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Reaction-to-fire tests — Heat release, smoke production and mass loss rate —

Part 2: Smoke production rate (dynamic measurement)

Essais de réaction au feu — Débit calorifique, taux de dégagement de fumée et taux de perte de masse —

Partie 2: Taux de dégagement de fumée (mesure dynamique)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this part of ISO 5660 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 5660-2 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

ISO 5660 consists of the following parts, under the general title *Reaction-to-fire tests — Heat release, smoke production and mass loss rate*:

— *Part 1: Heat release rate (cone calorimeter method)*

— *Part 2: Smoke production rate (dynamic measurement)*

— *Part 3: Guidance on heat and smoke release rate*

Annexes A, B and C of this part of ISO 5660 are for information only.

Reaction-to-fire tests — Heat release, smoke production and mass loss rate —

Part 2:
Smoke production rate (dynamic measurement)

1 Scope

This part of ISO 5660 specifies a small-scale method for assessing the dynamic smoke production rate of essentially flat specimens exposed to controlled levels of radiant heating under well-ventilated conditions with or without an external igniter. The rate of smoke production is calculated from measurement of the attenuation of a laser light beam by the combustion product stream. Smoke obscuration is recorded for the entire test, regardless of whether the specimen is flaming or not.

The measurement system prescribed by this part of ISO 5660 is an extension of the apparatus described in ISO 5660-1. Therefore, this part of ISO 5660 is used in conjunction with ISO 5660-1.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 5660. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 5660 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 5660-1:2002, *Reaction-to-fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate (cone calorimeter method)*

ISO 13943:2000, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this part of ISO 5660, the terms and definitions given in ISO 5660-1 and ISO 13943 and the following apply.

3.1
smoke obscuration
reduction, usually expressed as a percentage, in the intensity of light due to its passage through smoke

3.2
extinction coefficient
natural logarithm of the ratio of incident light intensity to transmitted light intensity, per unit light path length

3.3
smoke production
integral of the smoke production rate over the time interval being considered

3.4
smoke production rate
product of the volumetric flow rate of smoke and the extinction coefficient of the smoke at the point of measurement

4 Symbols

See Table 1.

Table 1 — Symbols and their designation

Symbol	Designation	Units
A	Exposed surface area of specimen	m^2
D'	Optical density	1
$\dot{m}_e$	Mass flow rate in exhaust duct	$kg \cdot s^{-1}$
F	Calibration factor	m^{-1}
I_0/I	Ratio of incident light to transmitted light	1
k	Linear Napierian absorption coefficient (commonly called extinction coefficient)	m^{-1}
k_1	Measured calibration extinction coefficient	m^{-1}
k_2	Calculated calibration extinction coefficient	m^{-1}
k_m	Measured extinction coefficient	m^{-1}
L	Light path length through smoke	M
m_{ig}	Specimen mass at ignition (sustained flaming)	kg
m_f	Specimen mass at the end of the test	kg
$\dot{m}$	Mass loss rate of specimen	$kg \cdot s^{-1}$
Δm	Specimen mass loss	kg
M	Molecular mass of the gases flowing through the exhaust duct	$kg \cdot mol^{-1}$
S	Total smoke production	m^2
S_A	Total smoke production per unit area	$m^2 \cdot m^{-2}$
$S_{A,1}$	Total smoke production per unit area before ignition	$m^2 \cdot m^{-2}$
$S_{A,2}$	Total smoke production per unit area after ignition	$m^2 \cdot m^{-2}$
P_s	Smoke production rate	$m^2 \cdot s^{-1}$
$P_{s,A}$	Smoke production rate normalized to the specimen area	$s^{-1} \left[= \left(m^2 \cdot s^{-1}\right)/m^2\right]$
Δt	Sampling time interval	s
T_s	Temperature of the smoke at the point of measurement	K
$\dot{V}_s$	Volume flow rate of smoke at the point of measurement	$m^3 \cdot s^{-1}$
ρ	Density	$kg \cdot m^{-3}$
σ	Specific extinction area	$m^2 \cdot kg^{-1}$
NOTE Detailed discussion of some of these parameters and their units is given in reference [12].		

