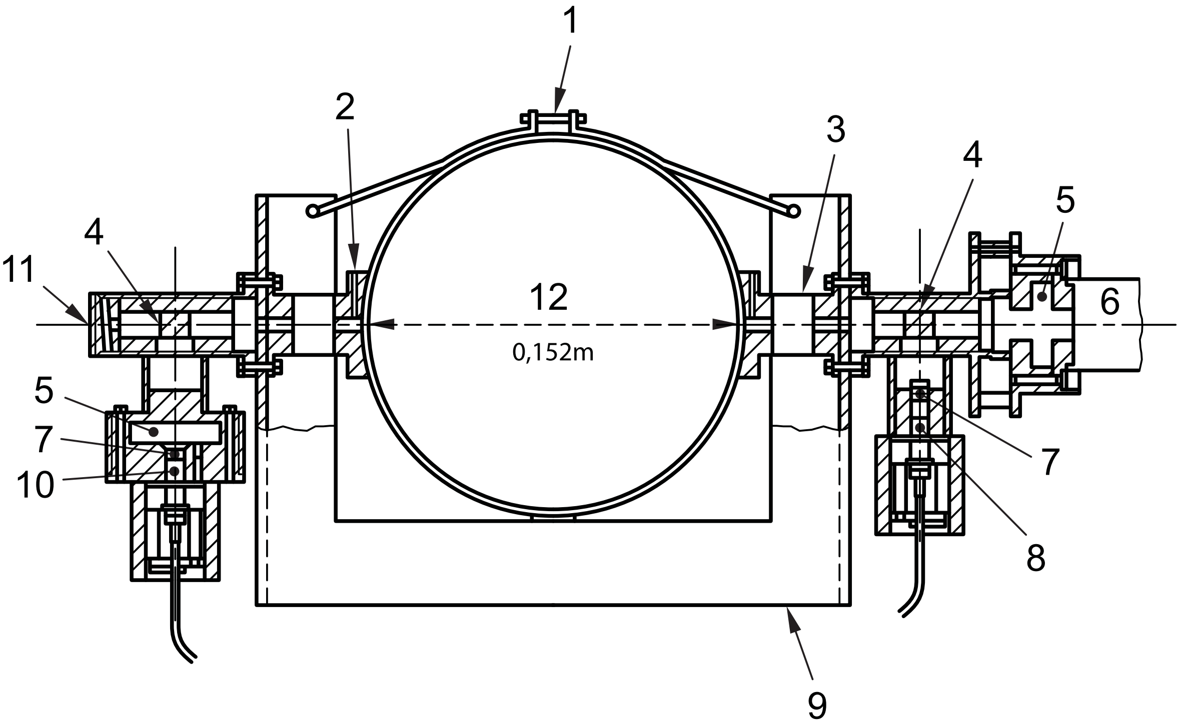
Figure 11 — Cable specimen holder

Annex A
(informative)

Laser smoke measuring system

A.1 Smoke measuring unit

The laser smoke measuring system (Figure A.1)[9] is installed in the test section duct (230 mm downstream of the gas sampling port) of the apparatus (Figure 2) and is designed to measure smoke extinction coefficient. Figure A.1 illustrates the cross section of the test section duct with an optical path length of 0,152 m. The smoke measuring system consists of a laser (0,5 mW nominal power helium-neon), which emits light energy at the red wavelength of 0,6328 µm, two photodiodes as main and compensating detectors, and associated electronics including amplifier and power supply. The laser smoke measuring system is fitted to a rigid cradle, which serves as an optical bench. The laser system is aligned so that light falls on the photo detector system, which has two signal outputs, typically in the range 0V to 2V.



Key

1	ceramic packing fibre
2	purge air orifices
3	silicone tubing
4	beam splitter
5	filter slot
6	0,5 mV helium-neon laser
7	opal glass
8	compensating detector
9	alignment cradle
10	main detector
11	cap
12	optical path

Figure A.1 — Laser smoke measuring system

A.2 Calibration of smoke system

Turn on the power of the laser smoke measuring unit at least 1 h before calibration. Two neutral density glass filters of optical density 0,3 and 0,8 values accurately calibrated at the laser wavelength of 0,6328 µm shall be used. The smoke system is initially calibrated to be read accurately for two different value neutral density filters, and also at 100 % transmission. Once this calibration is done, normally only the zero value of extinction coefficient (100 % transmission) is verified prior to each test.

