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Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment —

Part 1:
Criteria

Lignes directrices pour évaluer la validité des modèles de feu physiques pour l'obtention de données sur les effluents du feu en vue de l'évaluation des risques et dangers —

Partie 1: Critères

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 3, *Fire threat to people and environment*.

This third edition cancels and replaces the second edition (ISO 16312-1:2010), of which it constitutes a minor revision with the normative references and bibliography having been updated.

A list of all parts in the ISO 16312-series can be found on the ISO website.

Introduction

Providing the desired degree of life safety for an occupancy increasingly involves an explicit fire hazard or risk assessment. This assessment includes such components as the following:

- information on the room/building properties;
- the nature of the occupancy;
- the nature of the occupants;
- the types of potential fires;
- the outcomes to be avoided, etc.

This type of determination also requires information on the potential for harm due to the effluent produced in the fire. Because of the prohibitive cost of real-scale product testing under the wide range of fire conditions, most estimates of the potential harm from the fire effluent depend on data generated from a physical fire model, a reduced-scale test apparatus and procedure for its use.

The role of a physical fire model for generating accurate toxic effluent composition is to recreate the essential features of the complex thermal and reactive chemical environment in full-scale fires. These environments vary with the physical characteristics of the fire scenario and with time during the course of the fire, and close representation of some phenomena occurring in full-scale fires can be difficult or even not possible on a small-scale. The accuracy of the physical fire model, then, depends on two features:

a) degree to which the combustion conditions in the bench-scale apparatus mirror those in the fire stage being replicated;

b) degree to which the yields of the important combustion products obtained from burning of the commercial product at full scale are replicated by the yields from burning specimens of the product in the small-scale model. This measure is generally performed for a small set of products, and the derived accuracy is then presumed to extend to other test subjects. At least one methodology for effecting this comparison has been developed.[11]

This document provides guidance for accuracy assessment with and without the use of laboratory animals. Generally, accurate estimation of the toxic potency of the effluent can be obtained from analysis of a small number of gases (the *N*-gas hypothesis), as described in ISO 13571. This is especially true for product formulations similar to those for which the *N*-gas model has been confirmed. There are, however, cases where unusual toxicants have been generated in bench-scale apparatus. Thus, for novel commercial product formulations, confidence in the accuracy of the toxic potency measurement in the bench-scale device can be improved by a confirming bioassay and correlation with real-scale fire tests.

Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment —

Part 1:
Criteria

1 Scope

This document provides technical criteria and guidance for evaluating physical fire models (i.e. laboratory combustion devices and operating protocols) used in effluent toxicity studies for obtaining data on the effluent from products and materials under fire conditions relevant to life safety.[9] Relevant analytical methods, calculation methods, bioassay procedures and prediction of the toxic effects of fire effluents can be referenced in ISO 19701, ISO 19702, ISO 19703, ISO 19706 and ISO 13344. Comparisons are detailed in ISO 29903. Prediction of the toxic effects of fire effluents can be referenced in ISO 13571 and ISO/TR 13571-2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 13571:2012, *Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 General principles

4.1 Physical fire model

A physical fire model is characterized by the requirements placed on the form of the test specimen, the operational combustion conditions and the capability of analysing the products of combustion.

4.2 Model validity

For use in providing data for effluent toxicity assessment, the validity of a physical fire model is determined by the degree of accuracy with which it reproduces the yields of the principal toxic components in real-scale fires.

4.3 Test specimens

Fire safety engineering requires data on commercial products or product components. In a reduced-scale test, the manner in which a specimen of the product is composed can affect the nature and yields of the combustion products.

4.4 Combustion conditions

The yields of combustion products depend on such apparatus conditions 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 effluent produced, the stability of the decomposition conditions, and the interaction of the apparatus with the decomposition process, with the effluent and the flames.

4.5 Effluent characterization

4.5.1 For the effluent from most common materials, the major acute toxic effects have been shown to depend upon a small number of major asphyxiant gases and a somewhat wider range of inorganic and organic irritants. In ISO 13571, a base set of combustion products has been identified for routine analysis. Novel materials can evolve previously unidentified toxic products. Thus, a more detailed chemical analysis can be needed in order to provide a full assessment of acute effects and to assess chronic or environmental toxicants. A bioassay can provide guidance on the importance of toxicants not included in the base set. ISO 19706 contains a fuller discussion of the utility of bioassays.

