The Single Burning Item (SBI) test method – a decade of development and plans for the near future

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Harmonised technical specifications are needed to create a single European market. Although many test methods were available to assess the reaction to fire performance of building products, no set of existing test methods was both politically and technically acceptable. As a result the Single Burning Item (SBI) test method has been developed . For about 80% of the building products on the European market this assessment will be, and partly is already, compulsory. The paper describes the development process of the SBI test method, including the result of the second recently finalised round robin exercise. Items for further development are discussed with the emphasis on some uncertainty aspects of the test method.

Key words: Reaction to fire, SBI, test methods, round robin

1 Introduction

Through the use of harmonized technical specifications, thus removing technical barriers between Member States, the Construction Product Directive (CPD) [24] aims to create a single European market. It applies to all construction products that are produced for, or incorporated within, building and civil engineering construction works. It harmonises all construction products subject to regulatory controls for CE marking purposes.

The CPD defines six “Essential Requirements”, from which one is the “Safety in case of fire”. While in other Directives the essential requirements are directed to the products themselves, the CPD relates to the essential requirements of the works. The link between the requirements of the works and the technical specifications for building products is established through the “Interpretative Documents”. One of the fire characteristics for construction products to assess is the reaction to fire performance.

The CPD provides for a “Standing Committee on Construction” (SCC), which assists the European Commission in its implementation. The SCC members are representatives of the Member States. In general the SCC is a consulting body to the Commission, but for certain items indicated in the CPD it is a regulatory body. The SCC has set up a technical working group to assist in the interpretation of the Directive in fire safety related matters: the "Fire Regulators Group" (FRG), recently re-established and named "Experts Group on Fire issues under the CPD" (EGF).

One of the characteristics for construction products to assess is the reaction to fire performance. This characteristic is present in the national regulations of all European member states and plays an important role in evaluating possible uses of building products. The basis for the European reaction to fire classification, the EUROCLASSES, was put in place in 1993 by the Fire Regulators Group. The classification system was based on the performance of products under different fire conditions: the attack of a small flame; exposure to a fully developed fire; and some intermediate level. Due to the nature of fire under the influence of gravity forces, two basic applications of products were distinguished: products applied on a floor and all other products.

All but one of the tests needed in this new classification system were known international standard test methods. No existing test method representing the intermediate level that was both politically and technically acceptable. The missing test method, including the apparatus, representing the scenario of a Single Burning Item – to test building products excluding floor coverings – had to be designed from scratch. The apparatus soon got called the SBI [1].

The SBI test method was planned to assess the performance of building products in a (real scale) room corner scenario. The ISO 9705 Room corner test [5], which is a full-scale test method intended to evaluate the contribution to fire growth provided by a surface product applied in a room, was put forward as the reference test for this scenario. The main development objective therefore was that the product ranking in the SBI would have a high correlation with the ranking obtained in the ISO Room corner test. The second development objective followed from the requirement that the method had to be capable of measuring the required characteristics in a repeatable and reproducible way.

This paper describes major steps in the development of the SBI method, recent results acquired and the need for further improvements. For convenience a short description of the test method is given here.

