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Guidance for comparison of toxic gas data between different physical fire models and scales

Lignes directrices pour la comparaison de données de gaz toxiques entre divers modèles et échelles de feu physiques

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Foreword

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

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

ISO 29903 was prepared by Technical Committee ISO/TC 92, *Fire Safety*, Subcommittee SC 3, *Fire threat to people and the environment*.

Introduction

The production of toxic gases in fires can be a significant factor in determining whether people escape from a fire or not. Estimation of the time available for escape and the time required for escape each require values of the concentrations of toxic gases along possible escape paths. Typically, the yields of the gases from burning finished products are estimated or measured prior to conducting such calculations. In some rare cases toxic species production can be calculated during modelling of the fire development. Typically spread of the gases and their dilution with air is then simulated using equations or computational models.

The yields of these gases can be measured in a real-scale laboratory test of the entire finished product (e.g. a chair) or in a bench-scale test (using a physical fire model) of a specimen cut from the product or a component of the product. Since there are thousands of different combustibles, routine real-scale testing is both costly and impractical. Thus, there is a need to develop reliable methods to use physical fire models, conducted in less than real-scale, for the estimation of real-scale emissions.

The yields of the gases from the real-scale test are often considered to be the accurate values for the particular test conditions. In tests involving a portion of the finished product in a physical fire model, the specimen characteristics and the combustion conditions differ from those in the real-scale test. In most cases the physical fire model reproduces one part of the entire real-scale scenario, e.g. initial well ventilated conditions or later vitiated conditions. The yields of combustion products in a fire test depend on apparatus conditions such as: the fuel/air equivalence ratio, whether the decomposition is flaming or non-flaming, the persistence of flaming of the sample, the temperature of the specimen and the effluents produced, the stability of the decomposition conditions, and the interaction of the apparatus with the decomposition process, with the effluents and with the flames.

It is, therefore, important to have a standardised methodology for comparing the toxic gas yields generated in tests of different scales to determine the appropriateness of using the data from individual physical fire models in fire hazard and risk assessment. It is also valuable to be able to compare the yield data from different physical fire models to determine whether or when they generate comparable results.

This International Standard concerns the comparison of toxic gas data between small-scale (physical fire models) and large-scale tests and between different small-scale tests, i.e. it covers

a) the comparison of toxic gas data from fire tests of different physical scales and characteristics in terms of a methodology to identify whether the data are comparable and (provided it is comparable) how to make relevant comparisons, and

b) the prediction of large-scale results based on small-scale test data or vice versa.

Guidance for comparison of toxic gas data between different physical fire models and scales

1 Scope

This International Standard provides principles for characterizing the measured production of toxic gases from a laboratory fire test and provides bases for comparing the results between different types and scales of such tests. It also includes consideration of the uncertainties in the gas determinations. The combined uncertainty is a key factor in the ability to establish similarity or difference of test results.

The sufficiency of the agreement between a bench-scale test and a real-scale test depends on the precision needed in the fire hazard or risk assessment, which is not covered by ISO 29903:2012.

This International Standard defines the relevance and significance of toxic gas data from measurements in different fire tests. With such a definition it is possible to provide generic guidance on how such data can be compared between different sizes and types of fire tests.

The combustion conditions represented by the fire test, other specific characteristics of the test and the test specimen, the sampling strategy of the fire effluents, and the analysis technique for the toxic gas species are the most important factors when defining the significance of the toxic gas data.

This International Standard is intended to serve as a tool for the

a) definition of the relevance and significance of toxic gas data from fire tests,

b) comparison of toxic gas data from fire tests of different scales and characteristics, and

c) prediction of toxic gas data from a large-scale test based on small-scale data or vice versa.

This International Standard gives general guidance regarding comparison of toxic gas data between physical fire models of different scales, but is principally developed for the gases listed in ISO 13571, i.e. carbon dioxide (CO_2), carbon monoxide (CO), hydrogen halides (HCl, HBr, HF), sulfur dioxide (SO_2), hydrogen cyanide (HCN), nitrogen oxides (NO, NO_2), formaldehyde (CH_2O) and acrolein (C_3H_4O).

