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BSI Standards Publication

Common test methods for cables under fire conditions — Heat release and smoke production measurement on cables during flame spread test — Test apparatus, procedures, results

National foreword

This British Standard is the UK implementation of EN 50399:2011+A1:2016. It supersedes BS EN 50399:2011 which will be withdrawn on 18 April 2019.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by A1〉 〈A1.

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A list of organizations represented on this subcommittee can be obtained on request to its secretary.

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EN 50399:2011+A1

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English version

Common test methods for cables under fire conditions - Heat release and smoke production measurement on cables during flame spread test - Test apparatus, procedures, results

Méthodes d'essai communes aux câbles soumis au feu -
Mesure de la chaleur et de la fumée dégagées par les câbles au cours de l'essai de propagation de la flamme -
Appareillage d'essai, procédure et résultats

Allgemeine Prüfverfahren für das Verhalten von Kabeln und isolierten Leitungen im Brandfall -
Messung der Wärmefreisetzung und Raucherzeugung während der Prüfung der Flammenausbreitung -
Prüfeinrichtung, Prüfverfahren und Prüfergebnis

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Management Centre: Avenue Marnix 17, B - 1000 Brussels

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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 20, Electric cables.

The text of the draft was submitted to the formal vote and was approved by CENELEC as EN 50399 on 2011-02-28.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-02-28
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-02-28

Foreword to amendment A1

This document (EN 50399:2011/A1:2016) has been prepared by CLC/TC 20 “Electric cables”.

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-04-18
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2019-04-18

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Introduction

EN 50399 specifies the test apparatus and test procedures for the assessment of the reaction to fire performance of cables to enable classification under the Construction Products Directive [1] to be achieved.

The test method describes an intermediate scale fire test of multiple cables mounted on a vertical cable ladder and is carried out with a specified ignition source to evaluate the burning behaviour of such cables and enable a direct declaration of performance. The test provides data for the early stages of a cable fire from ignition of cables. It addresses the hazard of propagation of flames along the cable, the potential, by the measurement of the heat release rate, for the fire to affect areas adjacent to the compartment of origin, and the hazard, by the measurement of production of light obstructing smoke, of reduced visibility in the room of origin and surrounding enclosures.

The following parameters may be determined under defined conditions during the test:

a) flame spread;

b) heat release rate;

c) total heat release;

d) smoke production rate;

e) total smoke production;

f) fire growth rate index;

g) occurrence of flaming droplets/particles .

The apparatus is based upon that of EN 60332-3-10 but with additional instrumentation to measure heat release and smoke production during the test. It has been demonstrated [3] that the utilisation of these additional measurement techniques, proven for other standard tests, e.g. for building products, are appropriate for assessing the reaction to fire performance of electric cables. These techniques include heat release and smoke production measurements. Compared with existing test methods described in EN 60332-3-10, they enable a more comprehensive assessment system, which is both more precise and sensitive, and enables a wider range of fire performance levels.

Care should be exercised in relating the parameters measured to different safety levels in actual cable installations as the actual installed configuration of the cables may be a major determinant in the level of flame spread, heat release and smoke production occurring in an actual fire. These parameters depend upon a number of features, such as

a) the volume of combustible material exposed to the fire and to any flaming or heat which may be produced by the combustion of the cables;

b) the geometrical configuration of the cables and their relationship to an enclosure;

c) the temperature at which it is possible to ignite the gases emitted from the cables;

d) the quantity of combustible gas released from the cables for a given temperature rise;

e) the volume of air passing through the cable installation;

f) the construction of the cable, e.g. armoured or unarmoured, multi or single core.

All of the foregoing assumes that the cables are able to be ignited when involved in an external fire.

The conditions of cable mounting, including volume of material exposed and geometrical configuration of the cables on the test ladder, and volume of airflow through the chamber have been chosen to be in accordance with that required by the Commission Decision 2006/751/EC [2]. CENELEC has not been involved in the definition of these parameters. These standardised conditions provide the basis for classification but do not necessarily correspond to conditions found in a particular cable installation.

NOTE Further information on the use of standardised conditions for classification with respect to product end-use application may be found in European Commission Guidance Paper G [4].

EN 50399 gives details of the apparatus to be used in conjunction with the equipment described in EN 60332-3-10 in order to carry out the measurement of heat release and smoke production during the test. Details of the test procedures are also given.

1 Scope

EN 50399 specifies the apparatus and methods of test for the assessment of vertical flame spread, heat release, smoke production and occurrence of flaming droplets/particles of vertically-mounted bunched wires or cables, electrical or optical, under defined conditions.

NOTE For the purpose of this standard the term "electric wire or cable" covers all insulated metallic conductor cables used for the conveyance of energy or signals.

EN 50399 details the apparatus and the arrangement and calibration of the instrumentation to be installed in order to measure the heat release and the smoke production during the test. The combustion gases are collected in a hood above the test chamber and conveyed through an exhaust system, which allows the measurement of heat release rate and smoke production. Test procedures to be used for type approval testing for classification of cables in Euroclasses $B1_{ca}$, $B2_{ca}$, C_{ca} and D_{ca} are given. Cable installation on the test ladder and the volume of air passing through the chamber are in accordance with the Commission Decision 2006/751/EC [2] which is reflected in the requirements of this standard.

The apparatus described in this standard shall be used in conjunction with that described in EN 60332-3-10.

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.

A1⟩ EN 60332-3-10:2009, *Tests on electric and optical fibre cables under fire conditions – Part 3-10: Test for vertical flame spread of vertically-mounted bunched wires or cables – Apparatus (IEC 60332-3-10:2000)* ⟨A1

EN 60584-1, *Thermocouples – Part 1: Reference tables (IEC 60584-1)*

EN ISO 13943:2010, *-Fire safety – Vocabulary (ISO 13943:2008)*

ISO 3966, *Measurement of fluid flow in closed conduits – Velocity area method using Pitot static tubes*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in EN ISO 13943:2010 and the following apply.

3.1
heat release rate
HRR
thermal energy released per unit time by an item during combustion under specified conditions

3.2
total heat release
THR
integrated value of the heat release rate over a defined period

3.3
smoke production rate
SPR
smoke production per unit time

3.4

total smoke production

TSP

integrated value of the smoke production rate over a defined period

3.5

flame spread

FS

propagation of a flame front

NOTE In this standard the extent of flame spread is determined as the extent of damage measured by the onset of char.

3.6

fire growth rate index

FIGRA

highest value of the quotient between *HRR* and time

NOTE 1 In this standard *FIGRA* is expressed in W/s.

NOTE 2 Details of the calculation of *FIGRA* are given in Annex G.

3.7

flaming droplets/particles

material separating from the specimen during the test and continuing to flame for a minimum period as described in this test method

3.8

E-value

heat release per volume of oxygen consumed

4 Test apparatus

4.1 General

The test apparatus shall consist of the test chamber, standard ladder and ignition source, as described in EN 60332-3-10, with the additional features as specified in 4.2 to 4.8. Figure 1 shows a schematic diagram of the apparatus. The ignition source shall be one ribbon-type propane gas burner. The ladder shall be the standard ladder of (500 ± 5) mm width. The air supply shall be a system that blows air into the chamber at an airflow rate of (8 000 ± 400) l/min.

The additional features of the apparatus shall be capable of measuring the following parameters:

a) oxygen consumption;

b) CO_2 production;

c) volume flow in the exhaust duct;

d) smoke production.

WARNING Care should be taken in monitoring and extinguishing cable fires once the test specimen has started to propagate fire. Some specimens may have a very high capacity to generate high heat release levels that could damage the test equipment and instrumentation. It is important that testing staff are sufficiently trained in dealing with such fires and have adequate fire fighting facilities at their disposal during testing.

NOTE 1 It is recommended that indicative temperature measurements are taken through the use of thermocouples installed along the cable bunch being tested at 1,5 m and 2,5 m above the burner and at the top of the chamber or in the duct. Such measurements can give an early indication of any excessive temperature or burning condition that may require the test to be aborted in order to prevent damage to the test equipment.

All data shall be measured and recorded every 3 s. These point measurements shall be averaged over a period of 30 s for parameters relating to heat release and 60 s for parameters relating to smoke production, in order to provide the required data. The data shall be processed according to the requirements of this standard.

NOTE 2 It is necessary to produce the average measurement in order to damp the variability caused by frequent point measurement.

The additional features and their associated measurements shall allow for calculation of the following:

a) heat release (see Annex A);
   1) heat release rate (*HRR*);
   2) total heat release (*THR*);
   3) fire growth rate index (*FIGRA*);

b) smoke production (see Annex B);
   1) smoke production rate (*SPR*);
   2) total smoke production (*TSP*).

4.2 Air input

Air shall be introduced to the test chamber through a plenum box fitted directly underneath, and of approximately the same dimensions as, the air inlet aperture. The depth of the plenum box shall be (150 ± 10) mm. Air shall be blown into the plenum box from a fan through a rectangular straight section of duct of constant cross section of (300 ± 10) mm width and (80 ± 5) mm height and a minimum length of 800 mm, which shall enter from the rear of the chamber and be parallel to the floor and along the burner centre line as shown in Figure 1. The duct shall be arranged to inlet air to the plenum box through an aperture in the longest side, centred horizontally and such that the bottom of the duct shall be no greater than 10 mm above the bottom of the plenum box. A grid shall be fitted in the air inlet aperture to achieve uniform flow of the air. The grid shall be constructed of steel plate approximately 2 mm thick with holes of approximately 5 mm diameter drilled at approximately 8 mm spacing between centres.

The airflow rate shall be measured in a circular duct prior to the rectangular cross section duct. It shall be measured by a gas flow measuring device located at a straight section of the circular duct. The minimum length of straight circular section before and after the measuring device shall be selected according to the technical specification of the measuring device.

NOTE 1 A fluid flow measuring system according to either EN ISO 5167-2 (orifice plate) or EN ISO 5167-4 (Venturi tube) is recommended. Alternatively, a Pitot tube taking multiple samples across the section of the duct and averaging to account for variations across the section or a hot wire anemometer measuring at multiple positions across the section of the duct as described in Annex D may be used.

The airflow shall be set prior to a test at (8 000 ± 400) l / min and shall not be changed during the test. The airflow shall be checked throughout the test and shall not vary by more than 10 % of the set value.

NOTE 2 This information does not need to be recorded.

4.3 Hood

A hood (see Figure 2) having a truncated shape, and where the base has a minimum length of 1,50 m and a minimum width of 1,00 m, shall be centred above the outlet of the test chamber. The base of the hood shall be raised above the top of the test chamber, with the largest side of the hood parallel to the largest side of the outlet of the chamber.

NOTE 1 A gap of approximately 200 mm to 400 mm between the top of the test chamber and the base of the hood has generally been found suitable.

There shall be a chamber above the hood to allow a connection to the exhaust duct.

NOTE 2 Plates/baffles may be installed in the hood to improve mixing of the air / effluents.

The system shall be designed to collect all the combustion products leaving the test chamber through the outlet during the test. There shall be no leakage of flames or smoke. The exhaust capacity shall be at least 1 m^3/s at normal pressure and a temperature of 25 °C. The exhaust system design shall not be based on natural convection.

NOTE 3 In order to extract all gases and vapours, especially in the case of heavily burning cables, or cables which require to be specially extinguished and produce high volumes of gases and vapours, an exhaust system with a capacity of 1,5 m^3/s is recommended.

4.4 Exhaust duct

An exhaust duct shall be connected to the hood as described in 4.3. The inner diameter, D, of the duct shall be in the range 250 mm to 400 mm. The straight section of the duct shall have a minimum length of 12 x D, such that a uniform flow profile is established at the point of measurement.

NOTE A uniform flow profile can be obtained by introducing guide vanes (see Figure 3) before and after the measuring section such as described in EN 14390. This is highly recommended in order to obtain as precise measurements as possible.

4.5 Instrumentation in the exhaust duct

4.5.1 Volume flow

The flow shall be measured by a bidirectional probe located at the centre line of the duct and at a minimum distance from the beginning of the straight section of exhaust duct of 8 x D. The length of the straight section of duct beyond the probe shall be at least 4 x D. The probe which is shown in Figure 4 consists of a stainless steel cylinder, 32 mm long and with an outer diameter of 16 mm. The cylinder is divided into two equal chambers. The pressure difference between the two chambers shall be measured by a pressure transducer. The plot of the probe response versus the Reynolds number is shown in Figure 5 (see also Annex C).

The pressure transducer shall have a measuring precision better than ± 5 Pa. A suitable range of measurement is 0 Pa to 200 Pa (when using duct diameters between 250 mm and 400 mm).

The two connection pipes between the bidirectional probe and the pressure transducer shall be of the same length.

Gas temperature in the immediate vicinity of the probe shall be measured by a sheathed K type thermocouple with a maximum diameter of 1,5 mm in accordance with EN 60584-1. The thermocouple shall be positioned so that it does not disturb the flow pattern around the bidirectional probe.

NOTE If more than one thermocouple is used then all thermocouples shall be of the same size and type.

4.5.2 Sampling probe

The sampling probe shall be located where the exhaust duct flow is well mixed. The probe shall have a cylindrical form so that disturbance of flow is minimised. The gas samples shall be taken along the whole diameter of the exhaust duct. Examples of suitable sampling probes are shown in Figure 6. The intake of the sampling probe shall be turned downstream in order to avoid soot clogging in the probe. The sampling probe shall be connected to the gas analysers for oxygen (O_2) and carbon dioxide (CO_2) by a suitable sampling line.

4.5.3 Sampling line

The sampling line shall be manufactured from corrosion resistant material, e.g. PTFE. The combustion gases shall be filtered with inert filters to the degree of particle concentration required by the gas analysis equipment. The filtering procedure shall be carried out in more than one step. The system shall be capable of removing water vapour.

The combustion gas shall be transported by a pump which does not emit oil, grease or similar products, as these may contaminate the gas mixture.

NOTE A membrane pump is suitable.

A pump capacity between 10 l/min and 50 l/min is recommended. The pump shall generate a pressure differential of at least 10 kPa to reduce the risk of clogging of the filters by smoke.

The sampling line (see Figure 7) shall be connected at its end to O_2 and CO_2 analysers.

4.6 Extracting ventilator

At the end of the exhaust duct, an extracting ventilator shall be installed. A minimum exhaust capacity of 1,5 m^3/s at normal pressure and at a temperature of 25 °C is recommended.

NOTE Legal requirements may make it necessary for equipment for collecting and washing the effluent to be fitted to the test chamber. This equipment shall be such as to collect all the effluents without causing a change in the air flow rate through the test chamber.

4.7 Smoke production measuring equipment

4.7.1 General

The optical density of the smoke can be measured by two different measuring techniques as described in 4.7.2 and 4.7.3. Although the measurement principle differs for both systems, it has been shown that the two different systems do not give substantially different results [3].

A general arrangement of an optical system is shown in Figure 8.

NOTE 1 Other systems may be used provided that their equivalence to those specified has been demonstrated.

NOTE 2 Based upon experience, white light systems are recommended.

The smoke production measuring equipment shall be located where the exhaust duct flow is well mixed.

4.7.2 White light system

A light attenuation system, of the white light type, mounted with a flexible connection to the side ducts of the exhaust duct, shall consist of the following.

a) A lamp, of the incandescent filament type operating at a colour temperature of (2 900 ± 100) K. The lamp shall be supplied with stabilized direct current, stable within 0,5 % (including temperature, short-term and long-term stability).

b) A lens system, to align the light to a parallel beam and with a diameter of at least 20 mm. The photocell aperture shall be placed at the focus of the lens in front of it and it shall have a diameter, d, chosen with regard to the focal length of the lens, f, so that d/f is less than 0,04.

c) A detector, with a spectrally distributed responsivity agreeing with the CIE V(λ) function (CIE photopic curves) to an accuracy of within ± 5 %. The detector output shall, over an output range of at least two decades, be linear within 3 % of the measured transmission value or 1 % of the absolute transmission.

Calibration of the light attenuation system shall be carried out according to E.4. The 90 % response time of the system shall be not more than 3 s.

Air may be introduced in the side ducts so that the optics stay clean, within the given light attenuation drift requirements (see E.4.2). Pressurized air can be used instead of a self suction system.

4.7.3 Laser light system

A laser photometer system shall use a helium-neon laser with a power output between 0,5 mW and 2,0 mW.

Air may be introduced in the side ducts so that the optics stay clean, within the given light attenuation drift requirements (see E.4.2). Pressurized air may be used instead of a self suction system.

NOTE The optics should be regularly inspected and cleaned from smoke deposition whenever necessary.

4.8 Combustion gas analysis equipment

4.8.1 General

The analysis of oxygen, and carbon dioxide, requires that any water vapour in the combustion gases shall be trapped by means of a suitable drying agent.