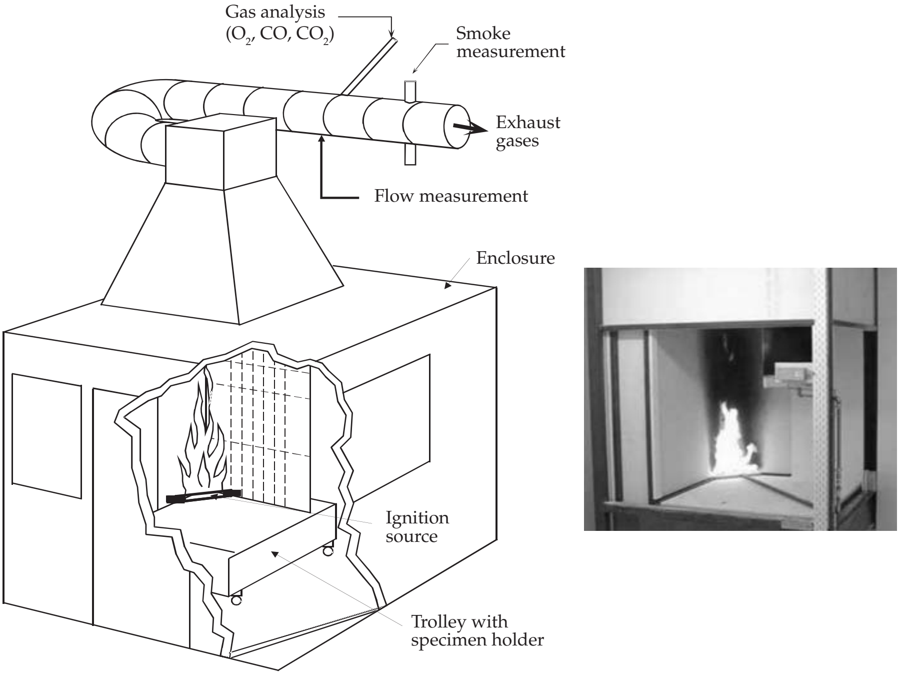

Figure 1. The Single Burning Item test set up in the normative 3 x 3 m² test room

The SBI test simulates a single burning item burning in a corner of a room. The test apparatus is presented in Figure 1. The total exposed specimen surface area is 1,5 m x 1,5 m. The specimen consists of two parts (height 1,5 m, width 0,5 and 1,0 m) which form a right-angled corner. Eventual corner joints as applied in end-use conditions form part of the product under test[1]. A triangular shaped propane diffusion gas burner running at 30kW acts as heat and ignition source representing a burning waste paper basket. It is placed at the basis of the specimen corner. The performance of the specimen is evaluated during 20 minutes. There is a floor in the test configuration but no ceiling. Floor, specimen and burner are installed on a trolley that can be removed from the room for easy mounting of the specimens. The combustion gases are collected in a hood and transported through a duct. The duct contains a measurement section with a differential pressure probe, thermocouples, a gas sample probe and a smoke measurement system, to measure heat and smoke production.

1 Due to specimen construction and size, construction behaviour like mechanical deformation may be of major importance for product performance in the SBI test method. This in contradiction to many other reaction to fire tests.

2 Development of the basic method

The development of the SBI test method was assigned by the European Commission and carried out under direct guidance by the Fire Regulators Group. A group of seven, later nine, fire laboratories from an equal number of EU member states was formed in 1993 with the development task. The aim was to develop a test method that produces results representative for the behaviour of building products when exposed to one single object, e.g. a coach or a litter basket, on fire placed in the corner of a room. A specific irradiance level that falls onto the specimen was prescribed.

Many design aspects were considered in the early stages. The major ones being:
- Type of heat source: Four heat sources were considered, leading to two serious candidates: a diffusion type burner and a gas fired radiant panel. The selection of the propane diffusion sandbox burner was finally made on the basis of practical aspects, repeatability and discrimination capability.
- Closed or open arrangement of the test apparatus: For reasons of reproducibility and operator protection a closed configuration was chosen. Preliminary CFD calculations showed no significant influence of the walls of the enclosure at the chosen size.
- Inclusion or not of a ceiling in the specimen arrangement. A specimen arrangement without ceiling was chosen based on the absence of a significant effect of the ceiling on the discrimination capability of the test, the measurability of parameters, or the repeatability and reproducibility of the results.

Other parts of the apparatus were taken from other standards: the oxygen depletion measurement technique and accompanying instrumentation were based on the ISO 9705 and ISO 5660 [3] design.

Not only the design of the apparatus received much attention. The test, calibration and calculation procedures were specified in great detail. Unlike the more global description of the calculations in many other standards, the calculations were introduced in detail to facilitate the writing of calculation software without (much) further technical knowledge of the measurement techniques.

After acceptance of the design by the European Commission, some fifteen to twenty additional SBI's were build and installed all over Europe in just a few months to perform a large round robin project. The round robin started in May 1997 with 20 laboratories, testing 30 building products in threefold. Fifteen laboratories managed to perform the tests in the required very tight time schedule. The result of the round robin was accepted by the Standing Committee in December 1997, as sufficient proof of the ability of the SBI test method to measure the required characteristics in a repeatable and reproducible way, however under the condition of certain improvements.