4.5.2 It is essential that the physical fire model enable accurate determinations of chemical effluent composition.

4.5.3 It is desirable that the physical fire model accommodate a bioassay method.

5 Significance and use

5.1 Most computational models of fire hazard and risk require information regarding the potential of fire effluent (gases, heat and smoke) to cause harm to people and to affect their ability to escape or to seek refuge.

5.2 The quality of the data on fire effluent has a profound effect on the accuracy of the prediction of the degree of life safety offered by an occupancy design.

5.3 Due to the large number of products to be included in fire safety assessments, the high cost of performing real-scale tests of products, and the small number of large-scale test facilities, information on effluent toxicity is most often obtained from physical fire models.

5.4 There are numerous physical fire models cited in national regulations. These apparatus vary in design and operation, as well as in their degree of characterization. This document defines what apparatus characteristics should define a physical fire model, identifies the data appropriate for assessing the validity of a physical fire model and provides technical criteria for evaluating them with regard to the accuracy of their data relevant to life safety.

5.5 This document does not address means for combining the effluent component yields to estimate the effects on laboratory animals (see ISO 13344) or for extrapolating the test results to people (see ISO 13571).

6 The ideal fire effluent toxicity test method

6.1 Fire stages

6.1.1 The combustion and/or pyrolysis conditions in the combustor section of the apparatus reproduce the conditions in one or more stages of actual fires, including incipient, growing and fully developed fires.

6.1.2 Specimens are burned under constant, pre-selected conditions of thermal insult and oxygen availability (ventilation). The decomposition conditions and decomposition behaviour of the specimen enable yields to be characterized for specific condition parameters.

6.1.3 For initial and progressive smouldering, the effects of specimen bulk and thermal properties are considered.

6.1.4 For growth and early fire simulations, including oxidative pyrolysis and well ventilated flaming, the in-use exposed surface of a material or product is exposed to the appropriate thermal insult.

6.1.5 For simulation of the developed stages of a fire, full burning of the test specimen is required.

6.2 Applicability

This method tests homogeneous materials (both solid and cellular) and commercial products (especially layered, non-uniform specimens), both melting and non-melting, in relevant form and under simulated fire scenarios. The nature and quantity of the decomposition products are representative of actual fire scenarios.

6.3 Apparatus independence

The apparatus does not impose any significant influence on the results, i.e. the results reflect the burning behaviour of the test specimen and not the apparatus effects. Flame quenching on surfaces should not affect the nature of the effluent and the effluent should not be subject to ageing effects. The combustion zone and effluent plume treatment are designed to ensure that these are achieved.

6.4 Operational efficiency

The test equipment is as simple as possible and capable of safe operation.

6.5 Data generated

6.5.1 The method produces direct measurements of the yields of toxic gases and smoke and/or measurements of the mass concentration of gases and smoke over time, from which the yields may be calculated. The gases include those expected to contribute to the toxic potency of fire effluent: CO_2, CO, HCN, HCl, HBr, HF, NO, NO_2, SO_2, acrolein and formaldehyde.

NOTE The relative importance of the various gases can depend on the harmful effect being considered.

6.5.2 The method produces a measurement of the mass of the test specimen. Preferably, this is obtained throughout the test to determine whether the yields of the combustion products are changing as the combustion proceeds. A determination of the final mass allows for the calculation of average yields over the duration of the test.

6.5.3 The physical fire model is compatible with the use of bioassay methods.

6.6 Accuracy

Sufficient test data and especially gas yield data from the physical fire model have been validated against full scale and/or real scale fire scenarios. The fire stages for which agreement is achieved and the degree of agreement are included in Annex A. The test conditions required to achieve that agreement with the specified fire stages are given.

6.7 Repeatability and reproducibility

Repeatability and reproducibility of data and limits of accuracy have been established by inter-laboratory trial and are incorporated as part of the standard method.