A.3 Smoke calculations

The optical density in the test section duct is determined from the following equation:

$$D = \frac{\ln(I_0 / I)}{L} \tag{A.1}$$

where

D is the optical density (m^{-1}) at a laser wavelength of 0,6328 µm;

I/I_0 is the fraction of light transmitted through smoke; and

L is the optical path length (m).

The volume fraction of smoke f_v is obtained from the following equation[10]:

$$f_v = \frac{D\lambda \times 10^{-6}}{c} \tag{A.2}$$

where

λ is the wavelength of the light source (µm);

c is the coefficient of smoke extinction taken as 7[10].

The mass generation rate ($\mathrm{kg/m^2s}$) of smoke is given by:

$$\dot{m}''_\mathrm{s} = \frac{f_\mathrm{v} \dot{v} \rho_\mathrm{s} \times 10^{-6}}{A} = \left(\frac{D\lambda}{7}\right)\left(\frac{\rho_\mathrm{s} \dot{v} \times 10^{-6}}{A}\right) \tag{A.3}$$

where

$\dot{v}$ is the volumetric flow rate in the test section duct ($\mathrm{m^3/s}$) as given in Equation (B.2);

A is the burning sample surface area ($\mathrm{m^2}$).

Incorporating the value of smoke density, $\rho_s = 1{,}1 \times 10^3\ \mathrm{kg/m^3}$ from Reference [10] and the laser wavelength of 0,6328 µm in Equation (A.3) then gives the following result:

$$\dot{m}''_\mathrm{s} = 0{,}0994 \times 10^{-3} \left(\frac{D\dot{v}}{A}\right) \tag{A.4}$$

The total smoke generated, M_s (kg) is obtained by the summation of the generation rate from ignition to flame-out time:

$$M_{\mathrm{s}} = A \sum_{n=t_{ig}}^{n=t_{ex}} \dot{m}''_{\mathrm{s}}(t_{\mathrm{n}}) \Delta t_{\mathrm{n}} \tag{A.5}$$

The total mass loss, M_{loss}(kg) is calculated by the summation of the mass loss rate, $\dot{m}''$ (kg/m^{2}s) from ignition to flame-out time:

$$M_{\mathrm{loss}} = A \sum_{n=t_{ig}}^{n=t_{ex}} \dot{m}''(t_{\mathrm{n}}) \Delta t_{\mathrm{n}} \tag{A.6}$$

The average value of smoke yield $\overline{Y}_{\mathrm{s}}$ is determined as follows:

$$\overline{Y}_{\mathrm{s}} = M_{\mathrm{s}} / M_{\mathrm{loss}} \tag{A.7}$$

The average value of smoke yield, $\overline{Y}_{\mathrm{s}}$, can also be obtained from the average specific extinction area, $\overline{\tau}$ (m^2/kg) at the same laser wavelength of 0,6328 μm[11]:

$$\overline{\tau} = \frac{\sum_{\mathrm{i}} \dot{v}_{\mathrm{i}} D_{\mathrm{i}} \Delta t_{\mathrm{i}}}{M_{\mathrm{m}}} \tag{A.8}$$

The average smoke yield is in this case calculated from the following equation[12]:

$$\overline{Y}_{\mathrm{s}} = 0{,}0994 \times 10^{-3} \overline{\tau} \tag{A.9}$$

Annex B
(informative)

Rationale

B.1 Background

The fire propagation apparatus (FPA) was first developed and used by Factory Mutual Research Corporation (FMRC) during the mid-1970s. The apparatus collects the flow of combustion gases from a burning test specimen, and then conditions this flow to uniform velocity, temperature and species concentration within the test section duct, where measurements are made. As described in Reference [13], this uniformity is achieved by passing the flow through an orifice at the entry to a mixing duct, 6 duct diameters upstream of the test section.