A further one year of development work resulted in changes to the smoke measurement, to the velocity profile in the exhaust duct and to the calculation and calibration procedures:

- Smoke measurement system improvements concern prevention of soot deposit on the lenses; a reduction of vibration in the optical system; and simple positioning of calibration filters.
- The velocity profile in the exhaust duct at the pressure probe position was asymmetric W-shaped instead of fully developed. Three changes were introduced to the exhaust duct: a shift of the guide vanes further away from the probe position, the introduction of a small orifice immediately behind the guide vanes and the introduction of 0,5 meter additional duct length. The result was a nearly flat profile over the mid half of the duct radius.
- Calculation procedures: two improvements were introduced:
  - Automatic synchronisation of gas analyses data: Since pressure, temperature, oxygen and carbon dioxide concentration, needed to calculate the heat release, have different dead times, a synchronization is needed. A fully automated procedure was introduced to exclude human interpretation.
  - Introduction of validity checks for the burner switch response time; drift in gas concentrations and light attenuation; malfunctioning of thermocouples; and for the deviation in heat and smoke burner output. A failure to meet the criteria invalidates the test result.
- Calibration procedures: nearly all calibration procedures were extensively rewritten; some new ones were introduced.

After five and a half years of development under direct guidance of the European Commission, the draft method was handed over to CEN in spring 1999. There the method was fine-tuned and transferred into a draft CEN standard. No fundamental design changes were introduced. However, a large number of small adjustments improved the standard considerably.
The SBI method was accepted in CEN as a European test method in the Autumn of 2001 and has been implemented in national regulations since then.

3 The reaction to fire classification system

The basis for the European reaction to fire classification, the EUROCLASSES, was put in place in 1993 by the Fire Regulators Group. The classification reflected the needs of the Regulators in the different member states to transpose current national performance levels into new European levels, and not implicitly the urge to design a technically well balanced set of classes. The classification of building products excluding floorings is assessed using four test methods. Three classifications apply: a main classification related to heat production (classes A1, A2, B, C, D, E or F, where A1 represents the highest level ("no contribution to fire") and F has no requirements or "no performance determined"), and additional classifications for smoke production (s1, s2 or s3, where s1 is the best, s3 has no requirements) and for flaming droplets and particles (d0, d1, d2, where d0 is the best, d2 has no requirements). The SBI test method is relevant for the main classes A2-D[2] and all additional classes.

Based on current practice in the member states, the EC choose to take a series of fire characteristics into account in the SBI: an index representing the speed of growth in heat release rate (FIGRA), the total heat released over the first 10 minutes (THR_{600s}), a simple lateral flame spread to the end of the specimen (LFSedge), an index representing the speed of growth in smoke production rate (SMOGRA), the total smoke produced over the first 10 minutes (TSP_{600s}), and a parameter defining three levels of flaming droplets and particles (FDP).

Due to differences in national regulatory needs the characteristics were combined in the three separate classifications mentioned earlier: a main, heat release based, classification, valid for all member states, a smoke production classification and a classification of falling flaming droplets and particles for only a part of the member states.
The FIGRA and SMOGRA indices use threshold values for total heat release and smoke production below which they are set to zero by definition. This in order to eliminate some ambiguous results obtained with very small release rates in the first tens of seconds in the test. Different levels of thresholds were introduced for FIGRA in different classes, leading to $FIGRA_{0,2MJ}$ and $FIGRA_{0,4MJ}$. A compilation of the SBI criteria[3] in the various classes is given in Table 1[4].

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2 The alternative special requirement option for external non-substantial components in class A1 is not noted.
3 Some typical examples of product classification according to the criteria: paper faced gypsum plasterboard: A2, s1, d0; steel with thin plastic weather coating C, s2, d0; most wood based products (not fire retardant treated): D, s2, d0; most uncovered not fire retardant treated thermoplastics: D, s2, d2 or E, s3, d2
4 The alternative special requirement option for external non-substantial components in class A1 is not noted.

4 Recent developments

Since its introduction the SBI test has been used extensively in a large number of European fire laboratories and considerable experience has been acquired. The European building sector is now working with the SBI test method to provide their products with a reaction to fire classification, and the particularities of the method have become increasingly apparent ever since.