4.8.2 Oxygen

The analyser shall be of the paramagnetic type and capable of measuring a range of 16 % to 21 % oxygen (V_{O_2}/V_{air}). The noise and drift of the analyser shall be not more than 0,01 % (100 parts per million) over a period of 30 min as measured in accordance with E.2.3. The manufacturer's declared response time of the analyser shall be not more than 12 s. The output from the analyser to the data acquisition system shall have a resolution better than 0,01 % (100 parts per million).

4.8.3 Carbon dioxide

Continuous analysis of carbon dioxide shall be achieved using an IR spectrometer. The analyser shall be capable of measuring a maximum range of 0 % to 10 % carbon dioxide. The linearity of the analyser shall be 1 % of full scale or better and the manufacturer's declared response time shall be not more than 12 s.

5 Qualification of test apparatus

5.1 General

The checks in 5.2 to 5.5 shall be undertaken to qualify the apparatus.

NOTE In this document, the use of the terminology "calibration" mirrors that in EN 13823 (the SBI test). It is used in a generic way, in some cases referring to a true calibration procedure whilst in others referring to a series of checks which may, in other documents, be referred to as a verification.

5.2 Flow distribution measurements

The determination of the flow profile in the exhaust duct, in the vicinity of the probes, is required for two main reasons:

a) to check that the design of the exhaust duct gives an acceptable profile;

b) to determine a k_c which shall be compared with the k_t obtained by the following calibrations.

Further information on how to perform this measurement is given in Annex D.

NOTE The value k_c should be approximately 0,86 for a 400 mm duct.

Measurements shall be performed by means of a calibrated hot wire anemometer (or other suitable instrument) moved along a vertical axis (OY) and then along a horizontal axis (OX) to obtain the vertical and horizontal air speed distributions inside the duct.

The velocity profile shall be measured at the same airflow rate as used during the actual test (see 6.6). Measurements at additional flow settings should be made and used to demonstrate the consistency of the velocity profile determination within the range of operation.

5.3 Sampling delay time measurement

Gas analysers take a finite time to respond to changes in gas concentrations. This is called the sampling delay time. The delay times shall be determined in order to synchronise the temperature, oxygen and carbon dioxide measurements. All data shall be corrected for any delay time before calculating the heat release. The delay time of the oxygen analyser shall be determined as the time difference between a 3 K change in the duct temperature and a 0,05 % change in the oxygen concentration. The delay time of the carbon dioxide analyser shall be determined as the time difference between a 3 K change in the duct temperature and a 0,02 % change in the carbon dioxide concentration.

Sampling delay times shall be determined before commissioning the apparatus and after each major change in the gas analysis system.

5.4 Commissioning calibrations

Before initial use of the apparatus and after each major change in the gas analysis system, exhaust flow measurement, gas and airflow measurement to the burner or smoke measurement, a series of calibrations shall be performed in order to

a) check the equipment, including any improvements adopted during the set-up stage or modification period;

b) determine a commissioning k_t factor to be used for daily testing;

c) check the stability of the smoke measurement system;

d) check the correct measurement of the white light measuring system.

The calibrations shall be carried out at different levels of *HRR* covering the range of heat releases that are expected when burning cables in a test, i.e. from about 20 kW to 200 kW. This is required in order to verify the linearity of the *HRR* measurement system. Further information on the *HRR* calibration and determination of the commissioning k_t factor is given in Annex E.

The procedure given in Annex E shall be carried out and its requirements met in order to calibrate and check the smoke measuring system.

NOTE It is recommended that the commissioning calibrations are carried out at least once per year depending on the frequency of use of the equipment.

5.5 Routine calibration

5.5.1 General

Each testing day a calibration test shall be performed using the ignition source given in EN 60332-3-10. A calibration burn of at least 10 min shall be performed, using the heat output of the burner relevant to the test procedure to be used that day (i.e. 20,5 kW or 30,0 kW as appropriate). The calibration test shall be carried out without the ladder in the test chamber. The result of the calibration test shall be recorded for each testing date. Testing shall not be carried out unless the criteria given in 5.5.4 are met.

NOTE See E.2.2 and E.2.4 for the daily adjustment of the oxygen and carbon dioxide analysers

5.5.2 Procedure

The calibration shall be performed in the following sequence:

a) a 5 min base line without the burner;

b) a further 10 min with the burner at the relevant heat output;

c) a further 5 min without the burner.

5.5.3 Calculations

The following shall be calculated after the calibration test using the commissioning k_t factor and the E-value for propane (16,8 MJ/m^3):

a) the drift of the HRR, oxygen % and light intensity during the first 5 min;

b) the average calculated HRR during the last 5 min of the burning period;

c) the start values of oxygen %, carbon dioxide %, light intensity and HRR, each as the average during the first minute of the 5 min base line period;

d) the end values of oxygen %, light intensity and HRR, each as the average during the last minute of the calibration test;

e) the difference between start and end values of oxygen %, HRR and light intensity.

5.5.4 Criteria

a) the average HRR during the last 5 min of the burner period shall be within ± 5 % of the set value of 20,5 kW or 30,0 kW;

b) the difference between the start and end values of oxygen % shall be less than 0,01 % (absolute value);

c) the difference between the start and end values of light intensity shall be equal to or less than 1 % transmission;

d) the difference between the start and end values of HRR shall be equal to or less than 2 kW;

e) the drift on the light intensity shall be less than 1 % during the 5 min before burner ignition;

f) the drift of oxygen % shall be less than 0,01 % (absolute value) during the 5 min before burner ignition;

g) the drift on HRR measurement shall be less than 2,0 kW during the 5 min before burner ignition.

NOTE The drift of oxygen %, HRR and light intensity shall be calculated by means of a linear trend line during the 5 min before burning ignition.

6 Test procedure

6.1 Initial test conditions

The test chamber and air supply temperature shall be in the range 5 °C to 40 °C.

6.2 Test sample

The test sample shall comprise a number of test pieces of cable from the same production length, each having a length of $(3{,}5\,^{+0{,}1}_{\;\;0})$ m. The number of test pieces in the test sample shall be as determined according to 6.4.

6.3 Sample conditioning

The test pieces shall be conditioned for at least 16 h at a temperature of (20 ± 10) °C. All packaging shall be removed prior to conditioning. The test pieces shall be dry.

A1⟩ 6.4 Determination of the number of test pieces

6.4.1 General

The following formulae shall be used to determine the number of test pieces (N) for the test.

6.4.2 Circular cables with a diameter greater than or equal to 20,0 mm

The number of test pieces, N, is given by:

$$N = \operatorname{int}\left(\frac{300+20}{d_c+20}\right) \tag{1}$$

where

d_c is the measured diameter of the cable (in millimetres, measured to one decimal place of a millimetre and rounded to the nearest millimetre according to Annex J);

int function the integer part of the result (i.e. the value rounded down).

6.4.3 Circular cables with a diameter greater than 5,0 mm but less than 20,0 mm

The number of test pieces, N, is given by

$$N = \operatorname{int}\left(\frac{300+d_c}{2d_c}\right) \tag{2}$$

where

d_c is the measured diameter of the cable (in millimetres, measured to one decimal place of a millimetre and rounded to the nearest millimetre according to Annex J);

int function the integer part of the result (i.e. the value rounded down).

6.4.4 Circular cables with a diameter less than or equal to 5,0 mm

A number of approximately 10 mm diameter bundles (N_{bu}) shall be mounted where:

$$N_{bu} = \operatorname{int}\left(\frac{300+10}{20}\right) = 15 \tag{3}$$

Thus 15 bundles shall be mounted.

The number of test pieces in each bundle (n) is:

$$n = \operatorname{int}\left(\frac{100}{d_c^2}\right) \tag{4}$$

where

d_c is the measured diameter of the cable (in millimetres, measured to two decimal places of a millimetre and rounded to one decimal place according to Annex J);

int function the integer part of the result (i.e. the value rounded down). ⟨A1

A1⟩ The total number of test pieces (N) will thus be:

$$N = n \times 15 \tag{5}$$

6.4.5 Non-circular cables with a major axis dimension greater than or equal to 20,0 mm, a minor axis dimension greater than 4,0 mm and a major to minor axis ratio less than or equal to 5

The number of test pieces, N, is given by:

$$N = \mathrm{int}\left(\frac{300 + 20}{m_c + 20}\right) \tag{6}$$

where

m_c	is the measured major axis of the cable (in millimetres, measured to one decimal place of a millimetre and rounded to the nearest millimetre according to Annex J);
int function	the integer part of the result (i.e. the value rounded down).

6.4.6 Non-circular cables with a major axis dimension greater than 5,0 mm but less than 20,0 mm, a minor axis dimension greater than 4,0 mm and a major to minor axis ratio less than or equal to 5

The number of test pieces, N, is given by:

$$N = \mathrm{int}\left(\frac{300 + m_c}{2m_c}\right) \tag{7}$$

where

m_c	is the measured major axis of the cable (in millimetres, measured to one decimal place of a millimetre and rounded to the nearest millimetre according to Annex J);
int function	the integer part of the result (i.e. the value rounded down).

NOTE For non-circular cables outside the dimensional and major to minor axis ratios given in 6.4.5 and 6.4.6, no mounting procedure has been defined.

6.5 Mounting of the test sample

6.5.1 Mounting of the test sample for all classes

The test sample shall be mounted on the front of the standard ladder. The lower part of each test piece or bundle of test pieces shall extend between 200 mm and 300 mm under the lower edge of the burner face, dependent on their actual length, such that ($3\,300\,^{+25}_{\;\;0}$) mm of the cables are above the lower edge of the burner face. Non-circular cables shall be mounted such that the major axis is presented to the burner face.

NOTE 1 The positive tolerance on the test sample length is to aid fixing on the ladder rung below the burner.

Each test piece or bundle of test pieces shall be attached individually to each rung of the ladder by means of a metal wire (steel or copper) using the crossed wire method of fixing shown in EN 60332-3-10:2009, Figure 3. For bundles, apply a metal wire around the bundle at each rung position before attaching the bundle to the rung with a further wire. ⟨A1

A1⟩ For cables up to and including 50 mm diameter (or major axis dimension for non-circular cables), wire between 0,5 mm and up to and including 1,0 mm in diameter shall be used. For cables above 50 mm diameter (or major axis dimension for non-circular cables), wire between 1,0 mm and 1,5 mm in diameter shall be used.

It is recommended that a drilled plate be used as a guide to maintain the relative position of each test piece when installing a bundle of test pieces.

For bundles, apply an intermediate metal wire (steel or copper) approximately midway between each rung of the ladder, as shown in Figure 9. Each metal wire shall be applied using two turns around the bundle.

When mounting the test pieces, the first test piece or bundle of test pieces shall be positioned approximately in the centre of the ladder and further test pieces shall be added on either side so that the whole array of test pieces is approximately centred on the ladder.

Whilst attaching the test pieces to the rungs of the ladder by means of a metal wire, the test pieces shall be maintained under tension to ensure they are set parallel on the ladder.

NOTE 2 It is useful for additional information to draw, at each height of 25 cm, a horizontal line in order to estimate the flame spread as a function of time, with the first line (i.e. zero line) at the same height as the burner.

The test pieces shall be mounted according to the cable overall diameter (or major axis dimension for non-circular cables), in accordance with Table 1.

Table 1 – Mounting as a function of cable diameter (or major axis dimension for non-circular cables)

Cable diameter **(circular cables)**	**Mounting**
Larger than or equal to 20,0 mm	20 mm spacing between cables
Between 5,0 mm and 20,0 mm	One cable diameter spacing between cables.
Less than or equal to 5,0 mm	The cables shall be bundled in bundles of approximately 10 mm diameter. The bundles shall not be twisted. The spacing between bundles shall be 10 mm.
Cable major axis dimension **(non-circular cables)**	
Larger than or equal to 20,0 mm	20 mm spacing between cables
Between 5,0 mm and 20,0 mm	One cable major axis dimension spacing between cables.

⟨A1

6.5.2 Special mounting requirements for class B1$_{ca}$

The test pieces shall be mounted in accordance with 6.5.1 except that at the back of the ladder, a non-combustible calcium silicate board shall be mounted. The board shall have a density of (870 ± 50) kg/m^3 and a thickness of (11 ± 2) mm and shall be mounted all along the ladder and fixed to the rungs. This board shall have a width of (415 ± 15) mm and a length of (3 500 ± 10) mm and may be mounted in two or more parts A1⟩ (see Figure 10)⟨A1.

NOTE Guidance on availability of suitable backing boards is given in Annex H.

The board shall be dry and shall then be conditioned at a temperature of (20 ± 10) °C and a relative humidity of less than 70 % for a minimum of 48 h before testing.

6.6 Exhaust volume flow

The volume flow rate in the exhaust duct shall be set to a value of (1,0 ± 0,05) m^3/s. The flow rate during the test shall be maintained in the range 0,7 m^3/s to 1,2 m^3/s.

NOTE 1 Due to changes in heat output, some exhaust systems (especially those provided with local fans) may need manual or automatic readjustment during the test in order to meet this requirement. If readjustment during the test is carried out, it is necessary to ensure that the measurement of heat release rate has not been influenced.

NOTE 2 The flow rate value of (1,0 ± 0,05) m^3/s is based upon the use of an exhaust duct diameter of 400 mm. A lower value may be more appropriate for exhaust ducts of smaller diameter, provided it is sufficient to ensure collection of all the combustion products leaving the test chamber.

6.7 Ignition source

The ignition source shall be one ribbon-type propane gas burner in accordance with EN 60332-3-10.

For Class B1$_{ca}$ the flow rate of propane shall be equal to a mass flow of (647 ± 15) mg/s which corresponds with a nominal *HRR* of 30,0 kW. The air flow to the burner shall be (2 300 ± 140) mg/s.

For Class B2$_{ca}$, C$_{ca}$ and D$_{ca}$ the flow rate of propane shall be equal to a mass flow of (442 ± 10) mg/s which corresponds with a nominal *HRR* of 20,5 kW. The air flow to the burner shall be (1 550 ± 95) mg/s.

NOTE 1 A net heat of combustion of 46,4 kJ/g and an E-value of 16,8 x 10^3 kJ/m^3 for the combustion of propane are used to calculate the propane flow rate.

NOTE 2 An analysed *HRR* value of 30,7 kW or 21,0 kW respectively results when analysing the *HRR* from the ignition source using the average E-value of 17,2 x 10^3 kJ/m^3 used in this test (see Annex A).

NOTE 3 The use of mass flow meters and controllers is strongly recommended to achieve the required propane and air flow rates.

The positioning of the ignition source for the test shall be in accordance with EN 60332-3-10.

6.8 Flame application time

The test flame shall be applied for (1 200 $^{+10}_{\ 0}$) s, after which it shall be extinguished.

6.9 Testing operations

a) Switch on the air input fan and adjust the airflow through the chamber to (8 000 ± 400) l/min

b) Set the volume flow of the exhaust to the predetermined value as stated in 6.6.

NOTE Any specific guidance, i.e. pre test operations from the supplier of the equipment, should be fulfilled before starting a test.

c) Record the duct temperatures and the ambient temperature for at least 300 s. The ambient temperature shall be within the range 5 °C to 40 °C, and the temperatures in the duct shall not differ more than 4 °C from the ambient temperature.

d) Record the pre-test conditions of the air going into the duct (ambient temperature, atmospheric pressure and humidity). Refer to A.3.

e) Start the time measurement and the automatic recording of data. The time of start is t = 0 s, by definition. The data to be recorded are those variables necessary for the calculation of *HRR* and *SPR*.

f) At t = 270 s the base line values shall be checked for *HRR* and transmission value (or corresponding extinction coefficient). If they differ more than 2,0 kW for the *HRR* or 2 % for the transmission value from the start values, the test shall be stopped and an error analysis should be carried out. This is extremely important to ensure the quality of the *HRR* and *SPR* measurement. The start values shall be determined as the average of the first 30 s of the test (between 0 s and 30 s).

g) At t = (300 ± 10) s : Ignite the burner and adjust the propane and air flow rates to the values given in 6.7 in order to have a nominal heat output of 20,5 kW or 30,0 kW as appropriate. Record the time of burner ignition, t_b.

h) Observe the burning behaviour of the cable including any flaming droplets/particles and record the necessary report data to complete the test report according to Clause 8. If the *HRR* reaches greater than 450 kW the test should be stopped. Extinguishing of the cable is permitted in order to protect the apparatus and its measuring devices.

i) At t = ($1\,500^{+10}_{\ 0}$) s: Switch off the propane supply to the burner.

j) At t = (1 530 ± 10) s: Stop the automatic recording of data and if cable burning or glowing continues, extinguish the fire.

Extensive burning of the cables and flaming outside the top of the rig might require the extinguishment of the test specimen and abortion of the test. If this occurs, it shall be reported together with the time of extinguishment.