5 Principle

This test method is based on the observation that, generally, the intensity of light that is transmitted through a volume of combustion products is an exponentially decreasing function of distance. This is commonly referred to as Bouguer's law. Specimens in the test are burned in ambient air conditions, while being subjected to a predetermined external irradiance within the range 0 $kW \cdot m^{-2}$ to 100 $kW \cdot m^{-2}$ and measurements are made of smoke obscuration, exhaust gas flow rate, and mass loss rate of the specimen. Smoke obscuration is measured as the fraction of laser light intensity that is transmitted through the smoke in the exhaust duct. This fraction is used to calculate the extinction coefficient according to Bouguer's law. The test results are reported in terms of smoke production and smoke production rate-both normalized to the exposed specimen surface area. Smoke production rate is calculated as the product of the extinction coefficient and the volume flow rate of the smoke in the exhaust duct. Smoke production is calculated by numerical integration of the smoke production rate over the time interval being considered. The variables reported are normalized to area because smoke production is proportional to area.

The test method is used to assess the contribution that the product under test can make to the rate of evolution of smoke and to the amount of smoke produced during its involvement in a well-ventilated fire. These properties are determined on small representative specimens.

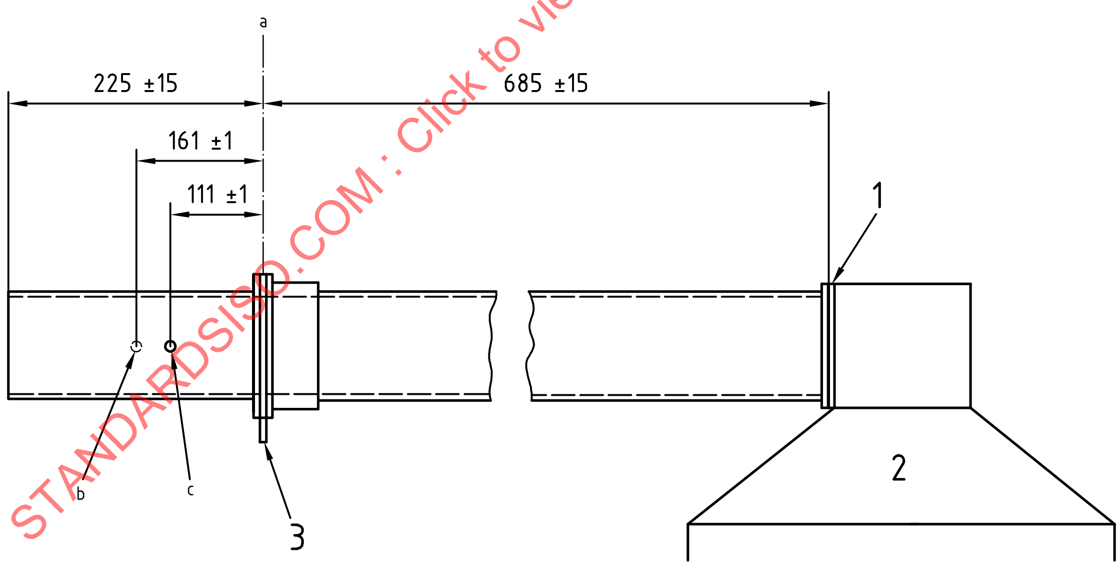
6 Apparatus

The apparatus is identical to that specified in clause 6 of ISO 5660-1:2002, except for the additional equipment described below.