Table 1. SBI classification criteria

Main classification		Smoke classification		Flaming droplets/particles classification	
A2 and B	$FIGRA_{0,2MJ} \leq 120$ W/s LFS < specimen edge $THR_{600s} \leq 7{,}5$ MJ	**s1**	SMOGRA ≤ 30 m^2/s^2 $TSP_{600s} \leq 50$ m^2	**d0**	No flaming droplets/part.
C	$FIGRA_{0,4MJ} \leq 250$ W/s LFS < specimen edge $THR_{600s} \leq 15$ MJ	**s2**	SMOGRA ≤ 180 m^2/s^2 $TSP_{600s} \leq 200$ m^2	**d1**	No flaming droplets/part. persisting > 10 s
D	FIGRA ≤ 750 W/s	**s3**	-	**d2**	-

Several organisations have started to further develop the method. EGOLF, the European Group of Organisations for Fire testing, Inspection and Certification[5], has listed ambiguous and insufficiently defined (parts of) procedures and proposed common solutions and interpretations for them to harmonise the way of working with the method between its members. These proposals, "recommendations" in EGOLF, are not changes to but only additions to the current standard, since EGOLF is not authorized to change the standard. The Fire Sector Group of Notified Bodies (FSG)[6] works along the same lines to support the work of the notified laboratories. Both EGOLF and the FSG send requests for changes in EN 13823 to CEN TC127[7] that has started the formal review of the method. An extensive list of work items has been drafted by TC127. Most purely technical issues already have been solved, but the remaining items might lead to a more or less fundamental change of the method leading to substantially different classifications of products. TC127 still has not decided on the advisability of such a change since guidance by the Commission is still awaited for.

5 EGOLF members are independent, official, nationally recognised, organisations that test, inspect or certify materials, components and products in support of legislation in Europe; current membership comprises 50 laboratories, of which 47 from EC and EFTA countries.

6 The European Commission supports a structure for the CPD Group of Notified Bodies (third party conformity assessment bodies under the CPD). Fire issues are dealt with in the "horizontal" Fire Sector Group as a general topic relevant for (nearly) all product family related Sector Groups.

7 CEN TC127 is the responsible CEN TC for the development of fire standards under the CPD.

As major weakness of the method (e.g. in terms of repeatability and reproducibility) is the importance of the mounting and fixing of specimens could be mentioned. However, this is a direct consequence of the CPD principle to test products in their end use application and to test specimen of considerable size where mechanical deformation behaviour plays an important role.

Real weaknesses are recognized in issues like:

- Fallen debris blocking the burner and/or closing the gas supply by blocking the visibility of the flames by the flame detector. The use of a grid to protect the burner only solves part of the problem; it will give no improvement for fluid debris.
- The oxygen analyser is used at the border of its specifications. Regular calibrations, day-to-day checks, good pre-measurement filtering and conditioning of the combustion gases and good maintenance do not solve all the problems here.
- There is no good check of the thermal attack on the specimens. This could be introduced by means of a heat flux measurement or a reference test on a reference material of well known behaviour. The solutions available at present are not reliable enough to override the propane gas supply requirement.

The remaining uncertainties about the accuracy and robustness of the method have lead to the joint initiative of EGOLF and CEPMC (Council of European Producers of Materials for Construction) to organise a second round robin with financial support by the Commission. The round robin was formally set up "to verify the efficiency of the various modifications previously made to the test method and the test procedure after the first round robin in 1997 and to investigate any further remaining deficiencies". The results were reported only recently [23] and can be summarized as follows:

- The repeatability and reproducibility of the continuous classification parameters ($FIGRA_{0,2MJ}$, $FIGRA_{0,4MJ}$, THR_{600s}, SMOGRA and TSP_{600s}), represented by the quotient of the standard deviation estimates (σ_r and σ_R) and the mean value of the parameters (μ), are between 11% and 20% for $\sigma r/\mu$ and between 21% and 34% for σ_R/μ), when very low[8] mean values are excluded. General proof of improvement of the accuracy of the method in comparison to the first round robin could not be found. Only the reproducibility of the smoke measurements shows some improvements.
- All laboratories show sufficient proof to measure heat release related data in an acceptable way; 90% of them does this acceptably for smoke production related data as well. It takes many laboratories however much longer than expected to comply with the calibrations. This creates concern about the abilities and level of training of the laboratories/operators.

8 Very low defined as a value 50 % or less of the lowest classification borderline for the Euroclasses A2 – E (i.e.: $FIGRA_{0,2MJ} \leq 60$ W/s, $THR_{600s} \leq 3{,}75$ MJ, SMOGRA ≤ 15 m^2/s^2 and $TSP_{600s} \leq 25$ m^2).

- Overall the current specified calibration procedure is acceptable and is able to evaluate a laboratories capability to measure heat release rate and smoke production rate in an accurate way. The procedure also helps to highlight problems and to locate them. The round robin shows that there is room for improvement of the calibrations and it is recommended to revise the calibration procedures. Furthermore it is recommended to further develop the calibration of the optical system and to make it normative.
- The results of the visual observations indicate that the set of products used may be a poor discriminator to check the ability of the method to assess the visual observation related parameters. The results however already indicate that large differences in interpretation of visual observations exist.

