INTERNATIONAL STANDARD

ISO 5659-1

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Plastics — Smoke generation —

Part 1:
Guidance on optical-density testing

Plastiques — Production de fumée —

Partie 1: Guide sur les essais de densité optique

Reference number
ISO 5659-1:1996(E)

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.

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.

International Standard ISO 5659 was prepared by Technical Committee ISO/TC 61, *Plastics*, subcommittee SC 4, *Burning behaviour*.

ISO 5659 consists of the following parts, under the general title *Plastics — Smoke generation:*

— *Part 1: Guidance on optical-density testing*

— *Part 2: Determination of optical density by a single-chamber test*

Annexes A and B of this part of ISO 5659 are for information only.

International Organization for Standardization
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Introduction

Smoke represents a major hazard in fires due to its capacity to obscure vision by the absorption and scattering of light. Consequently, two threats are obvious: the inhalation of hazardous gases and fumes and the obscuration of light by smoke particulates leading to disorientation. These threats interact in a complicated manner, but are usually dealt with by separate procedures.

Smoke particulates reduce the visibility due to light absorption and scattering. Consequently, people may experience difficulties in finding exit signs, doors and windows. Visibility is often determined as the distance at which an object is no longer visible. It depends on many factors, but close relationships have been established between visibility and measurements of the optical density of smoke, as depicted in figure 1.

The production of smoke and its optical properties are often measured simultaneously with other fire properties, such as heat release and flame spread. The measurements may be in small or full scale. They may be performed in small-scale, closed systems and are called cumulative or static methods. They may also be performed in a flow-through system, and these are called dynamic methods.

A distinction is sometimes made between smoke and soot (see 7.2), with the former being measured by optical means, while the latter is determined by actual weighing of particulates collected (gravimetric means). Since fire safety concerns are often with optical smoke measurements, the guidance on smoke tests will focus on obscuration of visibility.