B.2 Glossary of terms used in this annex

B.2.1
fire propagation index
FPI, ($m^{5/3}$/kW$^{2/3}$ s$^{1/2}$),
propensity of a material to support fire propagation beyond the ignition zone, determined, in part, by the chemical heat release rate during upward fire propagation in air containing 40 % oxygen

B.2.2
thermal response parameter
TRP, (kW·s$^{1/2}$/m^2),
parameter characterizing resistance to ignition upon exposure of a specimen to a prescribed heat flux

B.3 Heat release rate calculation

Total volumetric and mass flow rates of product-air mixture through the test section are calculated from measurements of volumetric flow, $\dot{v}$, and density of the flow, ρ, in the test section duct. Using these measurements, the duct mass flow rate, $\dot{m}_{\mathrm{d}}$, is calculated from the following relationship by assuming the mixture is essentially air:

$$\dot{m}_{\mathrm{d}} = \dot{v}\rho \tag{B.1}$$

The volumetric flow, v (m^3/s), in the test section duct is given by:

$$\dot{v} = A_{\mathrm{d}}K(P_{\mathrm{atm}} / 101000)^{-1/2}(2\Delta P_{\mathrm{m}}T_{\mathrm{d}} / 353)^{1/2} \tag{B.2}$$

where

353 (kg K/m^3) = $\rho\, T_{\mathrm{d}}$ for air at an atmospheric pressure of 101 (kPa).

The density of air, ρ (kg/m^3), assumed to be ideal, can be expressed as follows:

$$\rho = [353(P_{\mathrm{atm}} / 101000)] / T_{\mathrm{d}} \tag{B.3}$$

From Equation (B.1) to (B.3), the mass flow rate, $\dot{m}_{\mathrm{d}}$ (kg/s), is determined as follows:

$$\dot{m}_{\mathrm{d}} = A_{\mathrm{d}} K (P_{\mathrm{atm}} / 101000)^{1/2} (2 \times 353 \Delta P_{\mathrm{m}} / T_{\mathrm{d}})^{1/2} \tag{B.4}$$

The mass generation rate, $\dot{G}_{\mathrm{j}}$ (kg/s), of CO_2 or CO or compound j, is expressed as:

$$\dot{G}_{\mathrm{j}} = \dot{m}_{\mathrm{d}} X_{\mathrm{j}} MW_{\mathrm{j}} \tag{B.5}$$

where

$\dot{m}_{\mathrm{d}}$ is the duct mass flow rate from Equation (B.4),

X_{j} is the measured volume ratio or mole fraction of compound, j, (-), in the test section duct, and

MW_{j} is the ratio of the molecular weight of compound, j, to that of air.

The actual heat generated by chemical reactions in fires, defined as chemical heat, is calculated from the following relationships, based on generation rates of CO and CO_2 and the consumption rate of O_2:

$$\begin{aligned}\dot{Q}_{\mathrm{chem}} &= (\Delta H_{\mathrm{T}} / k_{\mathrm{CO_2}})(\dot{G}_{\mathrm{CO_2}} - \dot{G}_{\mathrm{CO_2}}{}^{0}) \\ &+ [(\Delta H_{\mathrm{T}} - \Delta H_{\mathrm{CO}} k_{\mathrm{CO}}) / k_{\mathrm{CO}}](\dot{G}_{\mathrm{CO}} - \dot{G}_{\mathrm{CO}}{}^{0})\end{aligned} \tag{B.6}$$

$$\dot{Q}_{\mathrm{chem}} = (\Delta H_{\mathrm{T}} / k_{\mathrm{O_2}}) \dot{D}_{\mathrm{O_2}} \tag{B.7}$$

The net heat of complete combustion is measured in an oxygen bomb calorimeter and the values of $k_{\mathrm{CO_2}}$, k_{CO} and $k_{\mathrm{O_2}}$ can be calculated from the measured elemental composition of the specimen material. The coefficients of $(\dot{G}_{\mathrm{CO_2}} - \dot{G}_{\mathrm{CO_2}}{}^{0})$ and $(\dot{G}_{\mathrm{CO}} - \dot{G}_{\mathrm{CO}}{}^{0})$ in Equation (B.6) or the coefficient of $\dot{D}_{\mathrm{O_2}}$ in Equation (B.7), for the particular type of material being tested, can be obtained from values tabulated in Reference [12] for that material type.

Analysis of the thermodynamics of more than 20 different classes of solids, liquids, and gases, described in Reference [7], shows that average values for the coefficients of $(\dot{G}_{\mathrm{CO_2}} - \dot{G}_{\mathrm{CO_2}}{}^{0})$ and $(\dot{G}_{\mathrm{CO}} - \dot{G}_{\mathrm{CO}}{}^{0})$ in Equation (B.6) are 13 300 (± 11 %) kJ/kg and 11 100 (± 18 %) kJ/kg, respectively, as opposed to 12 800 (± 7 %) kJ/kg for the coefficient of $\dot{D}_{\mathrm{O_2}}$ in Equation (B.7). Use of constant coefficients to determine chemical heat release rate is thus less accurate when using the CO_2 and CO generation method (mainly determined by the CO_2 uncertainty, since CO concentrations are generally very small in comparison) than for the oxygen depletion method. This inaccuracy in the use of constant coefficients is offset partly by the greater accuracy available for the direct measurement of CO_2 and CO concentrations, than that for depletion of oxygen, at low heat release rates. In both cases, accuracy is improved if the composition of the test specimen is known or is able to be assigned to one of the categories listed in Reference [12].