7 Characteristics of fire stages

7.1 The stages of fire are characterized in ISO 19706.

7.2 The environmental conditions that characterize the stages of both a fire and a physical fire model are the following:

- ambient temperature;
- temperature at the combustion site (for non-radiation-controlled burning);
- heat flux to the fuel surface (for radiation-controlled burning);
- surface temperature of the test specimen;
- mass loss rate;
- oxygen concentration at the fuel surface and around the flame;
- availability of fresh oxygen to replenish that depleted by combustion (ventilation rate and mixing).

7.2.1 The last three of these parameters are captured in the fuel/air equivalence ratio.

7.2.2 Typical values of these parameters for the various fire stages are presented in ISO 19706:2011, Table 1.

7.3 The outcomes of the combustion process also form a basis for characterization of the fire stage:

- yields of a (toxicologically important) subset of the hundreds of combustion products;
- carbon monoxide to carbon dioxide ratio ($[CO]/[CO_2]$);
- ratios of “telltale” second-order products of incomplete combustion, such as an aldehyde to carbon dioxide.

8 Characterization of physical fire models

8.1 Thermal environment in the test specimen

8.1.1 General

The three-dimensional temperature profile around a product undergoing combustion determines both the burning rate and the yields of the combustion products. The nature of this profile varies with the fire type and the time at which one is observing the burning (see Annex A).

8.1.2 Smouldering

This type of combustion, occurring only in porous materials, is characterized by

a) the direction in which the combustion front moves relative to the direction from which the air is arriving, and

b) a peak fuel temperature.

8.1.3 Pyrolysis

Radiative pyrolysis is characterized by a radiant flux to the surface (kW/m^2), a surface temperature and the thermal inertia of the test specimen. Conductive and convective heating are characterized by a surface temperature and the thermal inertia of the test specimen.

8.1.4 Flaming

Flaming combustion is characterized by any imposed radiant flux from the flames and from the apparatus surfaces, the fuel surface temperature and the thermal inertia of the test specimen.

8.2 Oxygen availability

8.2.1 General

The oxygen percentage (generally expressed as a mole, mass, or volume fraction or percent) determines the local and instantaneous burning rate of the product or material. There are multiple ways to characterize the availability of oxygen for burning.

8.2.2 Fuel/air equivalence ratio

8.2.2.1 Global equivalence ratios are most often cited (although not always cited as such) for the following reasons:

- the equivalence ratio is not usually uniform over the total combusting surface;
- the local values are not known;
- the instantaneous values vary during a test and there are rarely sufficient data to follow the changes.

Calculation methods are given in ISO 19703.

8.2.2.2 For a flow-through apparatus, the air flow is generally metered. The instantaneous mass loss is obtained by weighing the sample during the test or estimated from measurement of the principal carbonaceous by-products (mainly CO_2 and CO) and knowledge of the chemical formula of the sample. For determination of a global equivalence ratio, the total mass lost is determined by weighing the test specimen before and after the test.

NOTE Since different products burn at different rates and since products have varying chemical formulae, using the same air flow for all tests leads to global equivalence ratios that differ from product to product.

8.2.2.3 For a closed-cabinet apparatus, the instantaneous global equivalence ratio is determined from the sample mass loss rate (or the cumulative concentrations of carbonaceous by-products) and the oxygen concentration in the chamber.

Generally with these apparatus, there is a local decrease in oxygen concentration and the mixing of the chamber gases during the test might not be sufficient to create a homogeneous atmosphere. Thus, determination of the instantaneous equivalence ratio is not possible, and it is necessary to determine a global equivalence ratio. The decreasing oxygen availability decreases the completeness of combustion and the nature of the combustion off-gases. Thus, the production of toxic gases is weighted toward the end of the test, and the length of the procedure affects the determination of toxic potency of the effluent. This change in decomposition conditions during the test makes it difficult to determine yields for a specified fire condition if the specimen mass is not monitored.

NOTE The long residence time of the combustion products during a test can lead to significant depositing of combustion products on the chamber walls.