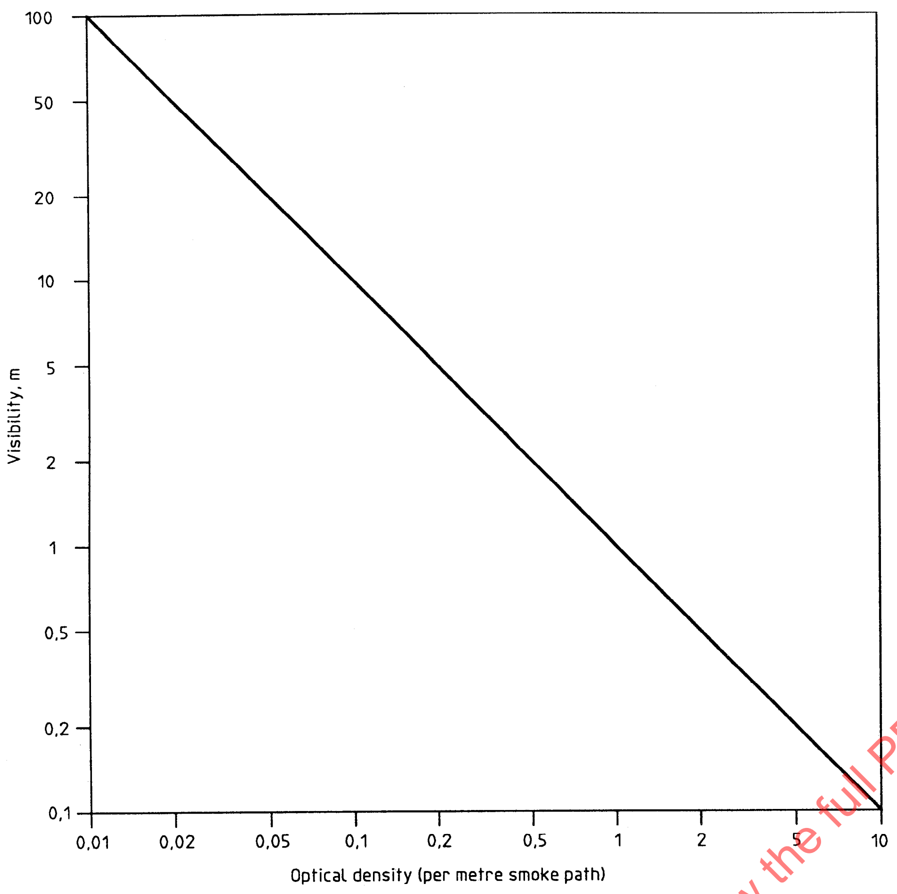

Figure 1 — Relationship between optical density and visibility (after Jin 1978[5] — see annex B)

Plastics — Smoke generation —

Part 1:
Guidance on optical-density testing

1 Scope

This guidance document constitutes part 1 of ISO 5659. Part 2 of this International Standard describes a static (or cumulative) single-chamber test procedure. At present, the scope of this guide is limited to the test procedure described in part 2.

NOTE 1 Should future work expand the scope of the standard to cover other smoke tests (for example, dynamic procedures), the scope of part 1 will be extended accordingly.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 5659. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 5659 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5659-2:1994, *Plastics — Smoke generation — Part 2: Determination of optical density by a single-chamber test.*

ISO/IEC Guide 52:1990, *Glossary of fire terms and definitions.*

3 Definitions

For the purposes of this part of ISO 5659, the definitions in ISO/IEC Guide 52 apply, together with the following definitions:

3.1 mass optical density (MOD): A measure of the degree of opacity of smoke in terms of weight loss of the material under the conditions of the test.

3.2 optical density of smoke, D**:** A measure of the degree of opacity; the negative common logarithm of the relative transmission of light.

3.3 specific optical density, D_S**:** The optical density multiplied by a factor which depends on the instrument and on the specimen size.

3.4 fire model: Means for the decomposition and/or combustion of test specimens under defined conditions to represent known stage(s) of a fire in order to generate fire effluents for assessment.

NOTE 2 This term should be distinguished from the term "fire modelling" which is used by the fire science community in the mathematical simulation of fire characteristics.

3.5 fire scenario: A detailed description of the conditions prevailing at certain stages in an actual fire, or in a full-scale fire simulation.

4 Objectives

It is the objective of this document to provide guidance on the applicability of the smoke density measurements described in part 2 of this International Standard.

ISO 5659-2 has been developed for improved assessment of the smoke-generating potential of burning materials under a wider range of heat flux conditions than alternative single-chamber smoke tests, as well as to allow thermoplastics to be tested in a horizontal orientation.

5 Fire scenarios and fire models

During recent years, major advances have been made in the analysis of fire effluents. It is recognized that the composition of the mixture of combustion products is dependent particularly upon the nature of the combusting materials, the prevailing temperatures and the ventilation conditions, especially access of oxygen to the seat of the fire. A number of factors which are important in categorizing fire atmospheres and in comparing atmospheres between laboratory-scale and full-scale fire studies are listed in table 1.

Fire involves a complex and interrelated array of physical and chemical phenomena. As a result, it is essentially impossible to simulate all aspects of a real fire in laboratory-scale apparatus. This problem of fire model validity is perhaps the single most perplexing technical problem associated with all of fire testing.

After ignition, fire development may occur in different ways, depending on the environmental conditions as well as on the physical arrangement of the combustible materials. However, a general pattern can be established for fire development within a compartment, where the general temperature-time curve shows three stages (see figure 2).

Stage 1 is the incipient stage of the fire prior to sustained flaming, with little rise in the fire room temperature. Ignition and smoke generation are the main hazards during this stage. The second stage (developing fire) starts with ignition and ends with an exponential rise in fire room temperature. Spread of flame and heat release are the main hazards in addition to smoke during this stage. The third stage (fully developed fire) starts when the surface of all of the combustible contents of the room has decomposed to such an extent that sudden ignition occurs all over the room, with a rapid and large increase in temperature (flashover).