6.1 Smoke obscuration measuring system, for measuring the attenuation of laser light in the exhaust duct. The system comprises a helium-neon laser (between 0,5 mW and 2 mW, polarized), silicon photodiodes as main beam and reference detectors, and appropriate electronics to derive the extinction coefficient and to set the zero reading. The meter is located horizontally 111 mm ± 1 mm downstream of the gas sampling ring, as shown in Figure 1. Two small diameter tubes welded onto each side of the exhaust duct serve as part of the light baffling for the purging air and also allow for any smoke that may enter, despite the purge flow, to be deposited on the tube walls before reaching the optical elements. One acceptable arrangement of a smoke measuring system is shown in Figure 2.

NOTE Experimental work has been performed with systems using a white light source with collimating optics[1]. Such systems have been shown to yield generally similar results[2],[3],[4] but not under all conditions[5]. Theoretical predictions[6] have been verified experimentally. White light systems may be used if shown to have an equivalent accuracy.

Dimensions in millimetres

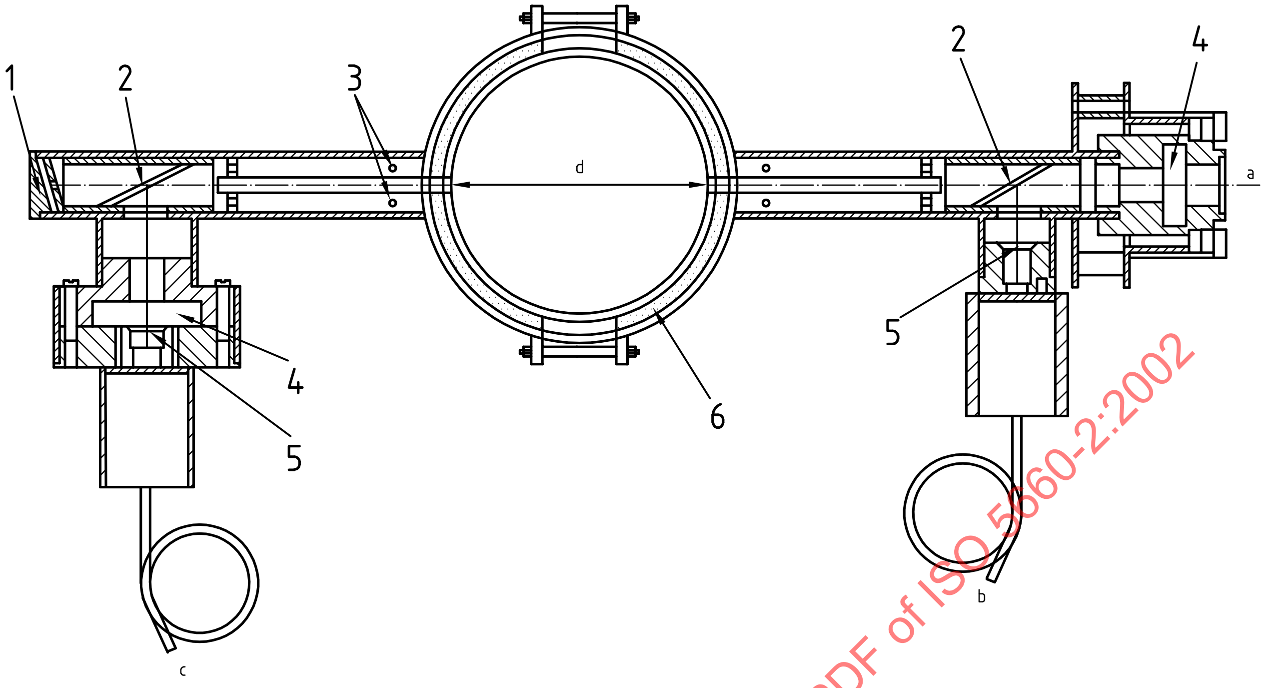


Key

1 Orifice plate
2 Hood
3 Gas sampling ring probe (sample holes face downstream)

[a] Centre
[b] Smoke thermocouple location
[c] Smoke meter location

Figure 1 — Schematic representation of the smoke meter and smoke thermocouple locations



Key

1 Cap
2 Beam splitter
3 Purge air orifices
4 Filter slot
5 Opal glass
6 Ceramic fibre packing

a He-Ne laser beam (0,5 mW)

b To compensation detector

c To main detector

d Optical path

Figure 2 — Cross-section of a typical smoke measuring system arrangement

6.2 Additional thermocouple, to measure the temperature of the gas stream near the smoke meter. This temperature shall be measured using a 1,0 mm to 1,6 mm outside diameter unearthed sheathed-junction thermocouple, or a 3 mm outside diameter exposed-junction thermocouple positioned in the exhaust stack on the centreline and 50 mm downstream from the smoke meter, as shown in Figure 1.