This International Standard does not cover characterization and comparisons of the toxicity of the effluents from fire tests.

2 Normative references

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

ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 13571, *Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data*

ISO 13943, *Fire safety — Vocabulary*

ISO 16730, *Fire safety engineering — Assessment, verification and validation of calculation methods*

ISO 19706, *Guidelines for assessing the fire threat to people*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943, ISO 5725-1 and the following apply.

3.1
small-scale fire test
fire test performed on a test specimen of small dimensions

NOTE 1 The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2 Such a test is synonymously referred to as a "bench-scale test."

NOTE 3 In these tests, the typical maximum length of a linear test specimen is less than 1 m. The typical maximum dimensions of a rectangular specimen are approximately 0.1 m.

3.2
medium-scale fire test
fire test performed on a test specimen of small-medium size dimensions

NOTE A fire test performed on a test specimen of which the maximum dimension is between 0.5 m and 1.0 m is here called a medium-scale fire test.

3.3
intermediate-scale fire test
fire test performed on a test specimen of medium dimensions

NOTE 1 The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2 A fire test performed on a test specimen for which the maximum dimension is between 1 m and 3 m is usually called an intermediate-scale fire test.

3.4
large-scale fire test
fire test, that cannot be carried out in a typical laboratory chamber, performed on a test specimen of large dimensions

NOTE 1 The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2 A fire test performed on a test specimen of which the maximum dimension is greater than 3 m is usually called a large-scale fire test.

3.5
real-scale fire test
fire test that simulates a given application, taking into account the real scale, the real way the item is installed and used, and the environment

NOTE 1 The definition above is taken from ISO 13943 and is given here for clarity and the convenience of the reader.

NOTE 2 Such a fire test normally assumes that the products are used in accordance with the conditions laid down by the specifier and/or in accordance with normal practice.

3.6
matrix effect
combined effect of all components of the sample other than the analyte on the measurement of the quantity

NOTE 1 Matrix effect (in analytical chemistry) as defined in IUPAC Compendium of Chemical Terminology [1].

NOTE 2 The matrix effect in analysis of toxic gases in a fire effluent will be the combined effect from the components of the effluent on the analyte.

NOTE 3 If a specific component can be identified as causing an effect then this is referred to as interference.

4 Combustion conditions

4.1 General

The yields and nature of the fire effluent component from a fire test of any scale are determined by the involved fuels and the prevalent thermal and oxidative conditions in the current stage of the fire. These conditions also determine the burning rate of the products/materials and thus the rate of effluent generation. See ISO 16312-1.

During a fire test of a finished product, the combustion conditions are likely to change. These changes include the chemistry of the combustible item and the sufficiency of the ventilation.

Whether decomposition is flaming or non-flaming is a dominant factor in the production of toxic gases.

The combustion conditions under which toxic gas data are developed shall be as close to equivalent as possible between the physical fire models or test scales compared (see Clause 6).

NOTE 1 A large change in the rate of combustion may affect the degree of oxidation of the emitted effluent. Smaller changes in combustion rate may have no significant effect.

NOTE 2 Fire stages and the corresponding combustion conditions are described in ISO 19706.

4.2 Thermal environment

The thermal boundary conditions in a test include the external applied heat flux and the heat flux from any flaming combustion. Also of importance is the heat flux distribution among radiation, convection, and conduction.

The thermal environment sensed by the test specimen during combustion includes both gas temperature and the temperature of the sample material, as defined by the thermal boundary conditions.

4.3 Ventilation

The oxygen availability (ventilation) in the physical fire models compared determines the combustion conditions. Comparison among different methods requires characterization of the ventilation conditions in order to assess the degree of similarity.