B.4 Application of the test methods to the evaluation of cable insulation, clean room materials and conveyor belting using a fire propagation index

B.4.1 Background

A fire propagation index (FPI) is calculated, based on the concept that fire propagation is related both to the heat flux from the flame of a burning material and to the resistance of a material to ignite[14][16]. Flame heat flux is derived from the chemical heat release rate per unit width of a vertical specimen during upward fire propagation and burning in air containing 40 % oxygen (this is needed to simulate the radiant heat flux from real-scale flames, see B.5 and References [17] and [18]). Resistance of a material to ignite is derived from the change in ignition time with changes in incident heat flux.

B.4.2 Determination of FPI

The fire propagation index is obtained from the following equation[16][19]:

$$FPI = 750(\dot{Q}_{\text{chem}} / W)^{1/3} TRP^{-1} \tag{B.8}$$

where:

$\dot{Q}_{\text{chem}}$ is a result from the fire propagation test performed with an inlet air supply containing 40 % oxygen,

W is the width of the vertical, essentially planar specimen or the circumference of the vertical cable specimen used in the fire propagation test, and

TRP is the thermal response parameter, discussed in B.4.3.

B.4.3 Determination of TRP^{-1} from ignition test results

TRP^{-1} is the slope of a straight-line regression fit to values for $t_{\text{ign}}^{-1/2}$ versus corresponding values for external heat flux (from the IR heaters). Ignition time results for this slope calculation correspond to incident heat flux values of 40, 45, 50, 55, and 60 kW/m^2. If the ratio of two standard deviations (standard errors) of the slope to the regression fit slope is greater than 10 %, additional ignition time results shall be obtained.

Figure B.1 illustrates the slope calculation as described above. Ignition times, t_{ign}, from a typical test are shown in Figure B.1. A linear regression fit to the five highest external heat flux values (40, 45, 50, 55, and 60) is shown as the solid line in Figure B.1. Regression software[4)] yields the slope of this fit, which equals TRP^{-1}, as well as the standard deviation (standard error) of the regression fit slope. Lines having a slope two standard deviations greater than and two standard deviations less than the regression fit slope also are shown in Figure B.1. In this case, the data scatter is acceptable since two standard deviations of the slope are less than 10 % of the regression fit slope.

B.5 Background on the use of a 40 % oxygen concentration for the fire propagation test

A key feature of the fire propagation index (FPI) discussed in B.4 is the use of fire propagation test results obtained for an inlet air supply containing a 40 % oxygen concentration. This is done to simulate, in a small-scale apparatus, the radiant heat flux from real-scale flames in various fire situations.

It is shown in References [12] and [18] that flame radiant heat flux associated with a variety of burning polymeric materials increases as the ambient oxygen concentration in air is increased, with radiant flux reaching an asymptotic value near an oxygen concentration of 40 %. This result is not surprising in view of the fact that increasing the oxygen concentration in normal air increases flame temperatures somewhat and increases soot production reaction rates substantially; hence, flames in air which have a 40 % oxygen concentration would be expected to have higher concentrations of luminous soot particles and to radiate much more efficiently than flames in normal air.