At the end of stage 3, the combustibles and/or oxygen have been largely consumed and hence the temperature decreases at a rate which depends on the ventilation and the heat- and mass-transfer characteristics of the system.

In each of these stages, a different mixture of decomposition products may be formed (see figure 1) and this, in turn, influences the smoke density produced during that stage. Moreover, information is required on the fire scenario being considered, in particular the conditions of incident heat flux, oxygen availability and smoke-venting facilities.

Table 1 — General classification of real fire stages in accordance with ISO/TR 9122-1[2]

Stage or phase of fire within a compartment	Vol % oxygen 1)	Ratio CO_2/CO 2)	Temperature of substrate °C	Irradiance kW/m² 3)
a) Non-flaming decomposition (incipient stage)				
1) Smouldering (self-sustaining)	21	not available	> 100	not available
2) Non-flaming (oxidative)	5 to 21	not available	> 500	< 25
3) Non-flaming (pyrolytic)	< 5	not available	> 1 000	not available
b) Flaming, developing fire	10 to 15	100 to 200	400 to 600	20 to 40
c) Flaming, fully developed fire				
1) Relatively low ventilation	1 to 5	< 10	600 to 900	40 to 70
2) Relatively high ventilation	5 to 10	< 100	600 to 1 200	50 to 150

1) Mean value in fire plume.
2) General environmental condition (average) within compartment, assuming some homogenization.
3) Radiation incident on the exposed surface (average).

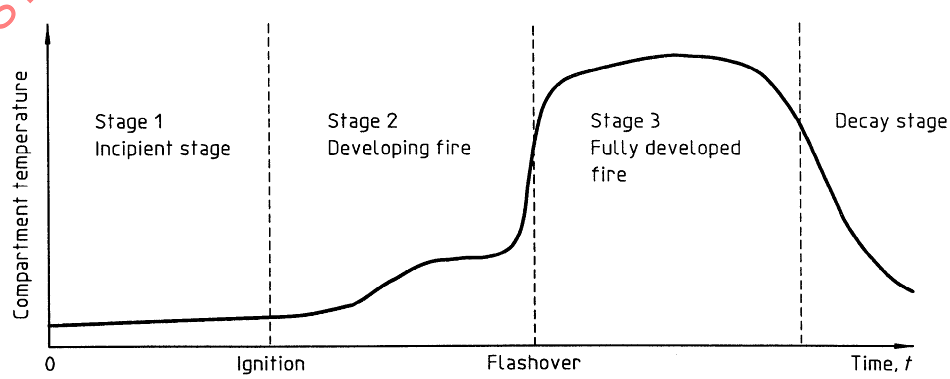

Figure 2 — Diagram showing the different phases in the development of a fire within a compartment

6 Principles of smoke density measurements

6.1 The main measurement made when carrying out testing to ISO 5659-2 is the amount of light transmitted by the smoke as a fraction (or percentage) of the initial light transmitted by the optical system. The minimum percent light transmitted is then used to calculate the maximum specific optical density for each mode of specimen exposure, e.g irradiance of 25 kW/m^2 with pilot flame or irradiance of 50 kW/m^2 without pilot flame. The choice of specimen exposure conditions may be critical in determining the onset of ignition, and the smoke generated from the specimen may vary considerably depending on whether the specimen combusts in a non-flaming or a flaming mode (see 7.2).

6.2 No means are provided for predicting the ability of the human eye to see through smoke and the effect of eye irritants in further restricting visual range. Some limited research suggests that eye irritants might reduce vision by 50 % to 95 %.

6.3 The use of maximum specific optical density as a unit of smoke measurement is based on Bouguer's law of light attenuation which is expressed as follows:

$$T = T_0 e^{-\sigma L}$$

where

- T is the percentage transmission;
- T_0 is the initial transmission (100);
- σ is the attenuation coefficient;
- L is the length, in metres, of the optical path;
- e is the base of natural logarithms.

