SLOVENSKI STANDARD

SIST ISO/TR 9122-4:1999

01-september-1999

Preskuġanje toksiļ nosti dima ï 4. del: Peļ i in seģigne naprave za preskuse v majhnem merilu

Toxicity testing of fire effluents -- Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)

Essais de toxicité des effluents du feu -- Partie 4: Modèle feu (fours et appareillages de combustion utilisés dans les essais à petite échelle)

Ta slovenski standard je istoveten z: **ISO/TR 9122-4:1993**

ICS:

13.220.99	Drugi standardi v zvezi z varstvom pred požarom	Other standards related to protection against fire

SIST ISO/TR 9122-4:1999 **en**

TECHNICAL
REPORT

ISO
TR 9122-4

First edition
1993-05-15

Toxicity testing of fire effluents —

Part 4:
The fire model (furnaces and combustion apparatus used in small-scale testing)

Essais de toxicité des effluents du feu —

Partie 4: Modèle feu (fours et appareillages de combustion utilisés dans les essais à petite échelle)

Reference number
ISO/TR 9122-4:1993(E)

Contents

Page

1 Scope 1

2 Characteristics of fire stages 1

3 Criteria for assessment of fire models 2

3.1 Relevance to real fires 2

3.1.1 Oxygen concentration 2

3.1.2 CO_2/CO ratio 2

3.1.3 Temperature and heat flux 2

3.2 Validity to toxic hazard assessment 3

3.3 Specimen composition and configuration 3

3.4 Documentation and experience 4

3.5 Exposure dose quantification 4

3.6 Procedural criteria 4

4 Fire models 4

4.1 "Box" furnace models 4

4.1.1 NBS cup furnace 4

4.1.2 UPitt box furnace 5

4.2 Tube furnace models 6

4.2.1 DIN 53436 tube furnace 6

4.3 Radiant heat models 7

4.3.1 US radiant furnace (modified) 7

4.3.2 Cone calorimeter 9

4.3.3 Japanese cone furnaces 10

4.3.3.1 BRI (Building Research Institute) cone furnace 10

4.3.3.2 RIPT (Research Institute for Polymers and Textiles) cone furnace 11

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

4.3.4 Japanese Ministry of Construction model 11

5 Selection of a fire model 12

Annex

A Bibliography 13

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.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 9122-4, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire tests on building materials, components and structures*, Sub-Committee SC 3, *Toxic hazards in fire*.

This document is being issued in the type 2 Technical Report series of publications (according to subclause G.4.2.2 of part 1 of the ISO/IEC Directives) as a "prospective standard for provisional application" in the field of toxicity testing of fire effluents because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this type 2 Technical Report will be carried out not later than two years after its publication with the options of: extension for another two years; conversion into an International Standard; or withdrawal.

ISO/TR 9122 consists of the following parts, under the general title *Toxicity testing of fire effluents*:

- *Part 1: General*
- *Part 2: Guidelines for biological assays to determine the acute inhalation toxicity of fire effluents (basic principles, criteria and methodology)*
- *Part 3: Methods for the analysis of gases and vapours in fire effluents*
- *Part 4: The fire model (furnaces and combustion apparatus used in small-scale testing)*
- *Part 5: Prediction of toxic effects of fire effluents*

Annex A of this part of ISO/TR 9122 is for information only.

Introduction

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.

For fire models used in evaluating fire effluent toxicity, additional restrictions and criteria are necessarily imposed due to the need for the laboratory combustion to be compatible with bioassay procedures using live test animals. For example, reduced oxygen levels and heat must not, in themselves, be unduly compromising to exposed animals. At the same time, sufficiently high concentrations of fire effluents must be produced so as to obtain measurable toxicological effects. As a result of these restrictions, compromises must often be made which can further reduce the apparent validity of the fire model.

Essentially two approaches are used to evaluate the toxicity of fire effluents; i.e. those using full-scale fire models and those using small-scale fire models. In full-scale procedures, fire models consisting of a room, multiple rooms or a complete building are used which are intended to simulate as far as possible the full characteristics of fires including ignition, growth and evolution of toxic fire effluents. Full-scale methods are usually applied in tests of the toxic *hazard* presented by the fire, although some attempts have been made to model the main features of toxic hazard in small-scale tests.

In small-scale fire models, it is considered possible to re-create the reactive chemical environments characteristic of various stages and types of fire conditions in terms of temperature, the presence or absence of flame and oxygen supply. Under these conditions, the relative yields of toxic products in the fire effluents from materials will be similar to those evolved at equivalent stages in full-scale fires. Thus, small-scale fire models are regarded as relevant to the testing of the toxic *potencies* of the chemical products evolved from materials under the defined decomposition conditions. These potency values may then be used as input data in toxic hazard assessments which take into consideration the dynamic characteristics of specific fire scenarios.