6.10 Observations and measurements during the test

The following parameters shall be determined during the test:

- heat release rate as a function of time;
- smoke production rate as a function of time;
- occurrence and duration of flaming droplets/particles.

The fall of flaming droplets or particles shall be recorded within the full 1 200 s of the test when the droplets/particles reach the floor of the test chamber. The following occurrences shall be recorded:

a) the fall of a flaming droplet/particle that remains flaming for not more than 10 s after reaching the floor of the test chamber;

b) the fall of a flaming droplet/particle that remains flaming for more than 10 s after reaching the floor of the test chamber.

7 Determination of parameters derived from the test

7.1 Calculation of *HRR* and *SPR* parameters

7.1.1 Peak heat release rate value (*Peak HRR*)

The *peak HHR* value is defined as the maximum value of $HRR_{av}(t)$, excluding the burner output, and shall be determined during the whole burner application time starting from ignition of the burner (t_b) to the end of burner application (t_b + 1 200) s. It shall be expressed in kW.

In order to exclude the burner output from the *HRR* in the calculation of $HRR_{av}(t)$, the nominal *HRR* from the burner of 30,0 kW (for Class $B1_{ca}$) or 20,5 kW (for Class $B2_{ca}$, C_{ca} and D_{ca}) shall be subtracted from the total *HRR*. All negative *HRR* values shall be set to zero.

Details of the calculation are given in G.1.

7.1.2 Peak smoke production rate value (*Peak SPR*)

The *peak SPR* value is defined as the maximum value of $SPR_{av}(t)$, and shall be determined during the whole burner application time between t_b and (t_b + 1 200) s. It shall be expressed in m²/s.

Details of the calculation are given in G.2.

7.1.3 Total heat release value (THR_{1200})

The total heat release value shall be calculated as the integrated value of the *HRR*, excluding the burner output over a period starting from ignition of the burner (t_b) to the end of burner application (t_b + 1 200 s). If the test has to be stopped early because of too high *HRR* value, then this value shall not be calculated but a clear record shall be made of this occurrence. Negative values of the *HRR*, excluding the burner, shall not be included in the integration. It shall be expressed in MJ.

7.1.4 Total smoke production value (TSP_{1200})

The total smoke production value is calculated as the integrated value of the *SPR* over a period starting from ignition of the burner (t_b) to the end of burner application (t_b + 1 200 s). If the test has to be stopped early because the *HRR* value was too high, then this value shall not be calculated but a clear record shall be made of this occurrence. Negative values of the *SPR* shall not be included in the integration. It is expressed in m².

7.1.5 Fire Growth Rate Index (*FIGRA*)

The *FIGRA* is defined as the maximum of the quotient $HRRav(t) / (t-t_b)$.

Details of the calculation are given in G.3.

7.2 Determination of extent of flame spread (*FS*)

After all cable burning or glowing has ceased or been extinguished, the test sample shall be wiped clean.

All soot shall be ignored if, when wiped off, the original surface is undamaged. Softening or any deformation of the non-metallic material shall also be ignored. The flame spread shall be measured as the extent of the damage. It shall be measured in metres to two decimal places from the bottom edge of the burner to the onset of char. The onset of char shall be determined as follows:

Press against the cable surface with a sharp object, e.g. a knife blade. Where the surface changes from a resilient to a brittle (crumbling) surface, this indicates the onset of char.

8 Test report

8.1 General

The written report shall contain a brief description of the overall test set-up. Any deviations from the procedure in this standard shall be stated. The mounting shall be described in detail. As a minimum, the information listed in 8.2 shall be present in each report. A clear distinction shall be made between the data provided by the applicant and data determined by the test.

8.2 Contents

8.2.1 General information

a) The name and address of the testing laboratory;

b) the date and identification number of the report;

c) the name and address of the applicant;

d) the name and address of the sample manufacturer/supplier, if known;

e) the date of test.

8.2.2 Information on the cable tested

a) An identification of the cable tested;

b) a description of the cable tested.

8.2.3 Information on the test

a) The number of this standard (i.e. EN 50399);

b) the number of test pieces;

c) the overall diameter of the test pieces;

d) the method of mounting (i.e. spaced or bundles);

e) the use of a backboard or not;

f) the flame application time (i.e. 20 min);

g) the output of the burner (i.e. 20,5 kW or 30,0 kW).

8.2.4 Results obtained

a) The extent of flame spread (as defined in 7.2);

b) the occurrence or not of flaming droplets and their duration (as determined according to 6.10);

c) $HRRav$ and $SPRav$ graphs as a function of time starting from the beginning of the test (i.e. 300 s before ignition of the burner), excluding the burner output and with any negative values set to zero;

d) any observations made during the test.

8.2.5 Calculated results

The calculated results shall be expressed with the following parameters:

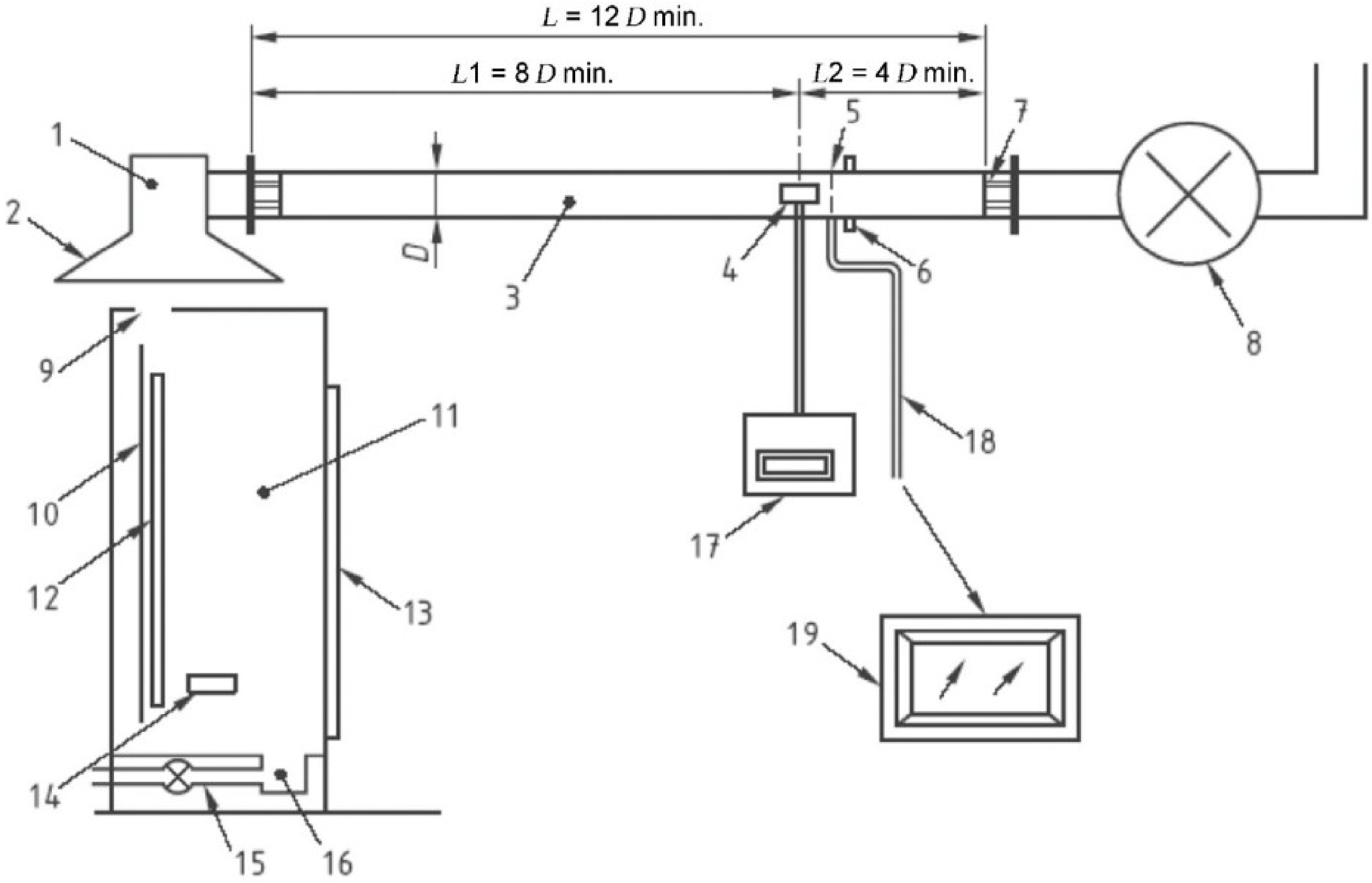
a) the *peak HRRav* value (as defined in 7.1.1);

b) the *peak SPRav* value (as defined in 7.1.2);

c) the *THR* (as defined in 7.1.3) over the period of the application of the flame burner;

d) the *TSP* (as defined in 7.1.4) over the period of the application of the flame burner;

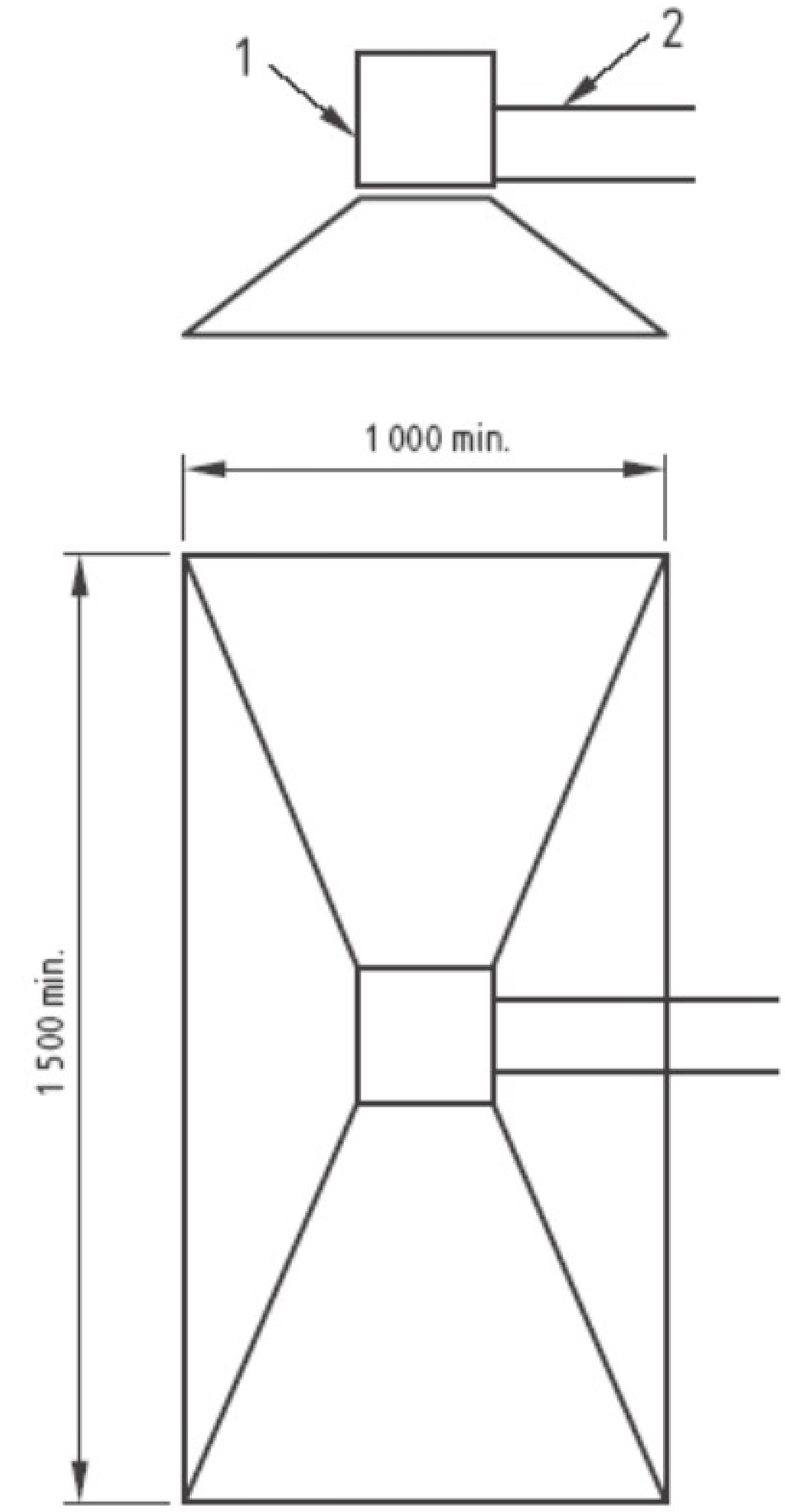
e) the *FIGRA* (as defined in 7.1.5).



Key

1	chamber		8	extracting ventilator		14	burner
2	hood		9	smoke outlet		15	air inlet duct
3	exhaust duct		10	ladder		16	air inlet box
4	bidirectional probe		11	test chamber		17	pressure transducer
5	sampling probe		12	cables tested		18	gas sampling line
6	smoke measuring equipment		13	door		19	O_2 and CO_2 analysers
7	guide vanes						