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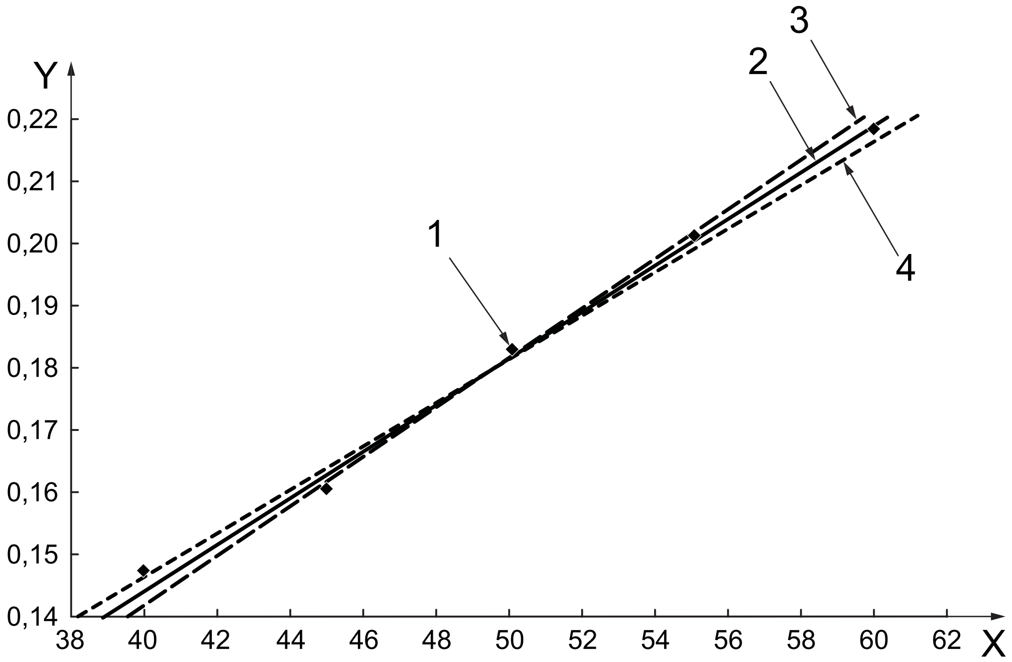
4) The LINEST function in Microsoft Excel is suitable for this purpose. Microsoft Excel is an example of a suitable product available commercially. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of this product.



Key

X external heat flux [kW/m^2]

Y $(i/t_{ign})^{1/2}$ [s$^{-1/2}$]

1 ignition test data

2 regression fit

3 regression fit slope + 2 standard deviations

4 regression fit slope − 2 standard deviations

Figure B.1 — Ignition time measurements to determine TRP

The following table, extracted from Table 1 in Reference [18], illustrates the point made in the preceding subclause for a combustion test of a 0,093 m diameter specimen of polypropylene without the use of the IR heaters (see Table B.1).

Table B.1 shows that the calculated flame radiant flux from a laboratory-scale specimen is only 14 kW/m^2 in normal air (21 % oxygen) but increases to the level of 40 kW/m^2 to 50 kW/m^2, characteristic of large-scale fires[18] when the oxygen concentration is increased to 40 %[20].

Table B.1 — Effect of oxygen concentration on flame radiant flux from a 93 mm diameter polypropylene specimen in the absence of external heating

Oxygen concentration in air, %	Flame radiant heat flux kW/m^2
21	14
24	23
28	37
34	41
40	44
47	53

B.6 Real-scale fire behaviour and the fire propagation index of cable insulation, clean room materials and conveyor belting

Values of fire propagation index (FPI, see B.4), as well as fire propagation behaviour during real-scale tests, are addressed in References [15] and [16] for electrical cables insulated with polymeric material and in References [19] and [20] for solid panels of polymeric clean room materials used in the semiconductor industry. The real-scale tests involved fires initiated by a 60 kW propane sand-burner located between vertical, parallel arrays of the cables or clean room materials. In addition, values of FPI for conveyor belts, as well as fire propagation behaviour of these belts in a U.S. Bureau of Mines large-scale fire test gallery, are addressed in Reference [21]. Fires in the large-scale gallery were initiated by a burning flammable liquid pool.

Table B.2, extracted from Table 1 in Reference [19] and from information in Reference [21], illustrates how the fire propagation index is related to real-scale fire propagation behaviour shown in Table B.2.

Table B.2 shows that a fire propagation index equal to or less than a value of 6 $m^{5/3}/kW^{2/3}s^{1/2}$ correlates very well with real-scale fire behaviour for which propagation is limited to the ignition zone.

Table B.2 — Comparison of FPI value with real-scale fire propagation behaviour

Material composition and arrangement[a]	FPI from fire propagation test method, $m^{5/3}/kW^{2/3}s^{1/2}$	Fire propagation beyond the ignition zone at real-scale[b]
Grey PVC panel	4	None
PVDF panel	5	None
White PVC panel	6	None
Rigid, Type I PVC panel	8	Limited
Modified FRPP panel	9	Yes
ETFE panel	9	Limited
FRPP panel	>10	Yes
PMMA panel	>10	Yes
XLPE/Neoprene cable	9	Limited
PVC/PVDF cable	7	None
XLPO cable	9	Limited
XLPE/EVA cable	7	Limited
PE/PVC cable	20	Yes
CR or PVC conveyor belts	<6	None
CR or SBR conveyor belts	7 to 8	Limited
PVC or SBR conveyor belts	>8	Yes