8.2.3 Combustion efficiency

8.2.3.1 Combustion efficiency should be measured continuously during a test since a change in its value indicates a change in the combustion conditions. However, it is often reported as a global value, averaged over the full burning time. As noted above, this can be misleading when considering toxicological implications, since most of the impact results from that period(s) when the combustion efficiency is low. The different measures (heat release efficiency, oxygen consumption efficiency, carbon dioxide formation efficiency) can give different values. The formulae and examples are given in ISO 19703.

8.2.3.2 The combustion efficiency is affected if the flames impact surfaces within the test apparatus or extend into a vitiated region.

8.3 Test specimen

8.3.1 The yields of effluent components from non-homogeneous materials are sensitive to the selection of a portion of the finished product for testing. For the test output to be accurate, the tested specimen shall be representative of the composition and conformation of the finished product. Loss of accuracy is manifested to the extent that component materials are disproportionately sampled, new surfaces are exposed, protective layers are perforated, etc.

8.3.2 For layered commercial products, the yields depend upon the layers exposed to decomposition in the physical fire model. For early non-flaming or flaming stages, only the upper surface can be involved. At intermediate and later stages, the whole composite can be involved. This shall be reflected in the test conditions.

8.4 Yields of combustion products

8.4.1 The species of interest are toxic gases, soot particulates and total aerosols.

8.4.2 Yields shall be expressed as mass of a species formed per mass of test specimen lost. This enables calculation of generation rates of effluent per mass of fuel studied and surface area of specimen studied.

8.4.3 The mass of a species formed is generally calculated from measurement of the concentration of that species. Depending on whether the concentration is measured continuously or from a grab sample, continuous or global values of the species yield are obtained.

8.5 Analytical instrumentation

The description of the method shall include the instrumentation used to characterize the fire environment, determine the sample mass loss and measure the combustion product yields. This includes details of the sampling lines if chemical species are extracted from the combustor for analysis. ISO 19701 describes the alternative techniques for combustion product analysis.

8.6 Use of test animals

If laboratory animals are used to characterize the fire effluent (see Clause 9), the method shall contain a detailed description of the apparatus in which the animals are exposed to the effluent, the means for transporting the effluent to the apparatus, the effect on the animals to be assessed and the means for determining the effect of the effluent on the animals.

9 Physical fire model accuracy

9.1 The experimental uncertainty in the data from the physical fire model is to be determined and reported.

9.2 A physical fire model can be validated using data from analytical instruments and/or live test animals.

9.2.1 Chemical measurement enables calculation of the yields of individual gases and aerosols that have previously been identified as important. Experience has shown that this is nearly always sufficient. However, not using test animals compromises the confidence in the toxic potency data generated using a test apparatus in two ways:

a) accuracy assessment without the use of animals leaves undetermined the sufficiency of the array of analytical instruments;

b) routine analytical testing cannot identify those materials or products whose effluent shows unusual or extreme toxic potency; it fails to include the value of components that have not been included in the instrumentation due to, for example, economy or lack of awareness of their existence.

9.2.2 The use of laboratory animals provides an integrated assessment of the toxic potency of the fire effluent on the animal species used. Alone, it, too, has shortcomings that can reduce the apparent validity of the fire model.

9.2.2.1 Unless coupled with appropriate instruments, it does not enable determining the cause of the toxicological effect or extrapolation to humans.

9.2.2.2 Additional experimental restrictions and criteria are necessarily imposed, e.g. reduced oxygen levels and heat shall not, in themselves, be unduly compromising to exposed animals, and it is necessary to produce sufficiently high concentrations of fire effluents so as to obtain measurable toxicological effects.

9.2.3 True validation of a small-scale test apparatus requires a combination of the two approaches.

9.3 The primary comparison is between the yield data for combustion products from a test specimen burning under conditions simulating a selected fire stage and yield data from the same stage of burning of the commercial product at real scale. The accuracy of yield data from a physical fire model is determined by the degree of numerical agreement with yield data from real-scale fire tests. The determination takes into account the repeatability and reproducibility of the data from both the reference tests and the physical fire model. The quality of the accuracy assessment depends on the number of complex commercial products for which assessment has been performed.

9.3.1 The yields of CO_2 from the physical fire model and the real-scale fire tests are considered to be equivalent if there is overlap between the numerical ranges defined by their respective measurement uncertainties. These uncertainties are generally under 20 % of the yield value.