Figure 1 – General arrangement of test apparatus

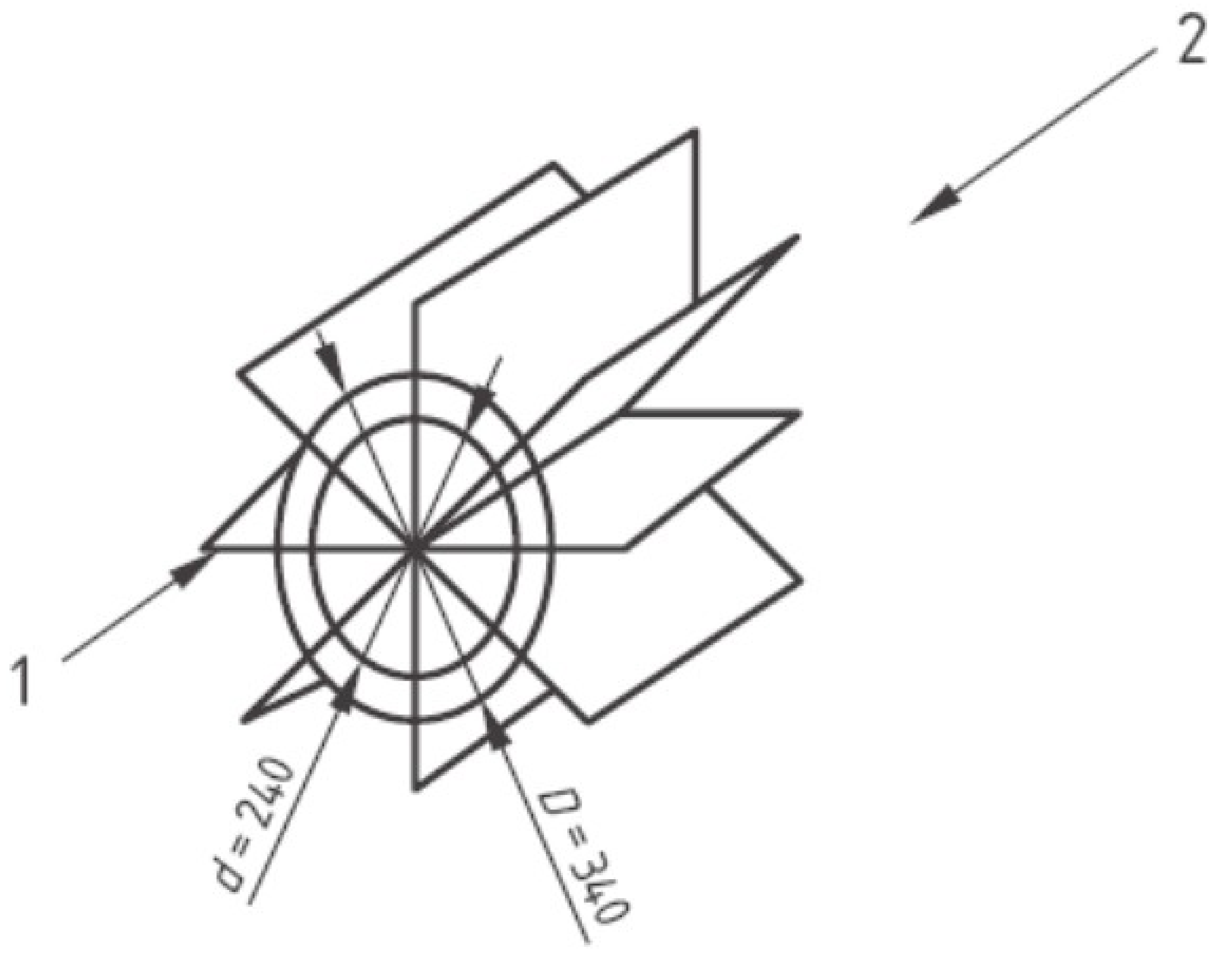


Dimensions in millimetres

Key

1	chamber	2	exhaust duct

Figure 2 – Schematic of a hood



Dimensions in millimetres

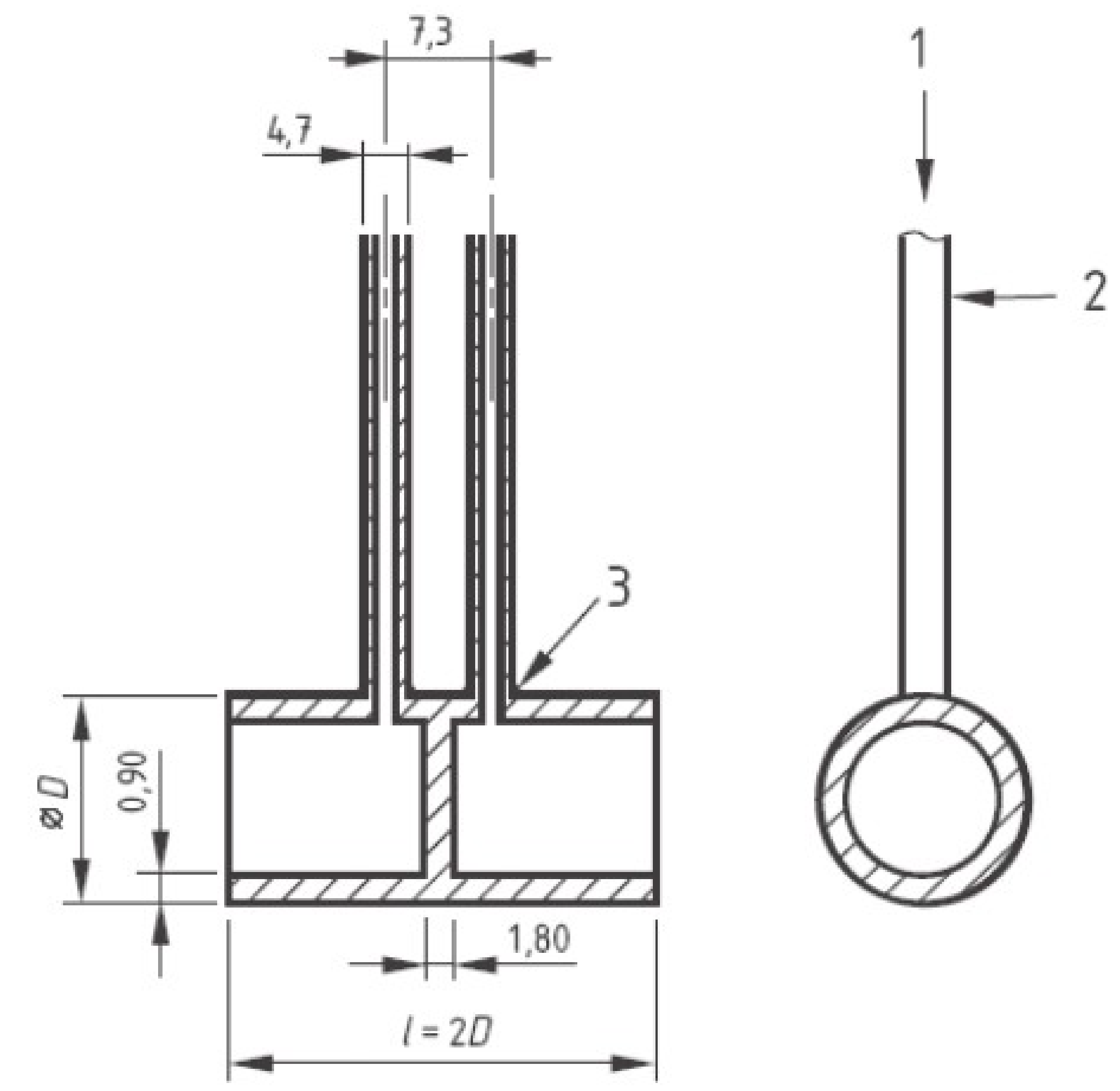
Key

1	4 steel plates 395 mm x 400 mm	2	air flow direction

NOTE 1 Dimensions indicated are for a 400 mm diameter duct.

NOTE 2 A better mixing has been observed with the air flow direction as indicated compared to the opposite direction.

Figure 3 – Typical guide vanes



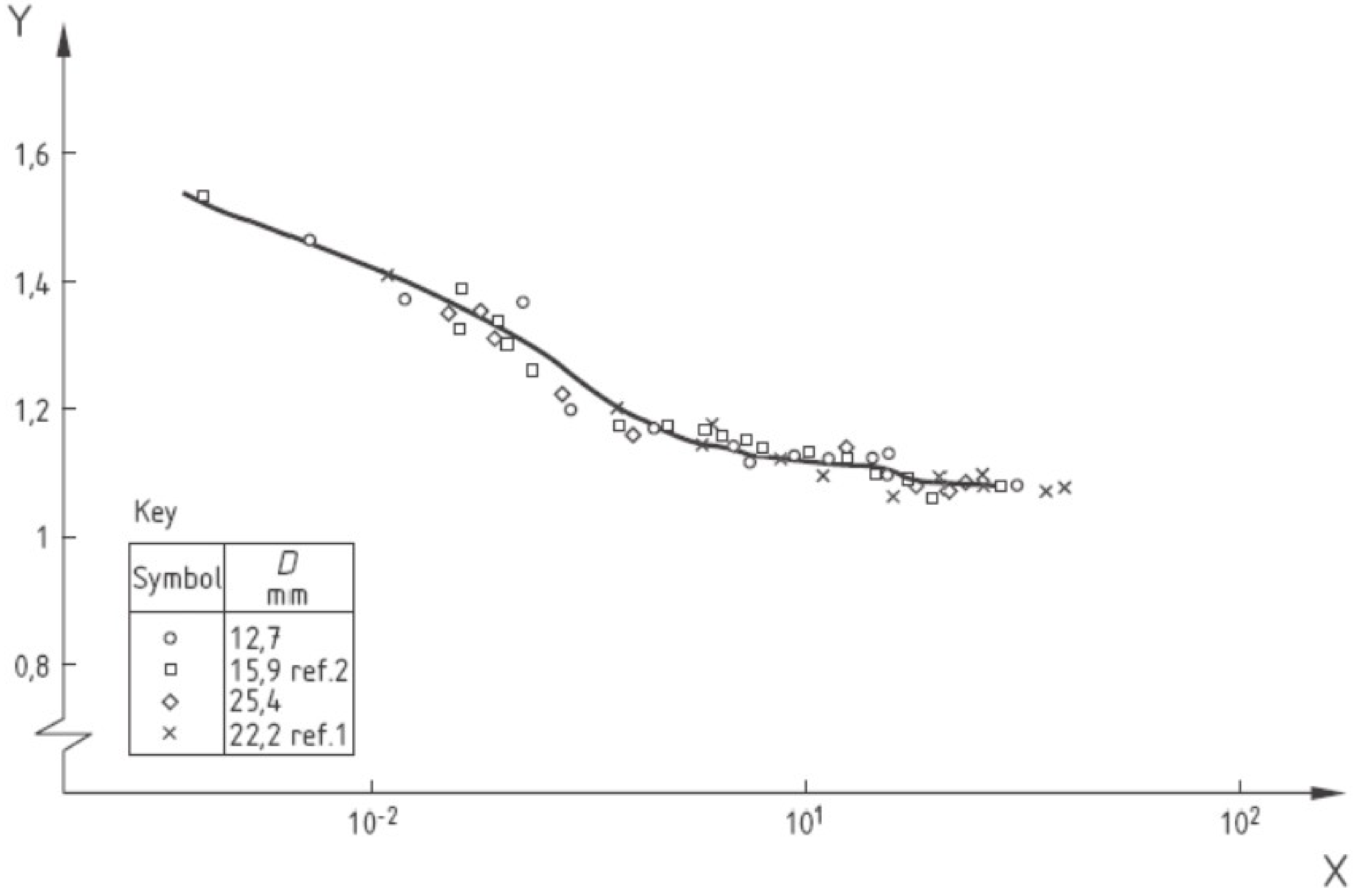
Dimensions in millimetres

Key

1	to Δp instrument	2	variable length support tubes
3	weld		

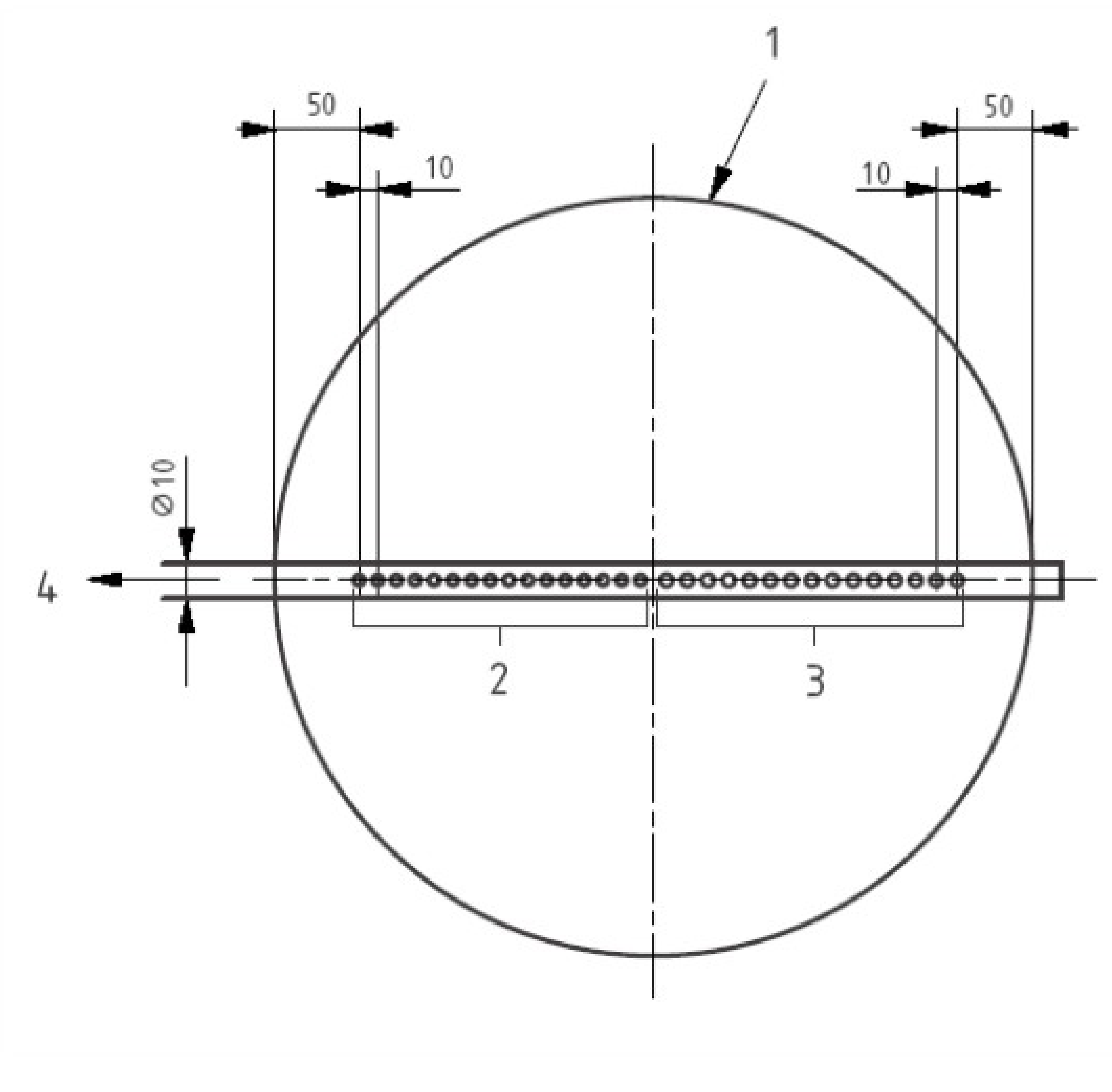
NOTE Taken from Mc Caffrey and Heskestad, *Combustion and Flame, 26* (1976) [5].

Figure 4 – Bidirectional probe

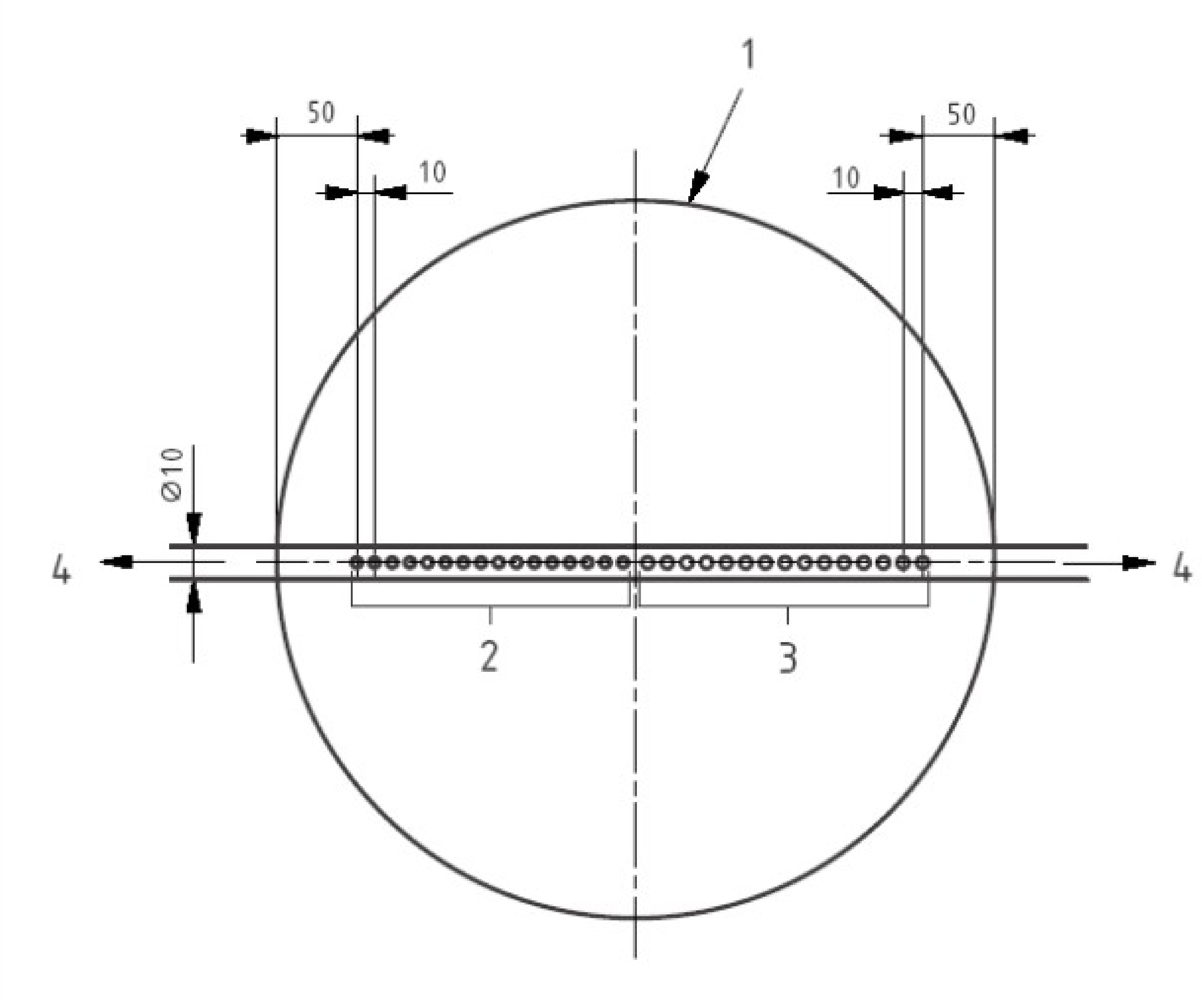


X $\mathrm{Re} = \dfrac{\rho V D}{\mu}$ Y $\dfrac{\left(\dfrac{2\Delta p}{\rho}\right)^{1/2}}{V}$