6.3 Optical filters, to calibrate the smoke obscuration measuring system. Two glass neutral density dispersion filters [7], accurately calibrated at the laser wavelength of 632,8 nm, are required. The filters used shall not be of the coated type because these filters can give rise to interference effects with laser light and can deteriorate with time. The filters shall have nominal optical densities of 0,3 and 0,8. Corresponding values of extinction coefficient, k, are obtained from the formula:

$$k = (2{,}303 D') L^{-1} \quad (1)$$

7 Suitability of a product for testing

Identical provisions apply as in clause 7 of ISO 5660-1:2002.

8 Specimen construction and preparation

Identical provisions apply as in clause 8 of ISO 5660-1:2002.

9 Test environment

Identical provisions apply as in clause 9 of ISO 5660-1:2002.

10 Calibration

10.1 General

The heater, oxygen analyser and weighing device systems shall be calibrated as specified in clause 10 of ISO 5660-1:2002. The calibration for the smoke obscuration measuring system shall be performed as described below.

Alternative means of calibrating the weighing device system may be employed if it can be shown that an equivalent accuracy is obtained.

10.2 Smoke meter calibration

10.2.1 Calibration with neutral density filters

The smoke meter shall be calibrated to read correctly (k to within 0,1 m^{-1}) for the two neutral density filters specified in 6.3, and also at 100 % transmission. This neutral density filter calibration shall be performed at least every 100 working hours or upon reassembling of the optics after cleaning and maintenance.

10.2.2 Calibration before test

Immediately before each test, the zero value of the extinction coefficient (100 % transmission) shall be set by hardware or software as appropriate.

11 Test procedure

WARNING — So that suitable precautions are taken to safeguard health, the attention of all concerned in fire tests is drawn to the possibility that toxic or harmful gases can be evolved during the exposure of test specimens.

The test procedures involve high temperatures and combustion processes. Therefore, hazards can exist such as burns or the ignition of extraneous objects or clothing. The operator shall use protective gloves for insertion and removal of test specimens. Neither the cone heater nor the associated fixtures shall be touched while hot except with the use of protective gloves. Care shall be taken never to touch the spark igniter which carries a substantial potential (10 kV). The exhaust system of the apparatus shall be checked for proper operation before testing and shall discharge into a building exhaust system with adequate capacity. The possibility of the violent ejection of molten hot material or sharp fragments from some kinds of specimens when irradiated cannot totally be discounted and it is therefore essential that eye protection be worn.

The test procedure is identical to that described in clause 11 of ISO 5660-1:2002. However, the test data shall not be discarded if piloted ignition does not occur, because the smoke production rate data may have relevance under non-flaming conditions. The zero value of the extinction coefficient shall be verified prior to every test as part of the procedures specified in 11.2 of ISO 5660-1:2002.

NOTE The heat release rate measurements described in ISO 5660-1 normally utilize piloted ignition. Separate non-standard tests may be conducted for research purposes without piloted ignition to evaluate smoke production rates under non-flaming conditions.

12 Calculations

12.1 General

The mass loss rate calculations are described in 12.5 of ISO 5660-1:2002. The calculation of the smoke obscuration is given below.