9.3.2 The yields of CO from the physical fire model and the real-scale fire tests are considered to be equivalent if

a) the bench-scale value is within ±30 % of the real-scale value, or

b) there is overlap between the numerical ranges defined by their respective measurement uncertainties, whichever is larger.

9.3.3 A compilation of post-flashover CO yields[10][12] shows that the yield of CO from post-flashover room fire tests of a variety of combustibles is 0,24 ± 0,09. Since this results from vitiation (and thus truncation of the fuel oxidation process) in the upper layer of the burn room, a physical fire model might be unable to replicate this result.

9.3.4 The yields of HCl, HBr, HF and HCN from the physical fire model and the real-scale fire tests are considered to be equivalent if

a) the bench-scale value is within ±50 % of the real-scale value, or

b) there is an overlap between the numerical ranges defined by their respective measurement uncertainties, whichever is larger.

There can be significant losses of these gases during sampling, and these losses can differ between the two apparatus. These losses need to be considered in comparing the results.

9.3.5 The yields of partially oxidized organic compounds (e.g. acrolein, formaldehyde) from the physical fire model and the real-scale fire tests are considered to be equivalent if

a) the bench-scale value is within a factor of two of the real-scale value, or

b) there is overlap between the numerical ranges defined by their respective measurement uncertainties, whichever is larger.

9.3.6 If the yield of any of the above gases constitutes less than 2 % of the FED or FEC, as calculated for the real-scale test in accordance with ISO 13571:2012, Formula (2) or (4), then the yield from the physical fire model shall be deemed equivalent if it is within a factor of five of the real-scale test value.

9.3.7 If the yield values from the validation tests are not equivalent, the degree of agreement is described by the ratio of the value from the physical fire model divided by the value from the real-scale fire test. The uncertainty in this ratio is also reported.

9.3.8 An additional criterion is that the relative importance of the individual terms in ISO 13571:2012, Formulae (2) and (4) shall not change in importance due to the different values from the real-scale and bench-scale determinations, nor shall the relative importance of the two formulae change relative to each other.

9.4 The overall accuracy of a physical fire model is also described by the accuracy of measured or predicted EC_{50} values. The accuracy is adjusted to account for significant disagreement over the yield of a secondary toxic species if that species can become significant under the circumstances of a particular fire hazard determination.

9.4.1 When laboratory animals are exposed to the effluent, the comparison is between the EC_{50} value determined from a test specimen burning under conditions simulating a selected fire stage and the EC_{50} value from the same stage of combustion of the commercial product at real scale.

9.4.2 When no animals are exposed to the effluent, the comparison is between the EC_{50} value estimated from the species yields from a test specimen burning under conditions simulating a selected fire stage and the EC_{50} value estimated for the species yields from the same stage of combustion of the commercial product at real scale.

Annex A
(informative)

Characteristics affecting combustion product yields

A.1 General

There are three components to defining what is occurring either in an actual fire or in a fire test apparatus. The first is the thermal (and energetic) environment that enables a stable material to become a fuel. The second is the availability of oxygen, the reactive partner of the fuel. A third factor, the combustion efficiency, results from both these two fire conditions and the nature of the fuel(s).

A.2 Thermal environment

A.2.1 General

There is a three-dimensional temperature profile within a product undergoing combustion. The nature of this profile varies with the fire type and the time at which one is observing the burning.

A.2.2 Self-sustaining (smouldering) combustion

This mode of combustion occurs when a porous product (e.g. cellulose insulation or polyurethane foam) is heated to the point where surface reaction of the solid occurs with air that is diffusing into the pores. The peak temperatures occur where the oxygen is reacting most rapidly, generally below the external surface of the product. The heat generated is transported away mainly by conduction, and combustion continues as infusing oxygen and this temperature peak meet at fresh fuel. Thus, there is a “thermal wave” that passes through the material. Because the oxygen concentration goes to zero at the reaction site (due to an excess of fuel) and because the combustion gases have a long residence time in a reducing atmosphere, a sizeable fraction of the carbonaceous gases is not fully oxidized to carbon dioxide. This type of combustion is characterized by

a) the thermal wave direction relative to the direction from which the air is arriving, and

b) a peak fuel temperature.