Figure 5 – Probe response versus Reynolds number



a) **Single flow**



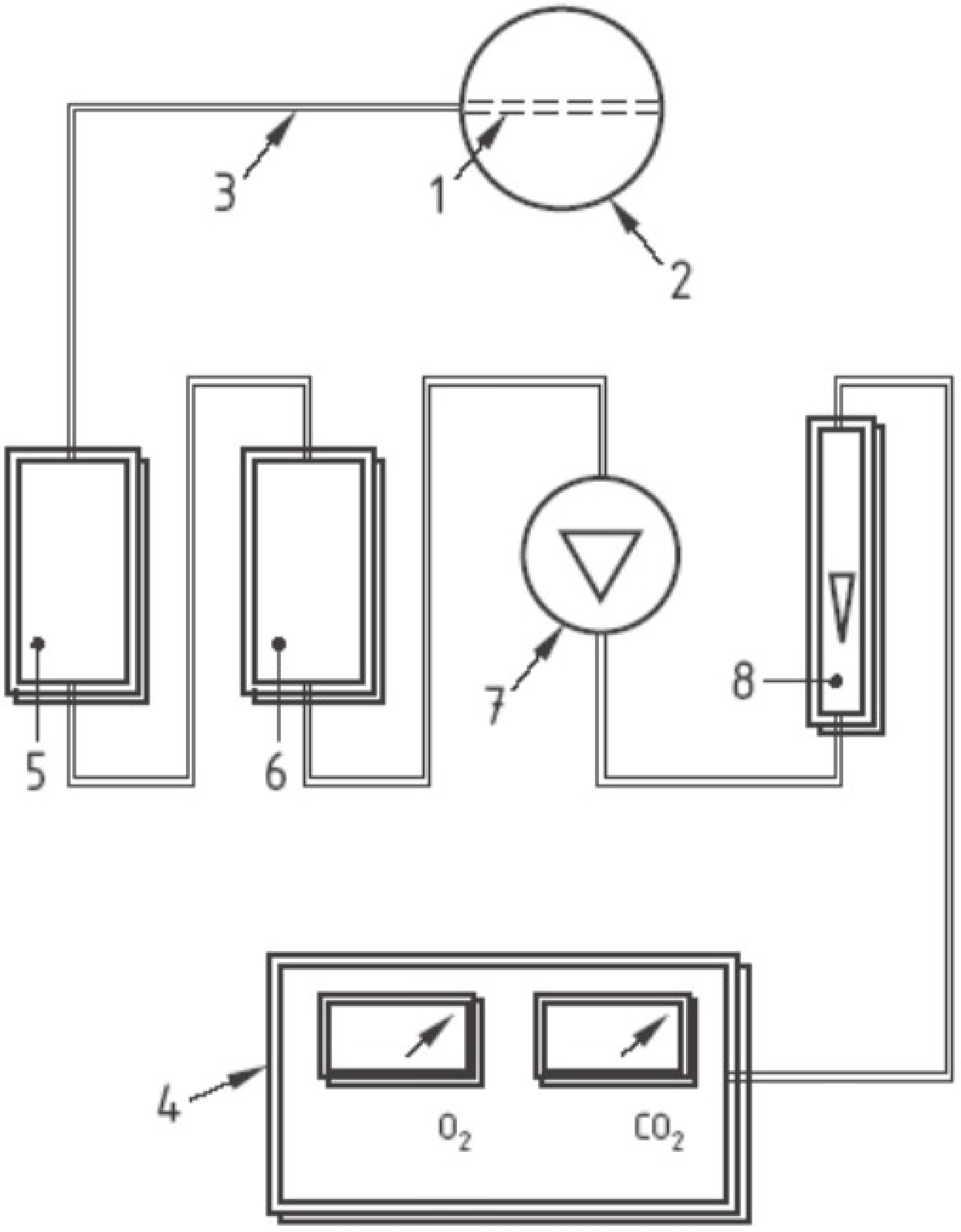
b) **Dual flow**

Dimensions in millimetres

Key

1	exhaust duct	3	15 holes on down stream side of flow (Ø 3 mm for arrangement a); Ø 2 mm for arrangement b))
2	16 Ø 2 mm holes on down stream side of flow	4	sample flow

Figure 6 – Sampling probe

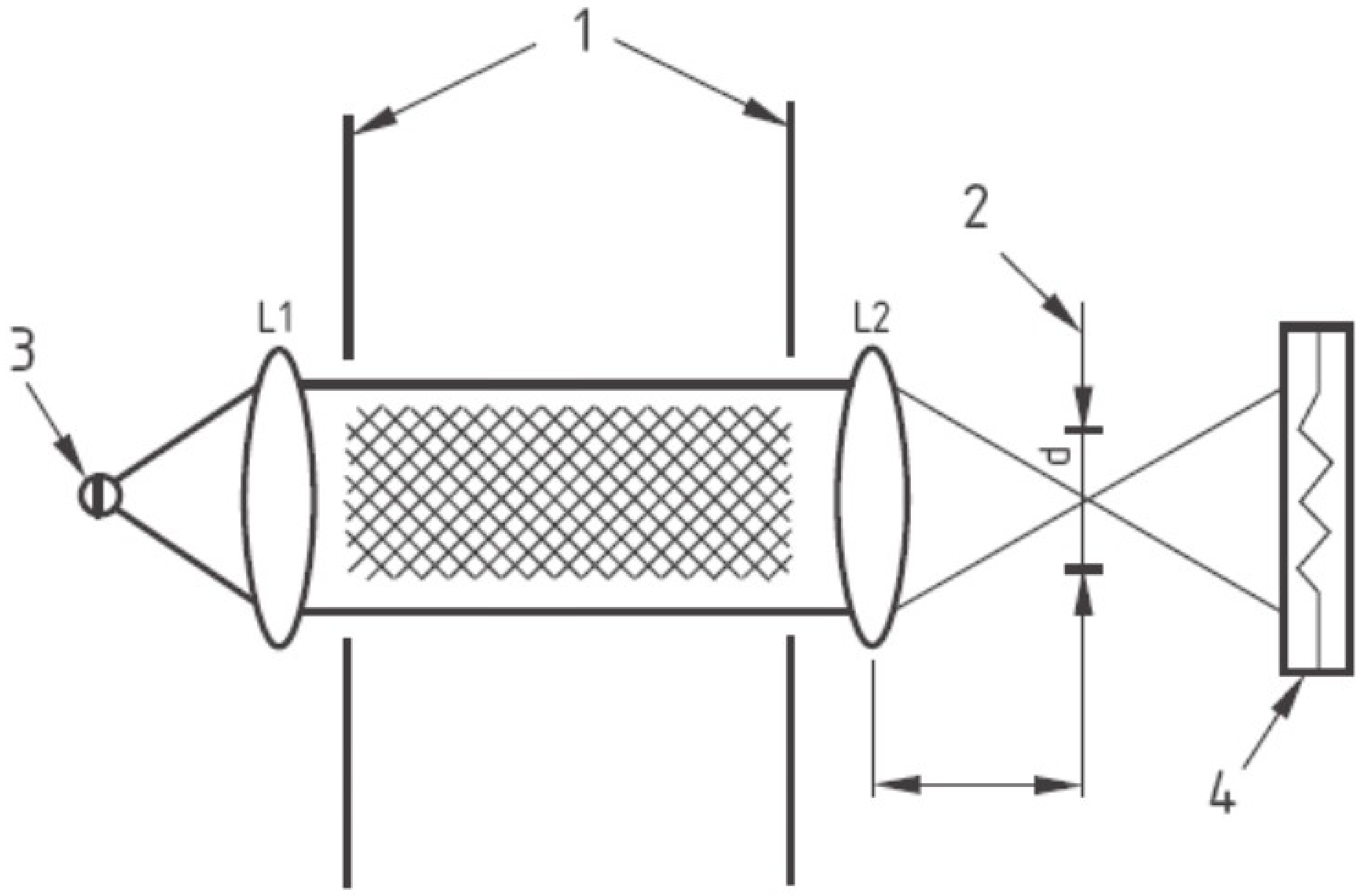


Key

1	sampling probe	5	filters
2	exhaust tube	6	gas cooling system
3	sampling line	7	membrane pump
4	analysers	8	gas flowmeter

NOTE Other gas cooling systems may be used. Cooling may be omitted if the water trap is sufficiently efficient.

Figure 7 – Schematic diagram of sampling line



Key

1 walls of exhaust duct

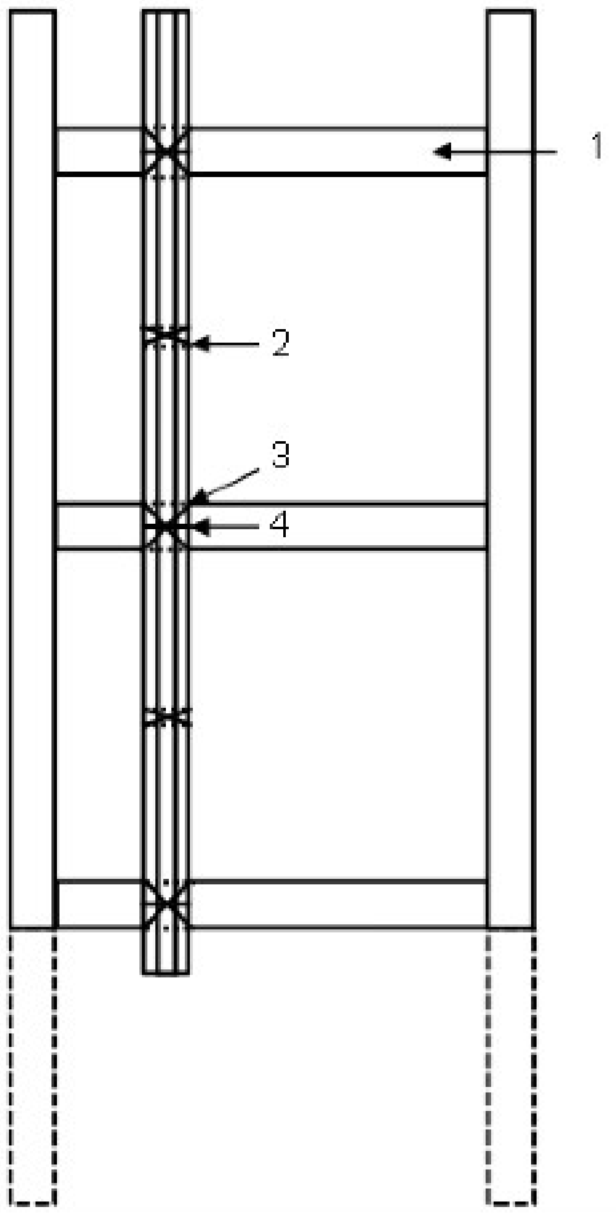
2 aperture

3 lamp

4 detector

Figure 8 – Optical system – General arrangement

A1



Key

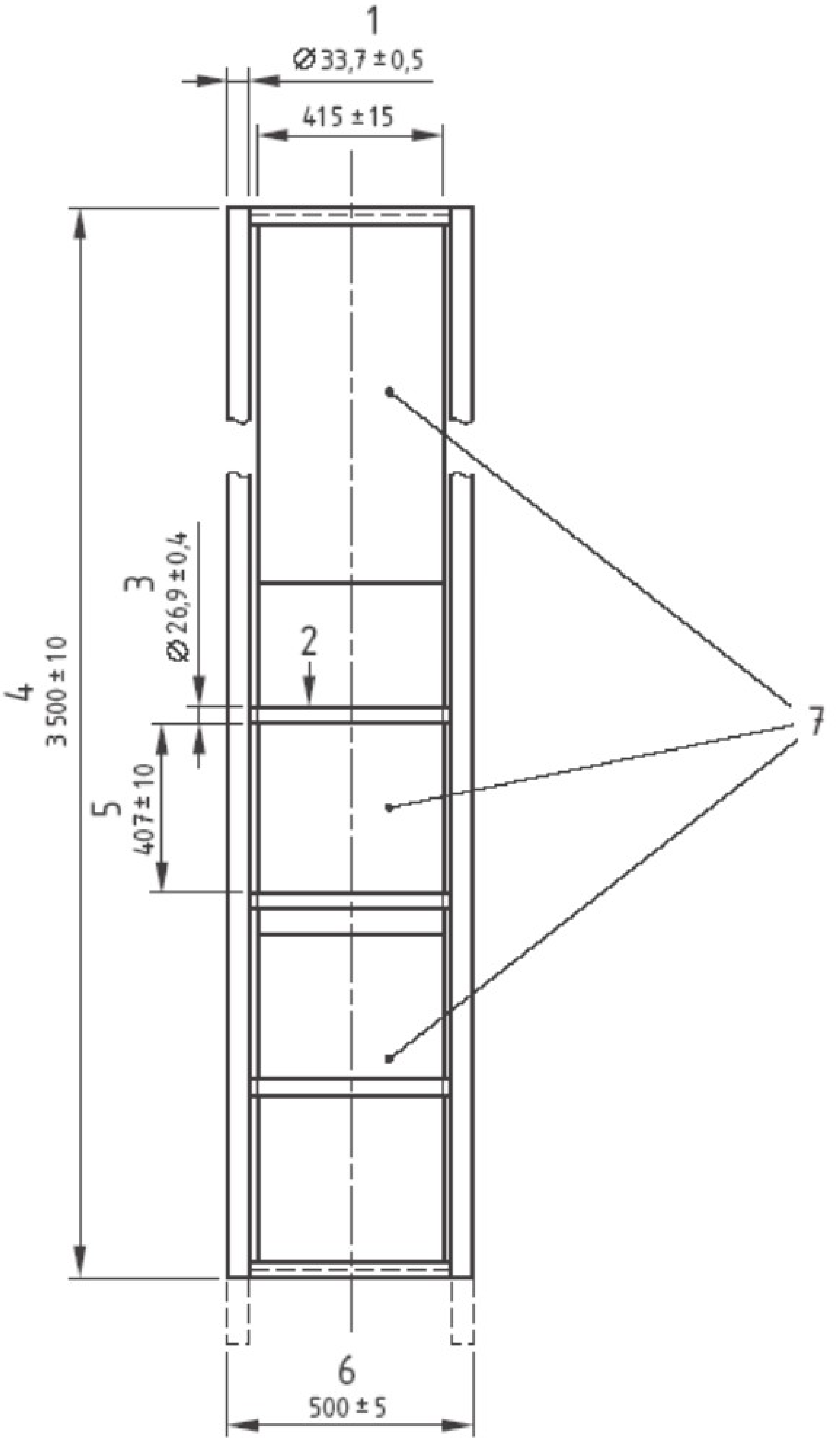
1 round steel rungs

2 intermediate metal wire

3 metal wire ties

4 metal wire that is applied around the bundle at each rung position before attaching the bundle to the rung

Figure 9 – Mounting of bundles (not on scale, only one of 15 bundles) A1



Dimensions in millimetres

Key

1	diameter of upright	5	distance between rungs
2	number rungs = 9	6	width
3	diameter of rungs	7	calcium silicate board
4	total height of ladder		

A1⟩ Figure 10 ⟨A1 – Backboard mounting arrangement for Class $B1_{ca}$

Annex A
(normative)

Calculation of heat release

A.1 Volume flow

The volume flow in the exhaust duct, V_{298}, expressed in cubic metres per second, related to atmospheric pressure and an ambient temperature of 25 °C, is given by the equations:

$$\dot{V}_{298} = (Ak_t / k_\rho) x \frac{1}{\rho_{298}} x (2\Delta p T_0 \rho_0 / T_s)^{1/2} \tag{A.1}$$

$$\dot{V}_{298} = 22{,}4(Ak_t / k_\rho)(\Delta p / T_s)^{1/2} \tag{A.2}$$

where

T_s is the gas temperature in the exhaust duct, in K;

T_o = 273,15 K;

Δp is the pressure difference measured by the bidirectional probe, in Pa;

ρ_{298} is the air density at 25 °C and atmospheric pressure, in kg/m³;

ρ_0 is the air density at 0 °C and 0,1 Pa, in kg/m³ (1,293 kg/m³);

A is the cross-sectional area of the exhaust duct, in m²;

k_t is the commissioning factor determined according to E.3.4;

k_ρ is the Reynolds number correction for the bidirectional probe suggested by Mc Caffrey and Heskestad [5]. In the exhaust duct, conditions are such that R_e is usually larger than 3 800 hence k_ρ can be taken as constant and equal to 1,08.

Equation (A.1) assumes that density changes in the combustion gases (related to air) are caused solely by the temperature increase. Corrections due to changed chemical composition or humidity content may be ignored. The calibration constant k_t is a combination of the correction factor for the flow profile (k_c),determined by measuring the flow profile inside the exhaust duct along a cross-sectional diameter, and the correction factors from the propane and methanol calibrations (see E.3.4).