For a mono-dispersed aerosol, the attenuation coefficient σ is found to be proportional to the product of particle size and the number of particles. If $\log_{10}(100/T)$ is defined as the optical density D, then

$$D = \log_{10}(100/T)$$

and hence

$$D = \sigma L/2{,}303$$

While the smoke produced from fire usually does not have all the characteristics of a mono-dispersed aerosol, it has been found to behave in a photometric manner such that, for engineering purposes, the optical density may be considered to be roughly proportional to the smoke particles produced. The measurement unit, specific optical density D_S, has been introduced to provide a conveniently factored rating scale as follows:

$$D_S = \left(\frac{V}{AL}\right) D$$

hence

$$D_S = \left(\frac{V}{AL}\right) \log_{10}(100/T)$$

where

- V is the volume, in cubic metres, of the chamber;
- A is the exposed area, in square metres, of the specimen;
- L is the length, in metres, of the light path.

For the ISO 5659-2 single-chamber procedure, $V/AL = 132$.

NOTE 3 Some test methods report smoke simply in terms of light transmission. The problem with such a reporting procedure is that people not familiar with the characteristics of smoke aerosols may assume that the percentage light transmittance is a reciprocal, linear function of the quantity of smoke produced. If they assumed that, as the quantity of smoke produced is doubled, the percentage light transmittance would be cut in half, they would be wrong.

6.4 The concept of specific optical density allows smoke development to be understood in terms that recognize the area of specimen involved, the volume of the smoke chamber, and the optical path length of the photometer. Specific optical density is dimensionless, but its value relates to the thickness of the specimen tested. Hence, the thickness of the specimen should always be reported whenever specific optical density for a material is quoted.

6.5 The relationship between obscuration and specimen mass loss is measured by a term called the mass optical density (MOD) which can be obtained using the ISO 5659-2 single-chamber apparatus modified with a load cell so that the loss in mass of the specimen may be determined during the test. Mass optical density (MOD) is given by the following equation:

$$\text{MOD} = \frac{D}{L} \times \frac{V}{\Delta m}$$

where Δm is the loss in mass, in grams, of the test specimen.

6.6 In the ISO 5659-2 procedure, light transmission measurements are made over a 10 minute period of exposure of the specimen to a cone radiator. This time period is usually sufficiently long to allow the rate of smoke generation to be determined. There is no requirement in ISO 5659-2 to record the maximum smoke density achieved. Some specimens will show a peak in the D_S/t graph, and smoke density may decrease after this peak during the 10 minute exposure. Other specimens may exhibit an increase in smoke density throughout the 10 minute exposure, or achieve a maximum value and retain this level of smoke until the end of the 10 minute period.

The early stages of smoke generation are the most important in terms of life threat, and so in the interests of economy of testing, and especially to allow more specimens to be included in the test procedure to improve repeatability, the procedure of ISO 5659-2 is restricted to 10 minutes to obtain D_S10. Longer accumulation times may be used at the discretion of the testing laboratory if the interest is in obtaining $D_S$max., but the exposure time should be kept constant throughout any series of comparative tests and be recorded in the test report.

6.7 In ISO 5659-2, higher D_S values will be measured as the specimen thickness increases. For comparative purposes, different materials should always be evaluated at the same thickness (see 6.4). It is recognized, however, that materials may not always be available at the same thickness and so for some practical exercises materials may be evaluated at their end-use thickness, although this should be stated whenever the results for these materials are quoted. For inherently smoky materials, it is recommended that these are tested at about 1 mm thickness to avoid smoke saturation within the smoke chamber and to avoid excessive oxygen consumption.

In addition, for materials generating high levels of smoke, it is recommended that the test should be stopped before the specified duration of 10 minutes; if this is done, the result should be reported as D_St, where t is the time from zero during which smoke measurements are made.

7 Factors affecting smoke production

7.1 General

Many factors affect the production of smoke and the properties of the smoke. Full characterization is not possible, but the influence of several important variables is recognized.