[a] Polymer abbreviations: PVC—polyvinylchloride; PVDF—polyvinylidene fluoride; FRPP—fire retarded polypropylene; ETFE—ethylenetetrafluoroethylene; PMMA—polymethylmethacrylate; XLPE—crosslinked polyethylene; XLPO—crosslinked polyolefin; EVA—ethylvinyl acetate; PE—polyethylene; CR—chloroprene rubber; SBR—styrene-butadiene rubber.

[b] Propagation behaviour definitions: Yes—fire propagates beyond the ignition zone to the boundary of the exposed material surface; Limited—fire propagates beyond the ignition zone but propagation stops well before the boundary of the exposed material surface; None—fire does not propagate beyond the ignition zone, defined as the area of flame coverage by the initiating fire source.

B.7 Examples of materials that have undergone the test methods

A wide range of polymeric materials and products have undergone the ignition, combustion, or fire propagation test methods, in addition to the polymers noted in B.6. Table B.3, extracted from Reference [12] and from Table 1 in Reference [19], lists these polymer groups.

The ignition and combustion test methods, as well as other tests performed in the FPA, have been used to obtain flammability characteristics of plywood specimens for use in a predictive model of upward fire propagation, as described in Reference [12]. Predictions from the computer model were in close agreement with the results of real-scale fire tests of vertical panels of the same plywood materials.

Table B.3 — Examples of materials that have undergone test methods

Description of polymer or material containing polymer	Parameters calculated
Polystyrene	TRP, EHC
Polypropylene	TRP, EHC
Polyoxymethylene	TRP, EHC
Nylon	TRP, EHC
Polycarbonate	TRP, EHC
Fibreglass-reinforced polyester	TRP, FPI, EHC
Fibreglass-reinforced epoxy	TRP, FPI,EHC
Fluorinated ethylene-propylene	TRP, FPI, EHC
Phenolic/Kevlar composite	TRP, FPI, EHC
Polyurethane foams	TRP, EHC
Polystyrene foams	TRP, EHC
Phenolic foams	TRP, EHC
Wood, cardboard containing cellulose	TRP, FPI, EHC

B.8 Precision

Table B.4 presents data on precision, based on a comparison of results from the ignition test method performed at two separate laboratories. Table B.5 presents data on precision, based on a comparison of results from the fire propagation test method with an inlet air supply containing 40 % oxygen, performed at the same two laboratories.

Table B.4 — Reproducibility of data on ignition time

Polymer-insulated cable type	Incident heat flux (kW/m²)	Time to ignition, apparatus 1 (s)	Time to ignition, apparatus 2 (s)	Relative difference of each ignition time from the mean value (%)
Insulated cable 1	20	265	260	1
Insulated cable 1	30	91	102	5,7
Insulated cable 1	40	45	58	12,6
Insulated cable 1	50	34	36	2,9
Insulated cable 1	60	21	24	6,7
Insulated cable 2	15	334	320	2,1
Insulated cable 2	30	42	41	1,2
Insulated cable 2	40	24	24	0
Insulated cable 2	50	17	17	0
Insulated cable 2	60	13	11	8,3

Table B.5 — Reproducibility of data on heat release rate

Specimen type	Peak heat release rate, apparatus 1 (kW)	Peak heat release rate, apparatus 2 (kW)	Relative difference of each heat release rate from the mean value (%)
Insulated cable 1	7	6	7,7
Insulated cable 2	5,6	5,2	3,7
Insulated cable 3	8	7,5	3,2
Conveyor belt 1	13,4	10,8	10,7
Conveyor belt 2	9,25	9,05	1,1

Annex C
(informative)

Comparison of results – vertical and horizontal exhaust ducts

C.1 General considerations

The fire propagation apparatus (FPA) has been developed using a horizontal exhaust configuration (see Figures 1 and 2). This alternative configuration has undergone extensive testing to ensure compatibility of results with the original, vertical exhaust duct FPA[6]. As part of the testing procedure, the uniformity of the flow in the measuring section of the horizontal exhaust duct was checked using probe traverses. It was determined that uniformity (in terms of flat velocity, temperature and concentration profiles) could be achieved with a 1,6 mm thick orifice plate having a mixing orifice diameter of 91,5 mm at an exhaust flow rate of 0,152 ± 0,015 m^3/s[6].