A.2 Generated heat effect

A.2.1 Heat release from the ignition source

During the calibration process, the heat release rate from the ignition source, $\dot{q}_b$, expressed in kilowatts, shall either be assumed to be constant and equal to the nominal *HRR* from the burner of 30,0 kW or 20,5 kW, or shall be calculated from the actual consumption of propane gas from Equation (A.4):

either

$$\dot{q}_b = 30{,}0 \text{ or } 20{,}5 \tag{A.3}$$

or

$$\dot{q}_b = \dot{m}_b \Delta h_{c,eff} \tag{A.4}$$

where

$\dot{m}_b$ is the mass flow rate of propane to the burner, expressed in grams per second (g/s);

$\Delta h_{c,eff}$ is the effective lower heat combustion of propane, expressed in kilojoules per gram (kJ/g).

Assuming a combustion efficiency of 100 %, $\Delta h_{c,eff}$ can be set equal to 46,4 kJ/g.

A.2.2 Heat release from a tested product

The heat release rate of the tested cable shall be taken as the total measured heat release rate minus the heat release rate of the burner. When the burner is ignited the measured heat release rate is not immediately equal to the nominal heat release or value calculated from the mass flow rate of propane (as a result of the transport delay and filling time of the chamber). This leads to negative values of heat release rate of the cable and such negative values shall be set to zero.

The heat release rate from a tested cable $\dot{q}$, expressed in kilowatts, is calculated from the equation :

$$\dot{q} = E^1 \dot{V}_{298} x^a_{O_2} \left(\frac{\phi}{\phi(\alpha-1)+1}\right) - \frac{E^1}{E_{C_3H_8}} \dot{q}_b \tag{A.5}$$

with ϕ, the oxygen depletion factor, given by

$$\phi = \frac{x^0_{O_2}(1-x_{CO_2}) - x_{O_2}(1-x^0_{CO_2})}{x^0_{O_2}(1-x_{CO_2}-x_{O_2})} \tag{A.6}$$

and $x^a_{O_2}$, the ambient mole fraction of oxygen, given by

$$x^a_{O_2} = x^0_{O_2}(1 - x^a_{H_2O}) \tag{A.7}$$

where

E is the heat release per volume of oxygen consumed, expressed in kilojoules per cubic metre (kJ/m³);

E^1 = 17,2 x 10³ kJ/m³ (25 °C) for the combustion of the tested product;

$E_{C_3H_8}$ = 16,8 x 10³ kJ/m³ (25 °C) for the combustion of propane;

$\dot{V}_{298}$ is the volume flow rate of gas in the exhaust duct at atmospheric pressure and 25 °C calculated as specified in Equation (A.1);

α is the expansion factor due to the chemical reaction of the air that is depleted of its oxygen (α = 1,105 for combustion of tested product);

$x^a_{O_2}$ is the ambient mole fraction of oxygen including water vapour as defined by equation (A.7);

$x_{O_2}^0$	is the start value of oxygen analyser reading, expressed as a mole fraction;
x_{O_2}	is the oxygen analyser reading during test, expressed as a mole fraction;
$x_{CO_2}^0$	is the start value of carbon dioxide analyser reading including ambient air content, expressed as a mole fraction;
x_{CO_2}	is the carbon dioxide analyser reading during the test, expressed as a mole fraction;
$x_{H_2O}^a$	is the ambient mole fraction of water vapour (to be calculated according to Equation (A.8) given in A.3).

NOTE The definition of start value is given in the appropriate part of this standard (see 5.5.3, E.3.2.3 and E.3.3.4).

Equations (A.3) to (A.7) are based on certain approximations leading to the following limitations.

a) The amount of CO generated is not taken into consideration. Normally, the error is negligible. If the concentration of CO is measured, corrections can be calculated for those cases where the influence of incomplete combustion may have to be quantified.

b) The influence of water vapour on measurement of flow and gas analysis is only partially taken into consideration. A correction for this error could be obtained by continuous measurement of the partial water vapour pressure but is not considered necessary for this test.

c) The value of 17,2 x 10^3 kJ/m^3 for the factor E, is an average value for a large number of products and gives an acceptable accuracy in most cases.

A.3 Calculation of the mole fraction of water vapour in the air

The mole fraction of water vapour in the air can be calculated from the conditions of the atmosphere (ambient temperature, θ_{atm}, relative humidity, RH, and atmospheric pressure, p_{atm}^0) taken at the start of the test.

The following equation is used for the calculation:

$$x_{H_2O}^a = \frac{RH}{100} \cdot \frac{1}{p_{atm}^0} \left[\frac{e^{23,2}}{e^{\left(\frac{3816}{(\theta_{atm}+273,15)-46}\right)}} \right] \qquad \text{(A.8)}$$

where

RH	is expressed in %;
p_{atm}^0	is expressed in Pa;
θ_{atm}	is expressed in °C.

Annex B
(normative)

Smoke production

The optical density is represented by the extinction coefficient, k, expressed in reciprocal metres (m^{-1}), and is defined as follows:

$$k = \tfrac{1}{L}\ln\left[\tfrac{I_0}{I}\right] \tag{B.1}$$

where

I_0 is the light intensity for 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 is the light intensity for a parallel light beam having traversed a certain length of smoky environment;

L is the length of beam through smoky environment (optical path length), expressed in metres.

The instantaneous rate of light-obscuring smoke SPR, expressed in square metres per second (m^2/s), and the total amount of smoke TSP expressed in square metres (m^2) are then calculated from:

$$SPR = k\,\dot{V}_s \tag{B.2}$$

$$TSP = \int_0^t k\,\dot{V}_s\,dt \tag{B.3}$$

where

$\dot{V}_s$ is the volume flow in the exhaust duct at actual duct gas temperature, expressed in cubic metres per second (m^3/s);

t is the time from ignition of the burner, expressed in seconds (s).

NOTE Negative SPR values indicate $I > I_o$ which is not a smoke related phenomenon.

Annex C
(informative)

Additional information on Reynolds number in Figure 5

The pressure differences are measured with a sensitive electronic manometer. The uniform low velocity flows are provided by two independent facilities as described in Mc Caffrey and Heskestad [5]. A hot wire anemometer and Pitot-static tube, where appropriate, are used to determine the stream velocity. For data reduction via computer, the polynomial curve fit obtained for the points shown in Figure 5 is:

$$\begin{aligned}&\frac{\left(2\frac{\Delta p}{\rho}\right)^{\frac{1}{2}}}{V} = 1{,}533 - 1{,}366x10^{-3} R_e \\ &+ 1{,}688x10^{-6} {R_e}^2 - 9{,}706x10^{-10} {R_e}^3 \\ &+ 2{,}555x10^{-13} {R_e}^4 - 2{,}484x10^{-17} {R_e}^5\end{aligned} \qquad \text{(C.1)}$$

This representation is valid for $40 < R_e < 3\ 800$ and is accurate to about 5 %.

A suitable value of D, the outer diameter of the probe, is 16 mm.

Annex D
(normative)

Flow distribution inside the duct

D.1 General

For the calculation of HRR, a velocity profile factor k_c shall be used. This factor shall be determined by measuring the velocity profile both in both the vertical and horizontal direction of the duct. The procedure to determine k_c is specified in D.2.

D.2 Velocity profile factor k_c

D.2.1 General

The k_c factor shall be measured after set-up, maintenance, repair or replacement of the bidirectional probe or other major components of the exhaust system. The measurements shall be made using a Pitot tube, a hot wire anemometer or the bi-directional probe, provided correct positioning can be ensured.

D.2.2 Measurement specifications

1) The equipment shall be run on a damping setting sufficiently high to obtain a steady reading.

2) The duct shall have 4 entry ports, spaced by 90° around the circumference, which are used to introduce the velocity measurement device. When inserted into the duct the measurement probe shall be positioned and fixed mechanically, rather than held by hand.

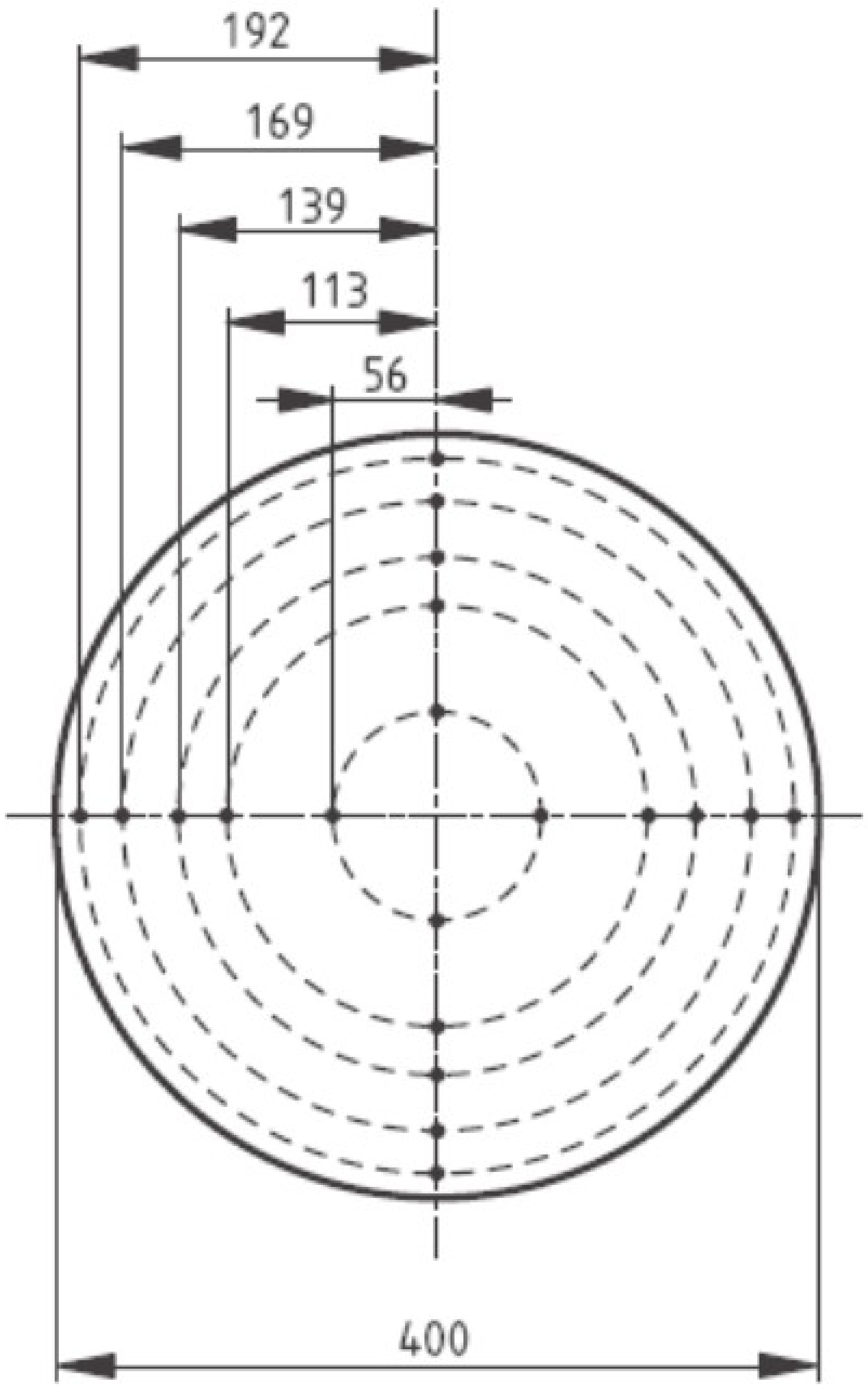
NOTE 1 It is also possible to measure the gas velocity profile at all measurement positions with a duct having two entry ports which are spaced by 90°.

3) Measurements shall be taken from each port in turn and the entry ports not used shall be closed.

4) At each port the gas velocity shall be measured at each of 5 measurement radius positions, once when traversing the flow measuring device outwards from the centre to the duct wall and once when traversing inwards to the centre. Each velocity measurement shall consist of 10 readings or scans (i.e. a total of 20 readings at each measurement position).

NOTE 2 It is not necessary to note 10 readings or scans for a measurement if an appropriate anemometer which automatically measures and calculates an adequate average value is used.

5) The radius measurement positions shall be at the following distance from the wall expressed as a fraction of the radius (taken from ISO 3966:2008): 0,038 – 0,153 – 0,305 – 0,434 – 0,722 and 1,000 (centre). The positions for measurement for a 400 mm duct are shown in Figure D.1.



Dimensions in millimetres

Figure D.1 – Section of the exhaust duct – Positions for measurement of the gas velocity

D.2.3 Actions

Perform the following steps.

Set the volume flow of the exhaust to the setting where the velocity profile has to be determined and at a volume flow in the range given in 4.3.

a) Measure the gas velocity in all measurement positions, six positions per entry port.

b) Calculate the gas velocity at all measurement positions as the average of the 20 values measured, giving V_c for the centre position and five V_n values for the five other positions for each entry port.

NOTE As a result, the velocity profile is measured and calculated both horizontally and vertically over the full diameter.

D.2.4 Calculation of k_c

For a given radius the average velocity at a radius n is given by V_N, which is the average of the four V_n values measured. The average velocity at the centre is given by V_C, which is the average of the four V_c values measured. The profile factor k_c is then (1/5) x (V_{N1} + V_{N2} + V_{N3} + V_{N4} + V_{N5})/ V_C where V_{N1} ... V_{N5} are the average velocities at the 5 radii.

D.2.5 Measurement report

The measurement report shall include the following information:

a) the velocity profile based on the average V_n at five radii and V_c, separately for each entry port (a vertical and a horizontal cross section);

b) the four values of V_n for each radius, the four values of V_c, the values V_N and V_C, and the resulting k_c.

Annex E
(normative)

Commissioning calibrations

E.1 General procedures for separate pieces of equipment

Several of the measuring instruments used need regular calibration. As a minimum, the calibrations in this annex shall be performed.

NOTE In this standard it is assumed that the instruments are also maintained and calibrated according to the manufacturers' specifications.

E.2 Gas analyser calibrations

E.2.1 General

The same gas flow shall be used for calibration and for the test.

E.2.2 Oxygen analyser adjustment

The oxygen analyser shall be adjusted for zero and span each day on which tests are performed. The analyser output for dried ambient air shall be (20,95 ± 0,01) %. A possible procedure to perform the adjustment is given in F.2.1.

E.2.3 Oxygen analyser output noise and drift

E.2.3.1 Noise and drift

Noise and drift of the oxygen analyser output using the data acquisition system shall be checked after set up, maintenance, repair or replacement of the oxygen analyser or other major components of the gas analysis system.

NOTE It is recommended that this check is carried out at least every six months depending on the frequency of use of the equipment.

E.2.3.2 Actions

a) Feed the oxygen analyser with oxygen-free nitrogen gas, until the analyser reaches equilibrium.

b) After at least 5 min in oxygen-free conditions, adjust the volume flow in the exhaust duct to (1,00 ± 0,05) m^3/s and switch to air from the exhaust duct with the same flow rate, pressure and drying procedure as for sample gases. When the analyser reaches equilibrium, adjust the analyser output to (20,95 ± 0,01) %.

c) Within 1 min, start recording the oxygen analyser output at 3 s interval for a period of 30 min.

d) Determine the drift by use of the least squares fitting procedure to fit a straight line through the data points. The absolute value of the difference between reading at 0 min and at 30 min of this linear trend line represents the drift.

e) Determine the noise by computing the root-mean-square deviation around the linear trend line.

NOTE Root-mean-square deviation ($RMSD$) is defined as:

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

where

y_i = measured value;

$\hat{y}_i$ = estimated/predicted value by linear trend line;

n = total number of measurements.

E.2.3.3 Criteria

The sum of drift and noise (both taken as positive values) shall be not more than 0,01 % of the (V_{O_2}/V_{air}) value.

E.2.3.4 Calibration report

The calibration report shall include the following information:

a) the graphs of O_2 (t) in % V_{O_2}/V_{air};

b) the noise and drift values calculated according to E.2.3.2 d) and e) and expressed as percentages of the V_{O_2}/V_{air} value.

E.2.4 Carbon dioxide analyser adjustment

The carbon dioxide analyser shall be adjusted for zero and span each day on which tests are performed. The analyser output shall be within 0,1 % (V_{CO_2}/V_{air}) of the calibration gases used. The analyser output for carbon dioxide-free nitrogen gas shall be (0,00 ± 0,02) %. A possible procedure to perform the adjustment is given in F.2.2.

E.3 *HRR* calibrations

E.3.1 General

The calibration shall be performed both by means of burners and liquids.

E.3.2 *HRR* calibration by means of the burner defined in EN 60332-3-10

E.3.2.1 Conditions

a) Burner levels : 20,5 kW to 30,0 kW and 40 kW to 50 kW;

b) Ratio air/gas: settings from standard ignition source (for 40 kW to 50 kW the use of 1 or 2 burners is allowed);

c) Burner gas and air flow measurement : by means of mass flow or rotameter;

NOTE Mass flow meters are recommended.

d) On line measurement of gas consumption by means of mass loss measurement.