12.2 Smoke obscuration

12.2.1 The extinction coefficient, k, is determined by the smoke meter electronics as follows:

$$k = \ln (I_0/I)\, L^{-1} \tag{2}$$

12.2.2 Smoke production rate per unit area of exposed specimen is given by:

$$P_{\mathrm{s},A} = A^{-1} k \dot{V}_{\mathrm{s}} \tag{3}$$

The volumetric flow rate at the smoke meter, $\dot{V}_{\mathrm{s}}$, is calculated from the mass flow rate measured with the orifice plate, $\dot{m}_{\mathrm{e}}$ via:

$$\dot{V}_{\mathrm{s}} = \left(\dot{m}_{\mathrm{e}} T_{\mathrm{s}}\right) \left(12{,}2 \times 10^3 M\right)^{-1} \tag{4}$$

The value of T_{s} is obtained from the thermocouple described in 6.2 and not from the thermocouple associated with the orifice plate mass flow measurement.

If O_2, CO_2, CO and H_2O analysers are present, $\dot{m}_{\mathrm{e}}$ and M are obtained from equations (F.8) and (F.9) respectively in annex F of ISO 5660-1:2002. For other analyser configurations discussed in ISO 5660-1, the mass flow rate shall be calculated from equation (9) in ISO 5660-1:2002, and M shall be estimated as 0,029 kg mol^{-1} (the value for air).

12.2.3 The total smoke production per unit area of exposed specimen obtained during the non-flaming (pre-ignition) period of the test shall be calculated from:

$$S_{A,1} = A^{-1} \sum_{i=s}^{i=f} \dot{V}_{\mathrm{s}} k \Delta t \tag{5}$$

and the smoke production per unit area of exposed specimen obtained during the flaming (post-ignition) period of the test shall be similarly calculated from:

$$S_{A,2} = A^{-1} \sum_{i=s}^{i=f} \dot{V}_{\mathrm{s}} k \Delta t \tag{6}$$

where the values s and f for i refer to the start and the end of the time period over which the average is calculated. Thus, for the non-flaming phase, s refers to the start of the test and f to the time of the start of sustained flaming. For the flaming phase (if any), s corresponds to the time of the start of sustained flaming and f corresponds to the end of the flaming phase.

13 Test report

The test report shall be as comprehensive as possible and shall include any observations made during the test and comments on any difficulties experienced during testing. The units for all measurements shall be clearly stated in the report. Recommended units convenient for reporting are given in Table 1.

In addition to the items listed in clause 13 of ISO 5660-1:2002, the following essential information shall also be given in the test report:

a) total smoke production per unit area of exposed specimen over the non-flaming phase for every specimen ($S_{A,1}$);

b) total smoke production per unit area of exposed specimen over the flaming phase for every specimen ($S_{A,2}$);

c) total smoke production per unit area of exposed specimen for every specimen ($S_A = S_{A,1} + S_{A,2}$);

d) a graph showing the rate of smoke production per unit area as a function of time for every specimen ($P_{s,A}$ versus time), showing the time at first ignition;

e) the exposed surface area of the test specimen (A).

Annex A
(informative)

Supplementary calculations — Normalization to the mass loss rate of the specific extinction area of the specimen

For the application of smoke data to fire models, it is sometimes desirable to report the data in terms of the yield of smoke per unit mass loss of specimen, independent of the apparatus flow conditions and specimen mass. To do this the specific extinction area is defined as the ratio of the extinction area of smoke to the mass loss of the specimen that is associated with the production of that smoke:

$$\sigma = k\dot{V}_{\mathrm{s}}\Delta m^{-1}t \tag{A.1}$$

where

σ is the specific extinction area, in square metres per kilogram;

k is the extinction coefficient, expressed per metre;

$\dot{V}_{\mathrm{s}}$ is the volume flow rate of smoke at the point of measurement in a specified period, in cubic metres per second;

Δm is the specimen mass loss in a specified period, in kilograms;

t is the period of time for Δm, in seconds.

At any given time during the flaming phase of a test, the specific extinction area can be calculated by dividing the rate of smoke production by the mass loss rate:

$$\sigma = k\dot{V}_{\mathrm{s}}\left(-\dot{m}\right)^{-1} \tag{A.2}$$

However, this equation should not be used if the mass loss rate factor is zero or less.