Since the smouldering process is relatively slow, there is little heating of the fire room.

A.2.3 Pyrolysis

Thermal breakdown of a product can be forced by an external heat source, ceasing when the source is removed from the fuel. Conductive heating, such as from contact with an overheated electrical unit, can result in the release of gaseous by-products with little or no oxygen participation (non-oxidative). When the breakdown occurs on a surface exposed to both heat and oxygen (such as flame radiation impinging on an outer surface of a non-burning object), a different set of gases and aerosols generally results. In both cases, the fuel temperature is at a maximum near the surface facing the heat source and falls away monotonically toward the interior. For layered products, the pyrolysis gases and aerosols change as the successive layers degrade. Pyrolysis due to conductive or convective heating is characterized by the surface temperature and an indicator of the fall-off of temperature with distance from the surface. Degradation due to radiative heating is generally characterized by the radiative heat flux to the surface, although this results in a qualitatively similar thermal profile to the other modes of heating. Non-oxidative pyrolysis is generally endothermic, and even oxidative pyrolysis generates little heat. Thus, there is little heating of the fire room. As in the smouldering case, the pyrolysis products are likely to be more noxious and irritating than the products of complete combustion.

A.2.4 Flaming

Flaming can be construed as radiation-enhanced surface pyrolysis of the fuel followed by vapour phase oxidation of the released gases. The surface temperatures can be higher than for pyrolysis, especially for charring materials. The temperature profile within the fuel is qualitatively similar to pyrolysis: high on the exposed surface, decreasing with depth. For layered products, the surface stratum can protect the lower layers; the burning rate changes as subsurface layers become involved. The rate of heat release from flaming combustion is generally far higher than for smouldering or pyrolysis, so the heating of the room is accordantly higher and faster. The hot environment becomes a second source of thermal radiation (in addition to the flames), which further enhances the burning rate. Thus, the various stages of flaming combustion are characterized by a total radiant flux that includes both immediate and room-scale contributions. The radiation to the fuel surface is proportional to the fourth power of the temperature of the radiant source, its optical thickness and the fraction of the field of view of the source by the fuel. Small flames are often optically thin and thus, impose lower levels of radiation than do larger flames over the same fuel; sooty flames are optically thicker than low-soot flames. Early in a fire, when the room is still relatively cool, external radiation from the hot upper layer is small; as flashover is approached, that radiation dominates.

A.3 Oxygen availability

Burning rates, burning efficiency, and the yields of specific combustion products depend heavily on the percentage of oxygen in the vicinity of the burning and the rate at which the local oxygen, depleted by the combustion, is replenished. The oxygen percentage (generally expressed as a mole, mass, or volume fraction or percent) determines the local and instantaneous burning rate of the product. The fire tries to maintain its oxygen supply, entraining air from the surroundings by thermal buoyancy and turbulent flame motion. The oxygen supply can be restricted by the presence of obstacles or limited openings in the fire compartment. Ambient (25 °C) air at 50 % relative humidity contains about 20,6 mole % oxygen. Small flames go out when the oxygen level drops below about 16 mole %. Radiation-enhanced flaming can continue below 5 mole % oxygen, but under these conditions a great deal of unburned pyrolyzate is generated.

A.4 Changing combustion conditions

As the combustion proceeds through different fire types, there will likely be dramatic changes in the nature and yields of the products of incomplete combustion. Thus, for the yield analysis to be meaningful, it is important that effluent samples be identified with only a single stage of a fire. This requires accurate accounting of the transit time from the combustion zone to the sampling device.

It also suggests that time-dependent yield information can be helpful in determining the time interval over which the assumption of a single fire stage is reasonable. Traditionally, there have been continuous analysers for very few combustion products, e.g. CO_2, CO, NO, NO_2 and water vapour. Fourier transform infrared analysers have made at least semi quantitative analyses possible for many additional compounds. Grab sampling during the test allows for subsequent analysis of multiple compounds as well, albeit with reduced time resolution. Combustion-generated particulates (soot) are generally collected during the full test and weighed at the conclusion, although there is limited capability for continuous measurement.

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