C.2 Test conditions

To compare results from the horizontal exhaust configuration (Figures 1 and 2) with those from the original vertical configuration, ignition, combustion and propagation test methods were performed following 11.1, 11.2 and 11.4 respectively, with acetone (liquid), clear PMMA with 9,5 mm thickness, rigid PVC with 9,5 mm thickness, rigid CPVC with 9,5 mm thickness, or a combination thereof. Acetone was tested without any external heat flux. The PMMA and rigid PVC specimens were exposed to 50 kW/m^2 external heat flux in normal air. The CPVC specimens were tested in a gaseous mixture with a 40 % oxygen concentration, by volume, generated by added oxygen to ambient air.

C.3 Effective heat of combustion

Table C.1 summarizes test results calculated in accordance with Clause 12.

Table C.1 — Effective heat of combustion

Specimen composition	Effective heat of combustion — vertical exhaust configuration (kJ/g)	Effective heat of combustion — horizontal exhaust configuration (kJ/g)	Relative difference from the mean value (%)
Acetone	27,1	26,8	0,6
Acetone	26,9	27,4	0,9
Acetone	27,8	26,9	1,6
PMMA	24,9	24,6	0,6
PMMA	24,8	25,0	0,4
PMMA	25,0	25,2	0,4
Rigid PVC	6,62	6,0	4,9
Rigid PVC	6,07	5,74	2,8
NOTE See Reference [6].			

C.4 Time to ignition

Table C.2 and Table C.3 present the measured time to ignition as a function of incident heat flux for PMMA and Rigid PVC specimens, respectively.

Table C.2 — Ignition test results for PMMA

Incident heat flux (kW/m²)	Ignition time — vertical exhaust configuration (s)	Ignition time — horizontal exhaust configuration (s)	Relative difference from the mean value (%)
30	37,4	38,7	1,7
40	22,4	24,0	3,4
50	14,4	15,4	3,4
60	10,1	10,9	3,8
NOTE See Reference [6]			

Table C.3 — Ignition test results for rigid PVC[a]

Incident heat flux (kW/m²)	Ignition time — vertical exhaust configuration (s)	Ignition time — horizontal exhaust configuration (s)	Relative difference from the mean value (%)
30	117	114	1,3
40	72,1	75,8	2,5
50	47,3	49,2	2
60	34,6	34,9	0,4
NOTE See Reference [6].			
[a] Samples were restrained with 24-gauge (0,5 mm diameter) nickel-chromium wire.			

C.5 Chemical heat release rate in the combustion test method

The peak chemical heat release rates (from running 15 s averages) for horizontal PMMA and rigid PVC are presented in Table C.4.

Table C.4 — Chemical heat release rate in combustion test

Specimen Composition	Chemical Heat Release Rate — Vertical Exhaust Configuration (kW)	Chemical Heat Release Rate — Horizontal Exhaust Configuration (kW)	Relative Difference from the Mean Value (%)
PMMA	9,8	10,2	2,0
Rigid PVC	0,88	0,91	1,7
Rigid PVC	0,80	0,91	6,4
NOTE See Reference [6].			

C.6 Chemical heat release rate during propagation test

Table C.5 gives peak heat release rate values from running 15 s averages during the fire propagation test method, as determined with both exhaust duct orientations. An air inflow with a 40 % oxygen concentration is used for three repeat tests with vertical CPVC specimens[6].

Table C.5 — Chemical heat release rate of vertical CPVC specimens during propagation test

FPA with vertical exhaust (kW)	**FPA with horizontal exhaust** (kW)	**Relative difference from the mean value** (%)
3,37	3,84	6,5
3,38	3,70	4,5
3,61	3,92	4,1

C.7 Observations

Based on the measurements and results in C.3 to C.6, the FPA incorporating a horizontal duct provides comparable results to those measured using the original FPA with a vertical exhaust duct as reported in Reference [6].