Calculation of the mass loss rate, $\dot{m}$, is described in 12.5 of ISO 5660-1:2002.

The average specific extinction area over the flaming phase of the test is given by:

$$\overline{\sigma}_{\mathrm{f}} = (m_{\mathrm{ig}} - m_{\mathrm{f}})^{-1}\sum_{i=t_{\mathrm{ig}}}\dot{V}_{\mathrm{s}}k\Delta t \tag{A.3}$$

where

m_{ig} is the specimen mass at ignition;

m_{f} is the specimen mass at the end of the test.

The reported variables would be

a) $\overline{\sigma}_{\mathrm{f}}$ over the flaming phase for every specimen, and

b) a graph of σ as a function of time for every specimen.

The average specific extinction area is a useful parameter in fire modelling because it is not sensitive to the scale of the fire. Thus, a value of σ obtained from a bench-scale test will be close to what is actually realized in a fire, provided that the combustion conditions are similar.

Additional information on smoke variables and their usage is given in references [12] and [13].

NOTE For materials containing absorbed water or molecularly bound water, mass loss measured will not fully represent mass lost by combustion.

Annex B
(informative)

Commentary and guidance notes for operators

B.1 Light sources

The obscuration of light by an aerosol such as smoke occurs by two different phenomena: absorption and scattering. For highly detailed aerosol science studies, these two components can be measured individually. For fire safety concerns, however, normally only the total smoke obscuration is measured. Smoke obscuration is, by definition, the total attenuation due to both absorption and scattering.

Most early fire test methods such as the ASTM E 662[8] or the DIN test methods used a white-light source and some collimating optics, with a photodetector for sensing the light energy. However, from a theoretical point of view, polychromatic light is unsuitable for such measurement because Bouguer's law is valid only for monochromatic light[6]. Experimental studies[5] have recently confirmed theoretical predictions of the errors introduced by using white light.

Errors of this type can be avoided by the use of monochromatic radiation. A monochromatic light source can be created by filters or by monochromators. It is more convenient, however, to use a laser, which is an intrinsically monochromatic source. Readily available helium-neon lasers provide such monochromatic radiation at the red wavelength of 632,8 nm. A laser source has other advantages. As the source has sufficiently high intrinsic collimation, no lenses are needed. It also has a narrow beam which decreases errors due to multiple scattering.

B.2 Soot deposition on the optics

Traditional smoke measuring equipment generally has incorporated windows to exclude smoke from the optics. This has undesired consequences since, during a test, soot is deposited on these windows. Consequently, the instrument sustains a drift of baseline and some approximate post-test corrections are needed. The availability of the very small diameter laser source allowed a different approach to be taken in the design of the apparatus[9] described in this part of ISO 5660. To avoid particle deposition on the optics, purging is provided by making use of the fact that the inside of the duct is at negative pressure with respect to the room outside. Furthermore, the beam tubes are purposely made long and narrow, so any ingressing particles will deposit on the tube walls instead of on the optics further out from the duct.

B.3 Photometer design

A conventional smoke photometer is a single-beam instrument. Thus, any changes in the source intensity due to power fluctuations, ageing, etc., are reflected directly as an error in the measured signal. Significantly better stability is obtained by a dual-beam design, whereby there are two photo detectors. One detector measures the smoke-attenuated light radiation, while the second detector only measures the source intensity, without any intervening smoke. By taking the ratio of these two signals, a high degree of stability is introduced into the measuring system. Such a dual-beam arrangement is provided in the present instrument[10].

The laser photometer assembly is made of two pieces rigidly mounted to each other, but mechanically coupled to the exhaust duct only by resilient gaskets. This technique isolates the photometer from vibrations of the exhaust fan. The photometer can be used by either using an electronic circuit that takes the two detector signals and gives a final output directly in terms of the extinction coefficient k, or by taking the two detector signals into the data collection system and performing the arithmetics within the data reduction process.