For a given experiment, it is necessary to identify how the ventilation is characterized and whether the characterization is local or global.

For a physical fire model in which the fuel gasification rate and the entering oxygen flow and concentration are each controlled independently, the relative oxygen availability can be characterized by a fuel/oxygen equivalence ratio. For other models and real-scale fire tests, one or both of the terms in the equivalence ratio may not be well-known. In those cases, a broader characterization is used. This could be a global equivalence ratio or a term such as “underventilated burning” or “well ventilated burning.”

NOTE 1 Methods for calculating equivalence ratios for physical fire models are given in ISO 19703.

NOTE 2 The local air speed rate can be a significant factor in some fire tests. This applies especially for a tube furnace, where the air speed can affect the results of the combustion.

4.4 Characteristics of test specimens

For finished products that consist of a single, homogeneous material, the test specimen used in a physical fire model shall be prepared to accommodate the constraints of the test apparatus.

For specimens from non-homogeneous products, the test specimen must also contain the same portions of the different materials present in the finished product in both tests compared.

For layered commercial products, an ideal physical fire model accommodates specimens that preserve the relationship of the layers. When this is not possible within the constraints of the model, the rationale for the configuration of the layers shall be documented.

NOTE The yields of toxic gases can depend on the surface exposed, and the timing and extent of penetration of the layers.

5 Toxic gas data

5.1 Identification of toxic species

The minimum set of gases that shall be considered are listed in ISO 13571.

Additional gases shall be appraised as warranted by the chemical composition of the test specimen and the finished product from which it is sampled.

5.2 Different expressions for toxic gas data

5.2.1 General

Subclause 5.2 contains a summary of different expressions typically used for toxic gas data obtained from fire tests and whether the data are suitable for comparison with similar data from other tests or as a basis for the prediction of large scale results based on small scale data or vice versa.

The experimental data on toxic gases from a fire test can be expressed in several ways. From unrefined measurement data, which is often expressed as gas concentrations from a specific physical fire model, to data in higher degrees of refinement, e.g. yields. What is determined depends in part on the physical fire model used. See Annex A for information concerning the characteristics of different fire models.

The data can be in the form of scalar data or vector data. Some types of data are suitable for direct quantitative comparison, but others require a model for quantitative comparison. The most common quantities used in presentation of toxic gas data are given in Table 1 below.

Table 1 — Common types of data on toxic gases from fire tests and properties for comparison

Type of data	Typical units	SI-units	Scalar or vector data	Direct or indirect comparison	Qualitative or quantitative
Concentration of toxicants	ppm (v/v), i.e. µL/L	m^3/m^3	Scalar / Vector [a]	Indirect (Direct) [d]	Quantitative (Qualitative [e])
The contribution to FED (or FEC) from individual toxicants	—	—	Scalar / Vector [a]	Indirect (Direct) [d]	Quantitative (Qualitative [e])
Lethal toxic potency	g/m^3	kg/m^3	Scalar	Direct	Quantitative
Total amount of toxicants released	kg	kg	Scalar	Indirect (e.g. as yield)	Quantitative
Yields	g/g	kg/kg	Scalar (Vector) [b]	Direct	Quantitative
Production rates	g/s	kg/s	Vector (Scalar) [c]	Indirect (Direct) [d]	Quantitative (Qualitative [e])
Normalized production rates	$g \cdot s^{-1} \cdot m^{-2}$	$kg \cdot s^{-1} \cdot m^{-2}$	Vector (Scalar) [c]	Direct	Quantitative

[a] Scalar if the model is steady-state or vector if the model studies changes in concentration over time.

[b] Typically calculated as scalar data for the whole experimental period but can be calculated as vector data at each point in time.

[c] Typically calculated as vector data at each point in time but can be calculated as scalar data for the whole experimental period.

[d] Indirect comparison using a model (as shown in Figure 1) allows quantitative comparison. In some cases direct comparison can be used for qualitative assessment.