7.2 Mode of decomposition

Smoke is basically a product of incomplete combustion. It may be flaming or smouldering (non-flaming) combustion, which may produce quite different types of smoke (see 6.1). In smouldering combustion, volatiles are evolved at elevated temperatures. When they mix with cool air, they condense to form spherical droplets, which appear as a light-coloured smoke aerosol. Flaming combustion produces a black carbon-rich smoke in which the particles have a very irregular shape. The smoke particles at flaming combustion are formed in the gas phase and in regions where the oxygen concentrations are low enough to cause incomplete combustion. The carbonaceous smoke particles in the flames emit radiant energy (as black-body emission) which is seen as yellow luminosity.

The particle size of the spherical droplets from smouldering combustion is generally in the order of 1 µm, while the size of the irregular soot particles from flaming combustion is often larger but much harder to determine and is dependent on the measuring technique.

It is often observed for wood fires that the amount of smoke is less with flaming combustion than with smouldering. For plastics, however, no such generalization can be made: the smoke produced under smouldering conditions can be less or more than under flaming conditions. For these reasons, it is important to record in a smoke test whether ignition occurs, as well as the times of ignition and extinction of flames on the specimen. In addition, cold smoke may be generated from the rear of composites; this may differ substantially in colour and composition from the smoke released from the exposed surface.

The heat flux to which the test specimen is exposed may influence how the material burns; it is good practice to evaluate the smoke generated from materials at low levels of incident irradiance (e.g. 15 kW/m^2 to 25 kW/m^2) as well as at higher levels (e.g. 40 kW/m^2 to 50 kW/m^2). In this way, the effects of the growth phases of a fire on the smoke-generating propensity of a material can be assessed (see clause 6).

7.3 Ventilation and burning environment

Smoke production depends upon the fire scenario and not just on what material is being burnt. It is known that, for some materials, production of smoke is increased considerably by restricted ventilation.

The rate of burning and the area involved in burning should always be considered when determining smoke production in real fire scenarios. A material generating small quantities of smoke per elemental burning area may actually give large quantities of smoke in a real fire environment due to rapid spread of flames over large surface areas.

7.4 Time and temperature

The particle size distribution of smoke aerosols changes with time; smoke particles coagulate as they age. Some properties also change with temperature so that the properties of aged, or cold, smoke may be different from young, hot smoke. These factors are important for fire engineers when they are considering potential smoke movement in large buildings. They also have to be considered when designing smoke tests.

7.5 Removal mechanisms for smoke particles

Large smoke particles may be removed by a number of mechanisms. In cumulative test procedures where the cone radiator is immersed in the combustion gases, reheated decomposition may occur as the smoke particles recirculate through the combustion chamber. Other mechanisms for removal of larger particles include deposition of particles on the internal surfaces of the chamber and the action of fan stirrers. Aspects of these mechanisms also occur in real fires when smoke circulates within a fire compartment. Because these effects are possible in cumulative smoke tests, it is recognized that the early stages of the exposure (for example, the first 10 minutes) are the most relevant for determination of the rate of smoke generation.

8 Applicability of results

8.1 Realistic assessments of the fire performance of a product can only be obtained by testing a real-scale specimen in the form and orientation in which it is actually used. An isolated test such as ISO 5659-2 can only indicate the response of a material to the fire model selected. It is emphasized that no fire or smoke test can in normal circumstances measure fire or smoke hazard; in addition, it cannot be assumed that satisfactory results of a single standard fire or smoke test will guarantee a given level of safety.

Results from a variety of fire tests, including both cumulative and dynamic smoke tests, will provide information to assist in the determination, and subsequent control, of fire and smoke hazards (see clause 5).

8.2 When reporting the results of a smoke density test such as ISO 5659-2, it is essential to include the following statement in the test report:

> "These results relate only to the behaviour of the product under the particular conditions of test; they are not intended to be the only criterion for assessing the potential smoke obscuration hazard of the product in use."