E.3.2.2 Procedure

Perform the following steps with the measuring equipment operating, with the airflow into the chamber set to (8 000 ± 400) l/min and the door closed.

a) Set the volume flow of the exhaust to: $\dot{V}_{298}$ = (1,00 ± 0,05) m³/s.

b) Record the temperature in the exhaust duct and the ambient temperature for at least 300 s. The temperatures in the duct shall not differ by more than 4 K from the ambient temperature.

c) Start the time measurement and the automatic recording of data: t = 0 s, by definition.

d) Ignite the burner and adjust the propane mass flow according to Table E.1 within the first 5 s of each step.

Table E.1 – Burner ignition times and *HRR* levels

Step number	Time s	Burner output kW
1	0 to 300	0
2	301 to 900	20,5 – 30,0 – 40 to 50
3	901 to 1 200	0

e) Stop the automatic recording of data at the end of step 3.

E.3.2.3 Calculations

Calculate the following parameters using the k_c value obtained from the flow profile determinations for the commissioning k_t factor and using the correct E-value for propane (16,8 MJ/m³):

a) the average *HRR* of burner between 540 s and 840 s;

b) the *THR* during the calibration test;

c) the mass loss of propane by means of weighing the gas bottle;

d) the start value of oxygen %, light intensity and *HRR* as the average during the first 60 s of the 300 s base line period;

e) the end value of oxygen %, light intensity and *HRR* as the average during the last 60 s of the calibration test;

f) the difference between the start and end values of oxygen %, *HRR* and light intensity.

E.3.2.4 Criteria

The following criteria shall be met:

a) the average *HRR* of burner between 540 s and 840 s shall be within 10 % of the set value;

b) the *THR* measured during the calibration test shall not differ by more than 10 % from the total heat release value determined from the mass loss measurement using the effective heat of combustion of propane (46,4 kJ/g). The error from this calculation (C_i) shall be used in the determination of the commissioning factor, k_t;

c) the difference between the start and end of test values for oxygen %, *HRR* and light intensity shall meet the requirements in 5.5.4.

E.3.3 *HRR* calibration by means of burning a flammable liquid

E.3.3.1 General

In addition to propane burns, calibration by burning a given mass of liquid in a tray shall be conducted in order to

a) compare the two kinds of calibration,

b) reach higher heat release levels, at least for short periods.

As an example, a procedure for methanol is given.

E.3.3.2 Conditions to be used for burning methanol

a) Combustible: methanol (99,5 % purity).

b) Tray area: area of approximately 0,4 m^2.

NOTE 1 The use of a circular tray is recommended.

c) Mass of combustible: (3 200 ± 25) g

d) Total mass loss measurement by measuring mass before and after test.

NOTE 2 The volume of methanol and tray area were chosen from the results of previous experiences as a compromise between the need to get a high enough peak *HRR* (approximately 150 kW) without jeopardising the chamber by releasing too much energy.

E.3.3.3 Procedure for methanol

Perform the following steps with the measuring equipment operating, with the airflow into the chamber set to (8 000 ± 400) l/min and the door closed during the burn:

a) set the volume flow of the exhaust to: $\dot{V}_{298}$ = (1,00 ± 0,05) m^3/s;

b) record the temperature in the exhaust duct and the ambient temperature for at least 300 s. The temperature in the duct shall not differ more than 4 °C from the ambient temperature;

c) start the time measurement and the automatic recording of data where the start time is defined as $t = 0$ s;

d) weigh the amount of methanol to be used and pour it into the container at $t = 240$ s;

e) ignite the liquid at $t = 300$ s;

NOTE Care should be taken when working with burning liquids.

f) after extinction of the burning liquid wait for another 300 s;

g) stop the automatic recording of data after this 300 s period.

E.3.3.4 Calculations

Calculate the following parameters using the k_c value obtained from the flow profile determinations for the commissioning k_t factor and using the correct E-value for methanol (17,47 MJ/m^3):

a) the *THR* (total heat release) during the calibration test;

b) the corresponding total heat release by using the mass loss of methanol;

c) the start value of oxygen %, light intensity and *HRR* as the average during the period 60 s to 120 s of the 300 s base line period.

d) the end value of oxygen %, light intensity and *HRR* as the average during the last 60 s of the calibration test i.e. during the last 60 s of the 300 s after the pool fire has extinguished;

e) the difference between the start and the end values of oxygen %, *HRR* and light intensity.

E.3.3.5 Criteria

The following criteria shall be met:

a) the *THR* (total heat release) measured during the calibration test shall not differ by more than 10 % from the total heat release value determined with the mass loss measurement using the effective heat of combustion of methanol of 19,94 kJ/g. The error from this calculation shall be used in the determination of the commissioning factor, k_t;

b) the difference between the start and the end of test values for oxygen %, *HRR* and light intensity shall meet the requirements in 5.5.4.

E.3.4 Commissioning factor k_t used for *HRR* calculations

A final commissioning k_t factor shall be determined after performing these calibrations with propane and liquid fuels as described in this annex. For this a correction factor is determined for both the propane and liquid fuel calibrations. This correction factor is determined as the *THR* calculated by means of the mass loss of propane or liquid divided by the *THR* measured by the *HHR* measurement system. The final k_t factor is the k_c factor determined in D.2 multiplied by the average of the correction factors from the propane (C_p) and methanol (C_m) calibrations.

However the final k_t factor used for the calculation of the heat release rate shall not differ by more than 10 % of the k_c factor determined in D.2. If the figure of 10 % is exceeded, then improvement of the velocity profile and/or troubleshooting shall be performed.

An example of this procedure is given below.

Assume that the k_c factor that was determined with the procedure in Annex D is equal to 0,9. The laboratory performs *HRR* calibrations at 20,5 kW, 30,0 kW and 40 kW to 50 kW with errors on *THR* of 3 %, 2,5 % and - 1,5 % resulting in an average correction factor for propane of 1,3 %. Then a methanol calibration results in a *THR* error of 6 %. The overall average is thus 3,7 %. The final commissioning k_t is then 0,93. Table E.2 and Figure E.1 give an overview of the procedure.

Table E.2 – Example of determination of commissioning k_t factor

Type of calibration	Correction factors	Average	*K* factor
k_c factor from flow profile of D.2	-	-	0,90
Propane 20,5 kW	1,03	1,013	-
Propane 30,0 kW	1,025		-
Propane 40 kW to 50 kW	0,985		-
Methanol (4 litres)	1,06	1,060	-
Final correction factor	-	1,037	-
Commissioning k_t	-	-	0,93

E.4 Smoke measurement system calibration

E.4.1 General

A1〉 The smoke measurement system calibration shall be performed after set up, maintenance, repair or replacement of the smoke measurement system holder or other major components of the exhaust system and at least every year, except for the optical filter check for white light systems (E.4.3) which shall be carried out at least every six months. The calibration consists of three parts: an output stability check, an an optical filter check for white light systems and a heptane burn. 〈A1

E.4.2 Stability check

Perform the following steps with the measuring equipment operating and with the ignition source in position in the test chamber.

a) Set the volume flow of the exhaust to: V_{298} = (1,00 ± 0,05) m³/s (as calculated according to A.1).

b) Start the time measurement ($t = 0$) and record the signal from the light receiver for a period of 30 min.

c) Determine the drift by use of a least squares fitting procedure to fit a straight line through the data points. The absolute value of the difference between reading at 0 min and at 30 min of this linear trend line represents the drift.

d) Determine the noise by computing the root-mean-square deviation ($RMSD$) around the linear trend line.

Criteria: Both noise and drift shall be less than 0,5 % of the start value.

E.4.3 Optical filter check for white light systems

A1〉 The optical density measurement system shall be calibrated with at least five neutral density filters in the optical density range of 0,04 to 2,00. 〈A1 The optical density calculated with the measured light receiver signal shall be within ± 5 % or ± 0,01 of the A1〉 calibrated value 〈A1 of the filters, whichever is the greater.

NOTE The optical density is defined as $d_{opt} = \log_{10}\left(\frac{I_0}{I}\right)$ where I_0 is the initial light intensity and I the light intensity with the filter in place.

A possible procedure to perform the calibration is given in F.4.

E.4.4 Smoke calibration by means of burning a flammable liquid

E.4.4.1 General

A calibration by burning a given mass of heptane in a tray shall be conducted in order to check the smoke measurement under conditions of high heat release.

E.4.4.2 Conditions to be used for burning heptane

a) Circular open steel fuel tray of internal diameter (350 ± 5) mm, with an internal wall height of (150 ± 5) mm and a wall thickness of (3,0 ± 0,5) mm.

b) Heptane of at least 99 % purity: (1 250 ± 10) g.

c) Water: (2 000 ± 10) g.

d) The tray, heptane and water shall be maintained within 2 °C of the ambient temperature for at least 4 h prior to conducting the calibration.

E.4.4.3 Procedure

Perform the following steps with the measuring equipment operating, with the airflow into the chamber set to (8 000 ± 400) l/min, the ladder removed from the chamber and the door closed during the burn:

a) Set the volume flow of the exhaust to: $\dot{V}_{298}$ = (1,00 ± 0,05) m^3/s.

b) Record the temperature in the exhaust duct and the ambient temperature for at least 300 s. The temperature in the duct shall not differ by more than 4 °C from the ambient temperature.

c) Place the fuel tray such that its centre is on the burner centre line and (435 ± 20) mm from the rear wall of the chamber. The fuel tray shall be placed on a standard calcium silicate board with dimensions of 400 mm x 400 mm. Supports of 100 mm high shall raise the board above the floor of the chamber,

d) Weight the amount of water to be used and pour it into the fuel tray.

e) Start the time measurement and the automatic recording of data where the start time is defined as $t = 0$ s.

f) Weigh the amount of heptane to be used and pour it gently onto the water in the fuel tray at $t = 240$ s.

g) Ignite the liquid at $t = 300$ s.

NOTE Care should be taken when working with burning liquids.

h) After burning of the liquid ceases, wait for another 300 s.

i) Stop the automatic recording of data after this 300 s period.

E.4.4.4 Calculations

Calculate the following quantities:

a) the total smoke production *TSP* during the calibration test from the time of ignition until the end of data recording;

b) the *TSP* divided by the mass of heptane used.

E.4.4.5 Criteria

The following criteria shall be met:

a) at the end of the calibration test, the signal from the light receiver shall be within 1 % of its initial value

b) the ratio *TSP* divided by mass of heptane shall be within the range (110 ± 25) m^2/1 000 g

NOTE Measurement of the *HRR* and calculation of the *THR* during the heptane smoke calibration test can give useful information on the performance of the system. The theoretical value of the *THR* (assuming complete combustion) is 44,6 MJ per 1 000 g of heptane assuming an E-value of 16,5 MJ/m^3.

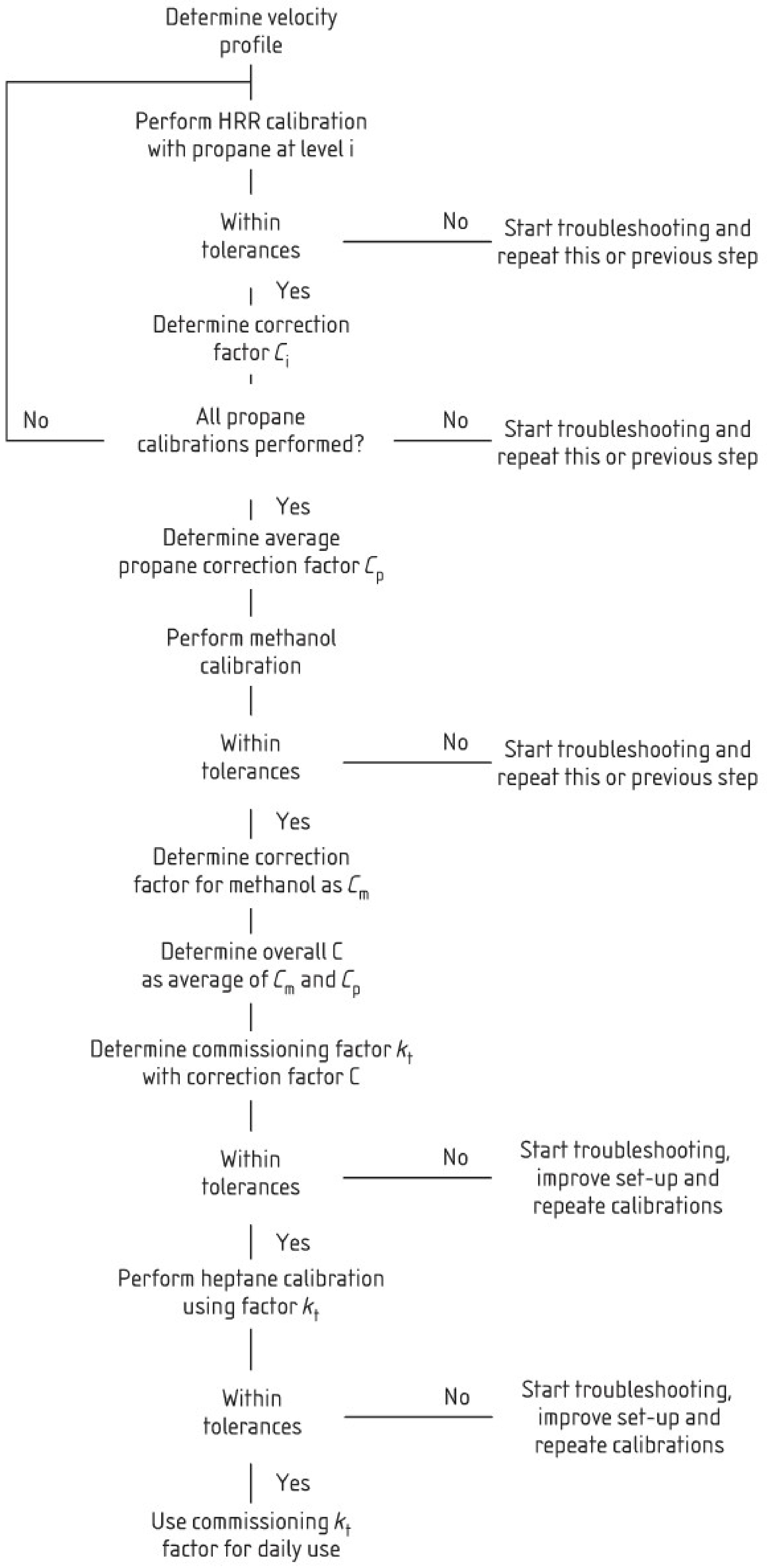


Figure E.1 – Overview of commissioning calibrations

Annex F
(informative)

Guidance for calibration procedures for specific measuring equipment

F.1 General procedures for separate pieces of equipment

This annex includes calibration procedures that satisfy the relevant performance based calibration requirement given in Annex E.

F.2 Gas analyser calibrations

F.2.1 Oxygen analyser adjustment

The oxygen analyser may be adjusted using the following procedure. An analyser adjusted according to this procedure is expected to meet the requirements of E.2.2.

A1⟩ a) For adjustment of the lower limit, either feed the analyser with oxygen-free nitrogen gas or with a specified gas with oxygen content of maximum (17,0 ± 0,1) %, with the same flow rate and pressure as for sample gases. When the analyser reaches equilibrium, adjust the analyser output to (0,00 ± 0,01) % if oxygen-free nitrogen gas used or to within 0,01% of the actual oxygen content if the specified gas is used. ⟨A1

F.2.2 Carbon dioxide analyser adjustment

The carbon dioxide analyser may be adjusted using the following procedure. An analyser adjusted according to this procedure is expected to meet the requirements of E.2.4.

a) For zeroing, feed the analyser with carbon dioxide-free nitrogen gas, with the same flow rate and pressure as for sample gases. When the analyser reaches equilibrium, adjust the analyser output to (0,00 ± 0,01) %.

b) For span calibration a specified gas with carbon dioxide content approximately 75 % of full scale range should be used. Feed the analyser with the gas, with the same flow rate and pressure as for sample gases. When the analyser reaches equilibrium, adjust the analyser output to the carbon dioxide content of the specified gas ± 0,01 %.

F.3 Check of propane mass flow controller or rotameter

F.3.1 General

The accuracy of the mass flow controller or rotameter may be checked by using a single cylinder of propane and the gas burner set at the propane mass flow rate as used for either the 20,5 kW or 30,0 kW nominal *HRR*. The gas usage rate is determined from the initial and final weight of the gas cylinder. Use a balance or weighing platform with an accuracy of 5 g or better.