[e] Direct comparisons without the use of a model can provide qualitative information.

NOTE The “Type of data” given in Table 1 are explained in 5.2.2 – 5.2.7.

5.2.2 Yields

Yield is typically the recommended comparison parameter. Yield is the measured mass of a toxicant generated during combustion, per unit mass of test specimen consumed in the fire test (mass loss) or alternatively, per unit mass of specimen exposed (mass-charge). The calculation of yields is defined in ISO 19703.

Yield is a quantitative comparison parameter and is independent of dilution or other apparatus specific parameters which do not impact on the combustion conditions.

NOTE 1 It can be difficult to calculate toxic gas yields in some large-scale physical fire models (e.g. ISO 9705), as the mass loss is normally not measured in these tests.

NOTE 2 Yield can be expressed relative to mass loss rate and thereby provide kinetic information or be a unique value representing an average of the complete test.

5.2.2.1 Mass of a toxic gas generated

A measurement or approximation of the mass of the toxic gas generated is essential to the calculation of toxic gas yields. The typical gas measurement during a fire test is the volumetric concentration of the gas in a volumetric sample of the total effluent. If the effluent from the fire test is not fully mixed, multiple concentration measurements across the effluent flow are necessary.

The concentration measurement shall be converted to a mass of the toxic gas generated during the sampling time interval using the ideal gas law. Corrections for condensation, solution, and deposition of the gas shall be included, as appropriate, in the calculation.

5.2.2.2 Mass of the test specimen consumed

A measurement or approximation of the consumed mass of the specimen is essential to the calculation of toxic gas yields.

The mass consumed shall be calculated in at least one of three ways.

— Mass loss based on continuous measurement of the remaining mass of the test specimen.

— Mass loss based on a final measurement of the remaining specimen mass.

— Estimation of the mass loss, when no gravimetric measurement is possible, using the chemical formulation of the test specimen and a carbon balance of the combustion products.

NOTE The third method can be in significant error if the chemical composition of the specimen residue is not the same as the initial chemical composition. This error can be reduced by determining the chemical composition of the residue.

5.2.3 Concentrations of toxicants

The concentrations measured in a specific physical fire model are a function of the degree of dilution in the sampling point. Concentrations are unique for the specific physical fire model and should not be used for a direct quantitative comparison. The agreement of relative concentrations between different physical fire models, can however be used for comparison.

The CO/CO_2 concentration ratio, for example, can be used as a comparison principle (see 6.2.2).

NOTE Concentrations are normally expressed as volume fractions.

5.2.4 The contribution to FED (or FEC) from individual toxicants

The ranking of the different toxicants measured based on the relative contribution to the total toxicity using the FED (or FEC) concept is a semiquantitative comparison principle. The measured concentrations of toxicants are weighted relative to lethality, or incapacitation limits, e.g. LC_{50}. See ISO 13344.

5.2.5 Lethal toxic potency

Total lethal toxic potency of the fire effluents measured from the physical fire model is a quantitative comparison parameter. The predicted lethal toxic potency (LC50) has the unit g/m^3 and requires data on mass loss or mass charge. The concept of lethal toxic potency referred to here is defined in ISO 13344.

5.2.6 Total amount of toxicant released

The total amount of a toxicant produced from a test is a unique parameter for a specific test only and is not a suitable comparison parameter unless weighted against surface area of sample, sample mass or mass loss.

5.2.7 Production rates

The production rate is temporally resolved data concerning the measured mass of a toxicant generated during combustion, e.g. expressed in g/s.

The production rate can be normalized relative to, e.g. the exposed surface area, and is in that case expressed in $g{\cdot}s^{-1}{\cdot}m^{-2}$. Normalized production rates are directly comparable quantitative parameters.

5.3 Significance of analysis data

5.3.1 General

It is important to ascertain that the analytical techniques used for measurement of the toxic gas components compared between fire models, give comparable data. Factors to take into consideration are

— resolution of data,

— response time,