The round robin clearly shows the benefit of having good calibration procedures, but only if they are applied and laboratory personnel knows how to act when criteria are not satisfied.

The eagerness of industry and fire laboratories to obtain information about the quality of the test results is not the only drive for further attention to the method. Accreditation bodies are increasing the pressure on fire laboratories to include an estimate of measurement uncertainty, other than obtained out of a round robin, in the test report.
According to EN ISO 17025:1999 [8], which sets out the general requirements for the competence of testing and calibration laboratories, and ISO 10012-1 [11], which sets out the requirements for assuring the quality of measuring equipment, uncertainties are to be reported in both testing and calibration reports.

In response to these international standards EGOLF has published a regulation document EGOLF/R4 [4] in 2001. The document provides guidelines by which EGOLF members should interpret and implement the European Standard EN ISO 17025 and the criteria by which they should be subject to accreditation and surveillance against that standard by accreditation authorities.
Different to EN 45001:1989 [9] which prevails EN ISO 17025, the latter makes the estimation and measurement of uncertainty of test results mandatory. Till the release of this new standard, EGOLF had been arguing that reporting uncertainty on fire test results is practically speaking not possible. This belief is still reflected in document EGOLF/R4, but more recent initiatives in EGOLF try to develop means to evaluate uncertainty of measurement for each individual method or family of methods.

In the mean time EGOLF uses the results of round robin exercises as a basis for prove of competence of its member laboratories. This however has some disadvantages:

- It does not differentiate between the uncertainties related to the apparatus, the operator, the product under test, etc.;
- It is costly and time consuming to organise them;
- The results are based on some 'representative' products; in practice however the spread in results may be different.

The round robins result in an estimation of the 'overall' relative repeatability and reproducibility standard deviation making use of the International Standard on Accuracy of Measurement Methods and Results, ISO 5725 [12].

On the other hand, fairly recently, some individual organisations have tried to quantify uncertainty associated with the calculation of heat release rate and smoke production rate [13][20][21][22] on a theoretical basis. However, out of a review of all major round robins, Janssens [14] found that the results suggest that the uncertainty is much greater than the theoretically found values, in particular for intermediate and large-scale tests.

So one of the biggest challenges for the fire community in the coming years, is to work out, for the different test methods, means to evaluate uncertainty of measurement. Due to the actual European harmonisation of fire testing (EN 13501-1 [2]) this is becoming even more important.

5 Determination of uncertainty

The general principles for evaluating and reporting uncertainties are given in the ISO Guide to the Expression of Uncertainty in Measurement (GUM [10]), but need to be adapted to the specific case of fire testing. Today, on the international scene, two entities are active on the subject. The first one is the Swedish national fire institute, SP, and the other one is a working group around the person of Tony Enright. However, in view of the pressure exercised by accreditation authorities, there is an increasing interest of testing laboratories worldwide in the subject.

Despite the initiatives taken, there is still an important way to go before reporting uncertainty along the lines of the GUM document.

The weak points in the work done so far are that:

- Not all relevant phenomena are taken into account, often because people are not aware of them or because they believe they can be neglected. Examples of these are the Reynolds dependence of the velocity pressure probe in the SBI, used to obtain the mass flow of the exhaust gases, and the angular dependence of that same probe.

- The 'guesses' made on uncertainties on the different components since the required statistical information is not readily available. Example of this is that the uncertainty on a gas concentration measurement is taken as the sum of noise and drift of that gas analyser over half an hour period.
- Dynamic effects of the apparatus have not been taking into account. Due to time constants superseding the data sampling rate, an additional source of error is introduced. This error can not be neglected especially not when considering momentary values like peaks and dips. This is the case in the SBI where the main classification criterion, FIGRA, is defined as the maximum of the quotient of Heat Release Rate by time elapsed to reach that level. To partially eliminate this effect the SBI standard prescribes that the heat release rate first should be smoothened by means of a running average over half a minutes period.
- Covariance's between the different measurands have been neglected. This is not justifiable as can easily be understood from the following example. Suppose a pure substance like for example propane is burnt,

  $$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

  we know that for every mole of oxygen consumed, 3/5 moles of carbon dioxide will be formed. So there is a perfect negative correlation between the two (r = -1).
  Furthermore, when there is oxygen consumption, there is heat release and temperature of the exhaust gases will rise with a resulting negative correlation. This negative correlation is also true for the differential pressure measured over the velocity pressure probe, which will increase due to an increased velocity in the exhaust duct when running the equipment at constant mass flow rate.