F.3.2 Actions

a) Place the cylinder on the weighing platform and connect it to the supply system.

b) Set up the test facility as in a normal calibration test with backing boards, if any, fitted. Ignite the main burner and adjust the gas supply to 20,5 kW or 30,0 kW, to have the burner running at the rate as used during normal tests.

c) Record the weight of the cylinder and simultaneously start a timing device.

d) After (1 800 ± 30) s, again record the weight of the cylinder and simultaneously stop the timing device.

e) Determine the average rate of usage of gas in mg/s.

F.3.3 Criterion

The average rate of usage of gas set in b) and determined in e) should be equal within 5 %.

F.4 Optical filter check for white light systems

F.4.1 General

The smoke measurement system may be calibrated using the following procedure. A light system calibrated according to this procedure is expected to meet the requirements described in Annex E. The filters used for this check should be of the absorption type and calibrated for the correct wave length(s) of the optical system.

F.4.2 Actions

Perform the following steps with the measuring equipment operating and with an empty ladder in position in the chamber.

a) Place a light blocking insert into the filter holder and adjust to zero.

b) Remove the light blocking insert and adjust the signal from the light receiver to 100 %.

c) Start the time measurement and record the signal from the light receiver for a period of two minutes.

A1⟩ d) Introduce one of the following filters and record the corresponding signal for at least one minute where the filters to be used are with optical density (d) 0,04 - 0,1 - 0,3 - 0,5 - 0,8 - 1,0 and 2,0. ⟨A1

e) Repeat step d) for the other filters.

f) Stop the data acquisition and calculate the mean transmission values for all filters.

F.4.3 Criterion

Each d-value calculated from the mean transmission value ($d = -\lg(I)$) should be within ± 5 % or ± 0,01 of the theoretical d-value of the filter, whichever is the greater.

A1⟩ NOTE Theoretical transmission values for the given d-values 0,04 - 0,1 - 0,3 - 0,5 – 0,8 - 1,0 - 2,0 using the given formula, are 91,20% - 79,43 % - 50,12 % - 31,62 % - 15,85 % - 10 % and 1 %. ⟨A1

Annex G
(normative)

Calculation of HRR_{av}, SPR_{av} and $FIGRA$

G.1 Calculation of HRR_{av}

The average HRR, HRR_{av}, is equal to $HRR30s$. Exceptions include the first 12 s following the ignition of the burner, and the 12 s period prior to 1 200 s, the completion of the burner on phase of the test.

G.1.1 For $t_b + 15\text{ s} \le t \le t_b + 1\,185\text{ s}$: $HRR_{av}(t) = HRR30s\,(t)$

$$HRR30s\,(t) = \frac{\left[((0.5 * HRR(t-15s)) + HRR(t-12s) + \ldots + HRR(t+12s) + (0.5 * HRR(t+15s))\right]}{10}$$

G.1.2 For data points collected over the first 12 s after burner ignition time, t_b, the average is taken only over the widest possible symmetrical range of data points within the exposure period:

$For\ t = t_b\ s$: $HRR_{av}\,(t_b\ s) = 0$

$For\ t = t_b + 3\ s$ $HRR_{av}\,(t_b + 3\ s) = \overline{HRR(t_b \ldots t_b + 6\ s)}$

$For\ t = t_b + 6\ s$ $HRR_{av}\,(t_b + 6\ s) = \overline{HRR(t_b \ldots t_b + 12\ s)}$

$For\ t = t_b + 9\ s$ $HRR_{av}\,(t_b + 9\ s) = \overline{HRR(t_b \ldots t_b + 18\ s)}$

$For\ t = t_b + 12\ s$ $HRR_{av}\,(t_b + 12\ s) = \overline{HRR(t_b \ldots t_b + 24\ s)}$

G.1.3 For data points collected over the final 12 s prior to extinguishing the burner, the average is taken only over the widest possible symmetrical range of data points within the exposure period:

$For\ t = t_b + 1\,188\ s$: $HRR_{av}\,(t_b + 1\,188\ s) = \overline{HRR(t_b + 1176 \ldots t_b + 1\,200\ s)}$

$For\ t = t_b + 1\,191\ s$ $HRR_{av}\,(t_b + 1\,191\ s) = \overline{HRR(t_b + 1182 \ldots t_b + 1\,200\ s)}$

$For\ t = t_b + 1\,194\ s$ $HRR_{av}\,(t_b + 1\,194\ s) = \overline{HRR(t_b + 1188 \ldots t_b + 1\,200\ s)}$

$For\ t = t_b + 1\,197\ s$ $HRR_{av}\,(t_b + 1\,197\ s) = \overline{HRR(t_b + 1194 \ldots t_b + 1\,200\ s)}$

$For\ t = t_b + 1\,200\ s$ $HRR_{av}\,(t_b + 1\,200\ s) = HRR(t_b + 1\,200\ s)$

G.2 Calculation of SPR_{av}

The average SPR, SPR_{av}, is equal to $SPR60s$. Exceptions include the first 27 s following the ignition of the burner, and the 27 s period prior to 1 200 s, the completion of the burner on phase of the test.

G.2.1 For t_b + 30 s $\leq t \leq t_b$ + 1 170 s: $SPR_{av}(t) = SPR60s\ (t)$

$$SPR60s\ (t) = \frac{\left[((0{,}5 * SPR(t-30\ s)) + SPR(t-27\ s) + \ldots + SPR(t+27\ s) + (0{,}5 * SPR(t+30\ s))\right]}{20}$$

G.2.2 For data points collected over the first 27 s after burner ignition time, t_b, the average is taken only over the widest possible symmetrical range of data points within the exposure period:

For $t = t_b\ s$: $SPR_{av}\ (t_b\ s) = 0$

For $t = t_b + 3\ s$ $SPR_{av}\ (t_b + 3\ s) = \overline{SPR(t_b \ldots t_b + 6\ s)}$

For $t = t_b + 6\ s$ $SPR_{av}\ (t_b + 6\ s) = \overline{SPR(t_b \ldots t_b + 12\ s)}$ *et cetera, until*

For $t = t_b + 27\ s$ $SPR_{av}\ (t_b + 27\ s) = \overline{SPR(t_b \ldots t_b + 54\ s)}$

G.2.3 For data points collected over the final 27 s prior to extinguishing the burner, the average is taken only over the widest possible symmetrical range of data points within the exposure period:

For $t = t_b + 1\ 173\ s$ $SPR_{av}\ (t_b + 1\ 173\ s) = \overline{SPR(1\,146\ t_b \ldots t_b + 1\,200\ s)}$

For $t = t_b + 1\ 176\ s$ $SPR_{av}\ (t_b + 1\ 176\ s) = \overline{SPR(1\,152\ t_b \ldots t_b + 1\,200\ s)}$ *et cetera, until*

For $t = t_b + 1\ 197\ s$ $SPR_{av}\ (t_b + 1\ 197\ s) = \overline{SPR(1\,194\ t_b \ldots t_b + 1\,200\ s)}$

For $t = t_b + 1\ 200\ s$ $SPR_{av}\ (t_b + 1\ 200\ s) = SPR\ (t_b + 1\ 200\ s)$

G.3 Calculation of the Fire Growth Rate Index (*FIGRA*)

The *FIGRA* is defined as the maximum of the quotient $HRR_{av}(t)\ /\ (t - t_b)$. The quotient is calculated only for that part of the exposure period in which the threshold levels for HRR_{av} and THR have been exceeded. If one or both threshold values are not exceeded during the exposure period, *FIGRA* is equal to zero.

$$FIGRA = 1\,000 * \max\left[\left(\frac{HRR_{av}(t)}{t - t_b}\right), for: \left(t \geq t_{t-HRR}\right) \wedge \left(t \geq t_{t-THR}\right) \wedge \left(t \leq t_b + 1\,200\ s\right)\right]$$

where

FIGRA	is the fire growth rate index [W/s];
$HRR_{av}(t)$	is the average of $HRR(t)$ as specified in G.1) [kW];
$max[a(t),b_t]$	is the maximum of the function $a(t)$ for the given t values b_t.

The moments in time the threshold values are exceeded are defined as:

t_{t_HRR}	is the first moment after $t = t_b$ at which $HRR_{av}(t) > 3$ kW;
t_{t_THR}	is the first moment after $t = t_b$ at which $THR(t) > 0{,}4$ MJ.

Annex H
(informative)

Guidance on the choice of test equipment

NOTE The information given in this annex, covering named products and their suppliers, is given for the convenience of users of this standard and does not constitute an endorsement by CLC/TC 20 of the product named. Other products meeting the requirements of 6.5.2 may be used.

Examples of materials which have been found to be suitable for the backing board are

a) Monolite M1;

b) Supalux;

c) Promatect H.

Annex I
(informative)

Guidance on the file format for data from the test

For easy exchange of test results, test data should be stored in a standard format. The principle objective is that the file should contain all the required information including both visually observed/recorded and automatically recorded data. It should be possible to perform all requested calculations.

The data of a test should be stored in an ASCII-file with 17 tab-separated columns of data. More columns (with non-compulsory data) are allowed when they are placed after the compulsory columns, not in between.

The file should contain a two-line header and additional lines with general information and automatically recorded (raw) data per time step.

The first header line contains the column header texts:

a) General information;

b) [empty];

c) time (s);

d) Gas mass flow meter (mg/s);

e) DPT (Pa);

f) Transmission (%);

g) mole percentage of oxygen (%);

h) mole percentage of CO_2 (%);

i) T_0 (K) [Ambient temperature];

j) T_1 (K) [Duct thermocouple 1];

k) T_2 (K) [Duct thermocouple 2];

l) T_3 (K) [Duct thermocouple 3];

m) mole percentage of CO (%);

n) Ambient pressure (kPa);

o) Air mass flow meter (mg/s);

p) Main photodiode output (-) [if using laser smoke system];

q) Compensating photodiode output (-) [if using laser smoke system].

The second line is not specified (empty by default).

Subsequent lines contain general information in the first two columns and automatically recorded (raw) data in the next 15 columns. Only the first 76 lines in columns one and two are used. In columns 3 to 17 the vector data from each transducer is given at a time interval of 3 s.

The general information (regarding the test, product, laboratory, apparatus, pre-test and end of test conditions, and visual observations) is given in column two, with a description of what is presented in column one. The row order of the different items is given in the example below.

Table I.1 – Example of the recommended raw data file format

	Column 1	*Column 2*
Row 1	**General Information**	
2		
3	**Test**	
4	Standard used	EN 50399
5		
6	Date of test	Record date
7		
8	**Product**	
9	Product Identification	Cable description
10	Specimen number	Record identifier
11	E' (MJ/m^3)	17,2
12	Sponsor	Sponsor of test
13	Date of arrival	Record date
14	Manufacturer	Manufacturer of cable
15	Cable diameter (mm)	As measured
16	NMV (l/m)	As calculated
17	Largest conductor size (mm^2)	As declared
18	Total number of cables	As calculated
19	Number of layers	1
20	Number of burners	1
21	Mounting	Test piece or bundle
22	Backing board on ladder? {Y/N}	Yes or No
23	Backing board	Board description
24	Flame application time (s)	1 200
25		
26	**Specifications: apparatus**	
27	Flow profile k_t (-)	As calculated
28	Probe constant k_p (-)	1,08
29	Duct diameter (m)	As measured
30	O$_2$ calibration delay time (s)	As measured
31	CO$_2$ calibration delay time (s)	As measured
32	CO calibration delay time (s)	For information only
33		
34	**Laboratory**	
35	Laboratory name	Laboratory name
36	Operator	Operator name
37	Filename	File reference
38	Report identification	Report reference
39		
40		

Table I.1 *(continued)*

41	**Pre-test conditions**	
42	Barometric pressure (Pa)	As measured
43	Relative humidity (%)	As measured
44		
45		
46		
47		
48		
49		
50		
51		
52	**Conditioning**	
53	Conditioned? {Y/N}	Yes or No
54	Conditioning temperature (°C)	As measured
55	Conditioning RH (%)	For information only
56	{Constant mass/fixed period}	Fixed period
57	Time interval (hours)	As measured
58	Mass 1 (g)	For information only
59	Mass 2 (g)	For information only
60		
61	**Comments**	
62	Pre-test comments	Comments entered before test
63	After-test comments	Comments entered after-test
64	FDP flaming ≤ 10 s {Y/N}	Yes or No
65	FDP flaming > 10 s {Y/N}	Yes or No
66	Falling of specimen parts {Y/N}	Yes or No
67	Smoke not entering hood {Y/N}	Yes or No
68	Damage length (m)	As measured
69		
70		
71		
72		
73		
74		
75		
76	*HRR* level (kW)	20,5 or 30,0

The 15 columns with automatically recorded data are in accordance with, and in the same order as below.

1) Time (t), in s (with 3 s time interval); at the start of recording of data, $t = 0$ by definition.

2) Mass flow rate of propane gas to the burner (m_{gas}) in mg/s.

3) Pressure difference between the two chambers of the bi-directional probe (Δp), at the general measuring section in the exhaust duct, in Pa.

4) Transmission recorded by the smoke system at the general measuring section in the exhaust duct, in %.

5) O_2 concentration in exhaust flow (xO_2), sampled at the gas sampling probe in the general measuring section in the exhaust duct, in %.

NOTE The oxygen and carbon dioxide concentrations are measured only in the exhaust duct; both concentrations are assumed to be constant in the air that enters the test room. It should be noted that the air supplied from a space where oxygen is consumed (e.g. by fire tests) can not fulfil this assumption.

6) CO_2 concentration in exhaust flow (xCO_2), sampled at the gas sampling probe in the general measuring section in the exhaust duct, in %.

7) Ambient temperature (T_0) in the test room in K.

8) Temperature measured by thermocouple 1 (T_1) in the general measuring section in the exhaust duct, in K.

9) Temperature measured by thermocouple 2 (T_2) in the general measuring section in the exhaust duct, in K.

10) Temperature measured by thermocouple 3 (T_3) in the general measuring section in the exhaust duct, in K.

11) CO concentration in exhaust flow (xCO), sampled at the gas sampling probe in the general measuring section in the exhaust duct, in %.

12) Ambient pressure in the test room in kPa.

13) Mass flow rate of air to the burner (m_{air}) in mg/s.

14) Signal from the main photodiode of a laser smoke system at the general measuring section in the exhaust duct [dimensionless].

15) Signal from the compensating photodiode of a laser smoke system at the general measuring section in the exhaust duct [dimensionless].

For columns 2, 7, 9, 10, 11, 12, 13, 14 and 15, if the transducer is not fitted then the value reported must be -1 for the whole length of the data vector.

The data file format presented here only concerns the raw data (before performing the calculations). No file format is given for processed data files. However, it is advisable to build the processed data file from the raw data file by adding columns and rows at the ends (and not in between). In this way a processed data file can easily be used as a raw data input file.

Annex J
(normative)

Rounding of numbers

The following rules apply when rounding numbers for values that require to be rounded. Rounding shall be carried out to the number of decimal places specified in the relevant clauses.

The method of rounding shall then be:

a) if the last figure to be retained is followed, before rounding, by 0, 1, 2, 3 or 4, it shall remain unchanged (rounding down);
b) if the last figure to be retained is followed, before rounding, by 9, 8, 7, 6 or 5, it shall be increased by one (rounding up).

To illustrate these rules, the following practical examples are given:

1) Rounding down:

EXAMPLE 1

2,12 ≈ 2,1 rounded to one decimal place
2,444 ≈ 2,4 rounded to one decimal place
25, 2 ≈ 25 rounded to the whole number
25, 47 ≈ 25 rounded to the whole number

2) Rounding up:

EXAMPLE 2

2,17 ≈ 2,2 rounded to one decimal place
2,454 ≈ 2,5 rounded to one decimal place
25, 7 ≈ 26 rounded to the whole number
25, 57 ≈ 26 rounded to the whole number

Bibliography

[1] Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products, OJ L 40, 11.2.1989, p. 12–26.

[2] Commission Decision 2006/751/EC of 27 October 2006 amending Decision 2000/147/EC implementing Council Directive 89/106/EEC as regards the classification of the reaction-to-fire performance of construction products (notified under document number C(2006) 5063), OJ L 305, 4.11.2006, p. 8–12.

[3] Fire Performance of Electric Cables – New test methods and measurement techniques (FIPEC). Final report on the European Commission SMT programme sponsored research project SMT4-CT96-2059.

[4] Guidance Paper G (concerning the Construction Products Directive – 89/106/EEC) – The European classification system for the reaction to fire performance of construction products, European Commission.

[5] Mc Caffrey and Heskestad. Combustion and Flame, 26 (1976).

[6] EN 13823, *Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item.*

[7] EN 14390, *Fire test – Large-scale room reference test for surface products.*

[8] EN ISO 5167-2, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 2: Orifice plates (ISO 5167-2).*

[9] EN ISO 5167-4, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 4: Venturi tubes (ISO 5167-4).*

[10] ISO 9705, *Fire tests – Full-scale room test for surface products.*

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