TECHNICAL REPORT **ISO/TR 9122-4:1993(E)**

Toxicity testing of fire effluents —

Part 4:
The fire model (furnaces and combustion apparatus used in small-scale testing)

1 Scope

This part of ISO/TR 9122 is restricted to the consideration of fire models (i.e. laboratory combustion devices) used in fire effluent toxicity studies, together with suggestions for the appropriate use of the fire models in standard testing. Reference should be made to other parts of ISO/TR 9122 for discussions of analytical methods, bioassay procedures, toxicity testing and prediction of toxic effects of fire effluents.

This part of ISO/TR 9122 defines the criteria for an acceptable fire model, reviews existing fire models against these criteria, and proposes that fire models be selected for use through consideration of these criteria which includes a capacity to generate fire conditions characteristic of known stages of fire.

This part of ISO/TR 9122 does not give a detailed analysis of the physics and chemistry of fire.

2 Characteristics of fire stages

For the purposes of a discussion of fire models and their appropriate use, the combustion conditions shown in table 1 are generally accepted as being characteristic of certain stages or phases of fire[1].

Table 1 — General classification of fire stages

Stage or phase of fire	**Oxygen content**1) (%)	CO_2/CO **ratio**2)	**Temperature** (°C)	**Irradiance**3) (kW/m^2)
Non-flaming decomposition				
a) Smouldering (self-sustaining)	21	not applicable	< 100	not applicable
b) Non-flaming (oxidative)	5 to 21	not applicable	< 500	< 25
c) Non-flaming (pyrolitic)	< 5	not applicable	< 1 000	not applicable
Flaming developing fire	10 to 15	100 to 200	400 to 600	20 to 40
Flaming fully-developed fire				
a) Relatively low ventilation	1 to 5	< 10	600 to 900	40 to 70
b) Relatively high ventilation	5 to 10	< 100	600 to 1 200	50 to 150

1) General environmental condition (average) within compartment.
2) Mean value in fire plume near to fire.
3) Incident irradiation on the sample (average).

The primary chemical process leading to formation of combustion products is that of the thermal bond-breaking and decomposition of polymeric materials which, in the presence of oxygen, leads to a variety of oxygenated species. Carbon compounds are pyrolysed into volatile hydrocarbon fragments which can be oxidized to form various oxidized organic species, carbon monoxide or carbon dioxide, depending upon thermal and oxidative conditions. Both carbon monoxide and carbon dioxide are usually present in a fire effluent atmosphere, with the ratio of the two often being used as an indicator characteristic of the particular type or stage of a fire. In small, developing fires, a CO_2/CO ratio of 100 or more would indicate freely-ventilated (fuel-controlled) combustion. In large, fully-developed fires which are usually ventilation-controlled when they occur in buildings, a CO_2/CO ratio of 10 or less would indicate relatively low ventilation, while a ratio of more than 10 would be indicative of relatively high ventilation.

Hydrogen is oxidized to water, chlorine is most commonly released as hydrogen chloride and nitrogen appears as nitrogenous organic compounds (especially nitriles), hydrogen cyanide, nitrogen oxides and molecular nitrogen, again depending upon the thermal and oxidative conditions. All flaming and non-flaming (including smouldering) fires can yield a myriad of combustion products due to incomplete decomposition and only partial oxidation of the fuels involved; however, non-flaming fires produce the highest yields of such products. It is important to remember that these are all chemical reactions, subject to the usual principles of thermodynamics and kinetics. Thus, stoichiometry and thermal energy play significant roles in determining the products of combustion that are formed over the range of fire classifications.

3 Criteria for assessment of fire models

3.1 Relevance to real fires

The best approach to the selection of an appropriate fire model for fire effluent toxicity testing involves careful consideration of data which would relate laboratory combustion conditions to the types and stages of real fires (see table 1).

All the fire models to be described are capable of simulating the conditions of non-flaming decomposition. However, it is recognized that the majority of fire injuries and deaths occur as a result of flaming fires. These include both small fires (often restricted to the item first ignited) where casualties occur in the room of origin and also large, fully-developed fires, where casualties occur remotely from the compartment of origin. In the latter, the toxic threat usually develops after flashover occurs[1] [2].

In terms of a correlation with most fire fatalities, the most important criteria for an appropriate fire model involve the conditions for a well-ventilated, developing fire and for either a low- or highly-ventilated, fully-developed (high temperature) fire. Particularly important are considerations involving ventilation (oxygen availability), CO_2/CO ratios, temperature and/or heat flux and residence times of fire effluents in the high temperature zone.

3.1.1 Oxygen concentration

The oxygen concentration is the residual concentration in the primary fire effluent before any dilution. Its value decreases during fire development from the normal ambient level of approximately 21 % to 10 %-15 % in a small or developing fire, and further decreases to between 1 % and 10 % in a fully-developed fire, depending upon the ventilation, burning rate and room geometry.