There is still a wide, unexplored field of research that needs to be filled up in the coming years. The following paragraph highlights some major research topics of interest in the field.

6 Research topics for the near future

Several categories for further improvement of the method still remain. The most important ones are good representation of product performance in practice, good control of the test conditions and determination and limitation of measurement errors. Items from all three categories have been discussed from the beginning of the development of the method, but with an emphasis on the first two. As discussed earlier, research topics in that area have been listed already by CEN, FSG and EGOLF. The third one, "how big are the errors and what can we do about it", has become more important due to the recent uncertainty discussions. Major research topics in that area are highlighted here. Gaining insight in the technique and getting to know its pitfalls, together with a streamlining of the initiatives would greatly improve the accuracy of the method and would allow to obtain a reliable estimation of the uncertainty interval.

6.1 ***Gas analysis***

The oxygen concentration is, by far, the most important component to be measured when measuring heat release rate. Evenly important as the concentration measurement itself is the gas sampling and preparation. This includes the sampling, filtering, transport over several meters distance and dehydration. The dehydration is performed in two steps by means of a cooler unit and a desiccant. Since the desiccant is so critical for an accurate measurement of both the oxygen and carbon dioxide concentration, further research is necessary. Indeed, when the partial vapour pressure increases, the measured oxygen concentration lowers resulting in an apparent oxygen consumption and resulting heat release rate. Also some products like Silica gel tend to absorb carbon dioxide initially, while releasing it back further on in the test. This results in a sloppy response curve and can be overcome by using products like Anhydrous Calciumsulphate. Also the problem of saturation – the product must be replaced before the colour indicator warns to do so –, under what circumstances can the product be regenerated and chemical interaction with the combustion gases needs further attention.

The uncertainty related to the oxygen concentration itself includes the calibration method, the calibration gas, ambient conditions like barometric pressure and room temperature, damping, vibrations, etc. The challenge here is to measure variations in concentration of the order of 50 particles per million (ppm) in the range from 17 to 21 Vol.%. These variations are in the same order as the allowed noise level. Although damping of the signal allows to eliminate a great part of the noise, it results in higher response times.

Determination of the uncertainty on the measurement requires much more than for example taking the sum of noise and drift as proposed by Enright [13].

6.2 ***Mass flow rate***

Only limited effort has been invested in the accurate determination of the mass flow rate and/or in the improvement of the extraction system (duct diameter, guide vanes, ...). Only a limited number of people within the fire testing community seems to be aware of the impact of the mass flow on the accuracy of the overall heat release rate and smoke release rate measurement. Prove of this are the pre-standards prEN 50399-1 [6], for the assessment of the reaction to fire performance of cables, and prEN 45545-2[7], for the assessment of the reaction to fire performance of materials for railway vehicles. Especially in the second standard, where one wants to measure heat release rates as low as 7 kW and variations of heat release rate smaller than 1 kW making use of hardware designed to cope with fires releasing up to 1 MW (Duct f = 400 mm; extraction rate 1.5 m^3/s at 298 K). The oxygen depletion at the 7 kW level under the given circumstances is only 250 ppm, which almost disappears in the measurement noise.

In general, there is a high degree of 'copy-pasting' from other standards, i.e. ISO 9705, into new developed standards without re-evaluating the method in these new circumstances. ISO 9705 is a full-scale test method intended to evaluate the contribution to fire growth provided by a surface product applied in a room. It goes for itself that appropriate downscaling for small and intermediate scale test methods is necessary.

Besides the improper downscaling, some physical phenomena or the way measurements are taken may increase the overall uncertainty.