Annex D
(informative)

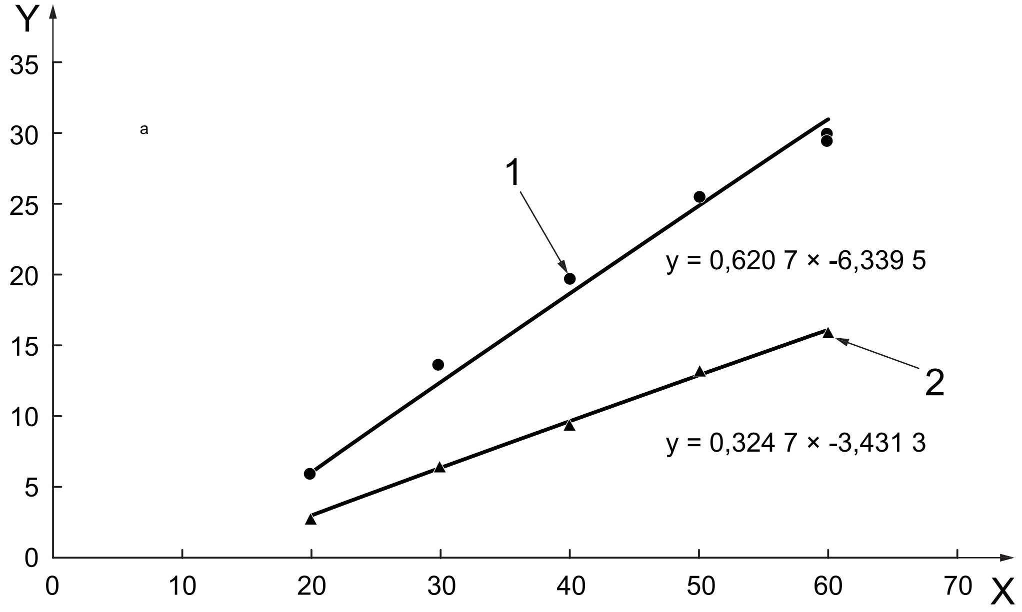
Heat of gasification

D.1 Introduction

Heat of gasification (kJ/g) represents the quantity of heat that should be absorbed by the material to gasify a unit mass of the material. As mentioned in 11.3, pyrolysis tests are conducted in a 100 % nitrogen environment, exposing the specimen to various external radiant heat flux values. The mass loss rate per unit specimen surface area as a function of time is measured for each external radiant heat flux.

D.2 Data analysis

Figure D.1 presents mass loss rate as a function of external radiant heat flux. In the case of black PMMA, the average steady-state mass loss rate is determined for each heat flux value. For charring material, such as PVC, the average peak value of mass loss rate per unit specimen surface area during the initial char forming period is considered. The inverse of the slope of each curve provides the heat of gasification value. Thus, the heats of gasification values are 1,61 kJ/g and 3,08 kJ/g for PMMA and PVC, respectively.



Key

X external heat flux (kW/m^2)
Y mass loss rate (g/m^{2}s)
1 black PMMA
2 grey PVC

[a] Pyrolysis at 0% oxygen concentration.

Figure D.1 — Mass loss rate as a function of external radiant heat flux

D.3 Heats of gasification for various materials tested in FPA

Heats of gasification determined from the mass loss rate per unit specimen surface area as a function of external radiant heat flux in non-flaming fire conditions (i.e. in 100 % nitrogen environment) in the FPA are listed in Table D.1 for selected materials. Agreement can be noted between the heats of gasification determined from the FPA and those obtained from the differential scanning calorimetry.

Table D.1 — Heats of gasification of various materials

Material	**Heat of gasification in fire propagation apparatus** (kJ/g)	**Heat of gasification in differential scanning calorimetry** (kJ/g)
Filter paper	3,6	—
Wood (Douglas fir)	1,8	—
Plywood/FR	1,0	—
Corrugated cardboard	2,2	—
Polypropylene	2,0	2,0
Polyethylene (low density)	1,8	1,9
Polyethylene (high density)	2,3	2,2
PE foams	1,4-1,7	—
Rigid polyvinylchloride (PVC)	3,08	—
PVC/plasticizer	1,7	—
Polyisoprene	2,0	—
PVC panel	3,1	—
Nylon 6/6	2,4	—
Polyoxymethylene (Delrin)	2,4	2,4
Polymethylmethacrylate	1,61	1,6
Polycarbonate	2,1	—
Acrylonitrile-butadiene-styrene	3,2	—
Polystyrene foam	1,3-1,9	—
Polystyrene (granular)	1,7	1,8
Flexible polyurethane foam	1,2-2,7	1,4
Rigid polyurethane foam	1,2-5,3	—
Polyisocyanurate foam	1,2-6,4	—
Fluorinated ethylene propylene	2,4	—
Tetrafluoroethylene	0,8-1,8	—
NOTE See Reference [12].		

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