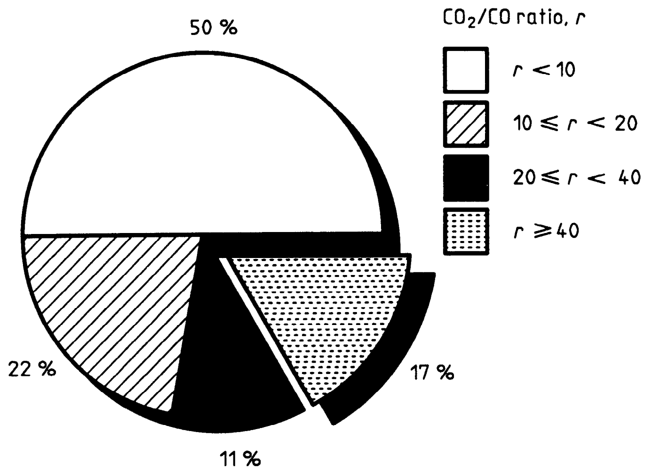
3.1.2 CO_2/CO ratio

The CO_2/CO ratio is calculated from the concentrations of these gases in the fire effluent atmosphere. Since its value is independent of dilution, the sampling point is not critical, providing it is beyond the point where oxidation reactions are in progress. The CO_2/CO ratio undergoes rapid changes during the development of a fire. Initially, in small fires under well-ventilated conditions, it is usually high (100 to 200). In fully-developed, ventilation-controlled fires, it reaches an almost constant value (1 to 10) depending upon the ventilation. Real fire data for CO_2/CO ratios are shown in figure 1[3].

3.1.3 Temperature and heat flux

The temperature is the mean value within a compartment. It gives a measure of the thermal exposure to the materials present and also to their thermal decomposition products. The radiant heat flux is also useful as a measure of exposure to thermal energy. In small or early-developing fires, the temperature in the immediate fire environment is typically in the 400 °C to 600 °C range, with the radiant flux between 20 kW/m^2 to 40 kW/m^2. In fully-developed fires, the temperature is in the 600 °C to 1 200 °C range with radiant fluxes of 50 kW/m^2 to 150 kW/m^2.

All these factors have a considerable influence on the composition of the fire effluent atmosphere. The important features from a toxicity point of view are that small or early-growing fires generally produce relatively low yields of carbon monoxide and hydrogen cyanide, together with a complex mixture of pyrolysis and oxidation products which have escaped the flame zone. Fully-developed fires, due to the high temperatures and oxygen vitiated conditions, generally produce high yields of toxic low molecular weight species, such as carbon monoxide and hydrogen cyanide.



Source : Boston fire department

Figure 1 — CO_2/CO ratio in real fire situations

3.2 Validity to toxic hazard assessment

Demonstration of the validity of a fire model in generating the toxic hazard of a real fire is an ideal criterion which can be approached but not necessarily reached. A few studies have been conducted using full-scale fires to evaluate the contribution of certain construction materials and furnishings to toxic hazard[2][4][5]. However, considerable caution should be exercised in generalizing conclusions from these studies. Even in full-scale tests, a range of different fires is possible in any one system.

The development of toxic hazard depends upon fire growth, which is essentially a large-scale phenomenon, and carefully conducted, full-scale tests do replicate at least some of the likely types of accidental fires. In general, however, it is economically unfeasible to conduct routine large-scale tests. Thus, the practical requirement becomes to provide bench-scale fire toxicity tests, whose predictions can be validated against the full-scale.

Since CO is the major toxicant in fires, much of the validity of bench-scale tests has traditionally been concerned with CO measurement, typically reported either as CO yield or CO_2/CO ratios. Experimental studies generally indicate that CO production is independent of oxygen concentration until the oxygen/fuel ratio drops to about 50 % more than that needed for complete or stoichiometric combustion[6]. From that point on, CO production rises sharply with decreasing oxygen. In fully-developed, post-flashover fires, CO yields of up to 0,2 kg CO per kilogram of material burned are encountered. This ratio appears to be fairly similar for a wide variety of combustibles.

In addition to differences in the heating of a specimen, the CO evolved from bench-scale experiments can differ from that produced with full-scale tests due to the following factors:

a) Air/fuel ratio. If this ratio is not the same in the two scales, CO production will be different;

b) Residence time effects. The time available to combust CO to CO_2 will often be much greater in the full-scale than in the small-scale device;

c) "Freezing in" of CO. Effects which tend to stop reactions from completion, thereby "freezing in" a certain proportion of CO. This effect is more pronounced for increasing scale size.

The net effect of the above phenomena is that bench-scale tests often have a tendency to show lower yields of CO than are observed in full-scale testing[7].

Small-scale tests, although they can give better reproducibility, provide only remote simulation of actual fire conditions. Despite these limitations, small-scale tests are attractive on the grounds of cost. The best assessments of toxic hazard consist of a combination of small- and large-scale tests, usually together with appropriate engineering calculations.

3.3 Specimen composition and configuration

Small-scale fire models require the use of relatively small sample specimens. The size, orientation and shape of the specimen holder and combustion compartment in the fire model should be considered when