6.2.1 Velocity profile – The effect of heating and cooling

The technique for measuring mass flow rate $\dot{m}$ currently used in intermediate to large scale calorimeter tests consists of measuring the velocity on the axis of the duct v_{axis} and to multiply this with a correction factor k_t to obtain the mean velocity. This mean velocity is then multiplied with the mean density $\bar{\rho}$ and the surface area A to obtain the mass flow rate.

$$\dot{m}(t) = \bar{\rho} k_t v_{axis}(t) A$$

k_t is the velocity profile correction factor and is defined as

$$k_t(t) = \frac{\int_A v(t)dA}{v_{axis}(t)A}$$

Since the distribution of the velocity is not known, k_t is approximated and taken as a constant over time. If we knew the velocity distribution, the mass flow rate could be approximated by

$$\dot{m}(t) = \bar{\rho} \int_A v(t)dA$$

which is only correct when the density is uniform over the measuring section. Ideally we would want to measure

$$\dot{m}(t) = \int_A \rho(t) v(t)dA$$

So far, uncertainty studies have disregarded the error made assuming the density is constant. Only recently, a study has been made that tries to quantify the uncertainty related to the ever changing velocity and density profile over the duct section induced by the ever changing combustion gas temperatures and the thermal inertia of the system [19].

The same group of researchers has also discovered that the velocity profile correction factor varies with, what they call, the *'effective' Reynolds number*, which is based on the turbulent viscosity, rather than with the 'instantaneous' Reynolds number [16]. They define the effective Reynolds number as:

$$Re_{eff} = \frac{\rho U_b D}{\mu_{eff}}$$

with ρ the density, D the inner duct diameter, U_b the bulk velocity and $\mu_{eff} = \mu + \mu_t$ the sum of the molecular and the turbulent viscosity.

6.2.2 The velocity measurement

The velocity measurement is made by means of a so called bi-directional pressure probe which is based on the pitot-static principle. The bi-directional probe [15] was originally designed for measuring the low velocity of (buoyancy-driven) fire induced flows associated with small to medium size fires. It has been 'copy-pasted' into various international standards and is considered to be the state of the art for measuring mass flows in combustion gases.

Although the probe is suited to work both in sooty environments and at elevated temperatures, its main disadvantage however is that it overestimates the measured velocity by approximately 1% per degree pitch or yaw angle initially [17]. This can be caused by improper alignment of the probe with the flow or by a radial velocity component in the exhaust flow.

The probe used in the SBI standard, which is a slightly modified design, is less angle sensitive but is, in contradiction with the standard bi-directional probe, Reynolds dependant. Due to the ever changing temperatures of the combustion gases and the varying velocity of said gases, the Reynolds number related to the probe outside diameter will vary, in most fire tests, in the range from 3.10^3 to 3.10^4 approximately. Further details can be found in [17].

So far, these effects have been disregarded resulting in a too low estimate of the uncertainty interval.

As a result of these findings, further research has been undertaken which has resulted in a new velocity pressure probe design that combines a low angular sensitivity and a Reynolds independency over a wide range [18].

6.3 *Transient error*

An additional source of error is introduced by the response times of the measuring devices. The gas analysis system – from sampling to analysis – has a time constant τ in the order of 10 seconds. This introduces a non negligible transient error which, in the case of oxygen, equals

$$\delta = \tau \frac{dXO_2}{dt} \quad .$$

Inverse techniques may help to restore the 'real' variation of oxygen concentration over time. This however needs further investigation and, if used, a general agreed consensus on how to do it.

In a nutshell the procedure is as follows. The gas analysis system works as a (first order) low pass filter with transfer function H(s). Taking the inverse in the Laplace domain $H(s)^{-1}$, allows us to restore the original signal if not that the high frequency disturbances like noise were to disturb the process. Indeed, the inverse system $H(s)^{-1}$ works as an amplifier for the high frequencies.

So inverse techniques should only be used with great care and will require appropriate filters to remove the high frequency noise from the measured signal. This will require a complete redesign of the data acquisition as we know it now, i.e. one sample taken every three seconds.

7 Conclusions

The SBI test method has had a turbulent history of development and strong, both political and economical, interests have governed the debates. The standard has been published early 2002 and people are getting used to the particularities of the test method. Over the years, the test method has also gained confidence both in test institutes and in industry.

It is our believe that it is now time to have a major revision of the test method and its calibration procedures based on both new theoretical insights and on experience gained during the second SBI round robin exercise.

The revision should not lead to a new test method, though to a higher measurement accuracy and an increased confidence. It should also lead to a guidance document that allows laboratories to include reliable uncertainty estimates in their test reports.

A multiplier effect can/will be that, in a first stage, all heat release rate related fire test standards will be revised to obtain higher measurement accuracy and to include guidance on the estimation of uncertainty. In a second stage, all other fire test standards would be revised to include guidance on uncertainty estimation.

References

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