The calibration of the photometer is done with the use of two optical filters of differing attenuation values which are inserted into a specially designed slot in the photometer. The use of two different values helps to verify that the calibration is linear. The photometer contains a second filter slot, located in front of the laser source. This filter slot is used to demonstrate that the two optical beams are in balance. If the detectors are properly matched and the system adjusted, then attenuating the source should not affect the final reading since both beams are equally attenuated.

The flow-through system used in the apparatus described in this part of ISO 5660 also minimizes other problems common to smoke measuring equipment; e.g. excessive wall losses and non-linear effects due to soot overloading are endemic to closed-box smoke measurement systems. It was demonstrated by extensive comparisons conducted by the Fire Research Station[11] that the present arrangement is less prone to such errors.

B.4 Principles of smoke production rate measurement

The primary data from the photometer are expressed as the extinction coefficient k. This is defined by the equation:

$$k = \ln (I_0 / I)\, L^{-1} \tag{B.1}$$

where

I is the attenuated beam intensity;

I_0 is the beam intensity in the absence of smoke;

L is the optical path length across the exhaust duct.

The smoke production rate, P_s, is calculated using the equation:

$$P_\text{s} = k \dot{V}_\text{s} \tag{B.2}$$

where $\dot{V}_\text{s}$ is the volume flow rate.

The smoke production rate per unit area of exposed specimen, $P_{\text{s},A}$, is calculated using the equation:

$$P_{\text{s},A} = P_\text{s} A^{-1} \tag{B.3}$$

where A is the exposed surface area of the test specimen.

B.5 Calculation of the volume flow rate

The mass flow rate in the exhaust duct, $\dot{m}_\text{e}$, is calculated as described in clause 12 of ISO 5660-1:2002. However, in order to calculate the smoke production rate it is necessary to know the volume flow rate. This is derived from the mass flow rate using the equation:

$$\dot{V}_\text{s} = \dot{m}_\text{e} \rho^{-1} = \dot{m}_\text{e} \frac{T_\text{s}}{\rho_0 T_0} \tag{B.4}$$

where ρ is the density of air at the photometer and is calculated using the equation:

$$\rho = 1{,}29 \text{ kg m}^{-3} \, (273 \text{ K}/T_\text{s}) \tag{B.5}$$

The density of air at standard temperature and pressure, p_0, is 1,29 kg m^{-3}. T_s is the temperature in the duct close to the laser photometer, as determined by a thermocouple measurement at that location. No corrections are made for variations in pressure.

B.6 Smoke meter calibration using a calibration factor

Calibration using filters assumes that the system used to calibrate the filter is superior to the optical system of the smoke meter. The photodiodes used in the smoke meter specify a high degree of linearity. The optical density quoted for a commercially supplied filter is usually the average over a range of wavelengths and the value at the frequency of the laser may not be this average value. Therefore the use of a filter is better confined to use as a daily checking routine of the functionality of the system rather than as a primary calibration. The user may therefore calibrate by checking the zero and 100 % transmission values and utilizing the linearity of the photodiodes.

If filters calibrated at the correct wavelength are used, the following routine may be followed.

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

$$k_1 = \ln (I_0/I)\, L^{-1} \quad \text{(B.6)}$$

where L is the light path length through the smoke. The correct value, k_2, is given by the formula:

$$k_2 = (2{,}303 D')\, L^{-1} \quad \text{(B.7)}$$

where D' is the optical density of the calibration filter.

A correction factor, k_2/k_1, is calculated from these two values and is used to correct all subsequent measured k values, thus:

$$k = (k_2/k_{\text{f}})\, k_{\text{m}} \quad \text{(B.8)}$$

where k_{m} is the measured value.

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

$$F = (k_2/k_1)\, L^{-1} \quad \text{(B.9)}$$

and subsequent k values are calculated using the equation:

$$k = F \ln (I_0/I) \quad \text{(B.10)}$$