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## Estimation of uncertainty in the single burning item test

Messunsicherheit - Thermische Beanspruchung durch einen einzelnen brennenden Gegenstand (SBI)

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## European foreword

This document (CEN/TR 16988:2016) has been prepared by Technical Committee CEN/TC 127 “Fire Safety in Buildings”, the secretariat of which is held by BSI.

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## 1 Scope

### 1.1 General

The measuring technique of the SBI (single burning item) test instrument is based on the observation that, in general, the heats of combustion per unit mass of oxygen consumed are approximately the same for most fuels commonly encountered in fires [Huggett [12]]. The mass flow, together with the oxygen concentration in the extraction system, suffices to continuously calculate the amount of heat released. Some corrections can be introduced if CO<sub>2</sub>, CO and/or H<sub>2</sub>O are additionally measured.

### 1.2 Calculation procedure

#### 1.2.1 Introduction

The main calculation procedures for obtaining the HRR and its derived parameters are summarized here for convenience. The formulas will be used in the following clauses and especially in the clause on uncertainty.

The calculations and procedures can be found in full detail in the SBI standard [1].

#### 1.2.2 Synchronization of data

The measured data are synchronized making use of the dips and peaks that occur in the data due to the switch from 'primary' to 'main' burner around  $t = 300$  s, i.e. at the start of the thermal attack to the test specimen. Synchronization is necessary due to the delayed response of the oxygen and carbon dioxide analysers. The filters, long transport lines, the cooler, etc. in between the gas sample probe and the analyser unit, cause this shift in time.

After synchronization, all data are shifted so that the 'main' burner ignites – by definition – at time  $t = 300$  s.

#### 1.2.3 Heat output

##### 1.2.3.1 Average heat release rate of the specimen (HRR<sub>30s</sub>)

A first step in the calculation of the HRR contribution of the specimen is the calculation of the global HRR. The global HRR is constituted of the HRR contribution of both the specimen and the burner and is defined as

$$\text{HRR}_{\text{total}}(t) = E' \dot{V}_{D298}(t) x_{a,O_2} \left( \frac{\phi(t)}{1 + 0,105\phi(t)} \right) \quad (1)$$

where

- $\text{HRR}_{\text{total}}(t)$  is the total heat release rate of the specimen and burner (kW);
- $E'$  is the heat release per unit volume of oxygen consumed at 298 K, = 17 200 (kJ/m<sup>3</sup>);
- $\dot{V}_{D298}(t)$  is the volume flow rate of the exhaust system, normalized at 298 K (m<sup>3</sup>/s);
- $x_{a,O_2}$  is the mole fraction of oxygen in the ambient air including water vapour;
- $\phi(t)$  is the oxygen depletion factor.

The last two terms  $x_{a,O_2}$  and  $\left( \frac{\phi(t)}{1 + 0,105\phi(t)} \right)$  express the amount of moles of oxygen, per unit volume, that have chemically reacted into some combustion gases. Multiplication with the volume flow gives the

amount of moles of oxygen that have reacted away. Finally this value is multiplied with the 'Huggett' factor. Huggett stated that regardless of the fuel burnt roughly a same amount of heat is released.

The volume flow of the exhaust system, normalized at 298 K,  $V_{D298}(t)$  is given by

$$V_{D298}(t) = cA \frac{k_t}{k_\rho} \sqrt{\frac{\Delta p(t)}{T_{ms}(t)}} \quad (2)$$

where

$$c = \sqrt{(2T_0 / \rho_0)} = 22,4 \text{ [K}^{0,5} \cdot \text{m}^{1,5} \cdot \text{kg}^{-0,5} \text{]}$$

A is the area of the exhaust duct at the general measurement section (m<sup>2</sup>);

$k_t$  is the flow profile correction factor; converts the velocity at the height of the bi-directional probe in the axis of the duct to the mean velocity over the cross section of the duct;

$k_\rho$  is the Reynolds number correction for the bidirectional probe, taken as 1,08;

$\Delta p(t)$  is the pressure difference over the bi-directional probe (Pa);

$T_{ms}(t)$  is the temperature in the measurement section (K).

The oxygen depletion factor  $\phi(t)$  is defined as

$$\phi(t) = \frac{\bar{x}O_2(30s...90s)\{1 - xCO_2(t)\} - xO_2(t)\{1 - \bar{x}CO_2(30s...90s)\}}{\bar{x}O_2(30s...90s)\{1 - xCO_2(t)\} - xO_2(t)} \quad (3)$$

where

$xO_2(t)$  is the oxygen concentration in mole fraction;

$xCO_2(t)$  is the carbon dioxide concentration in mole fraction;

Ys...Zs mean taken over interval Y s to Z s.

The mole fraction of oxygen in ambient air, taking into account the moisture content, is given by

$$x_{a_{O_2}} = \bar{x}O_2(30s...90s) \left[ 1 - \frac{H}{100p} \exp \left\{ 23,2 - \frac{3816}{T_{ms}(30s...90s) - 46} \right\} \right] \quad (4)$$

where

$xO_2(t)$  is the oxygen concentration in mole fraction;

H is the relative humidity (%);

p is the ambient pressure (Pa);

$T_{ms}(t)$  is the temperature in the general measurement section (K).

Since we are interested in the HRR contribution of the specimen only, the HRR contribution of the burner should be subtracted. An estimate of the burner contribution  $HRR_{burner}(t)$  is taken as the  $HRR_{total}(t)$  during the base line period preceding the thermal attack to the specimen. A mass flow controller ensures an identical HRR through the burners before and after switching from primary to the main burner. The average HRR of the burner is calculated as the average  $HRR_{total}(t)$  during the base line period with the primary burner on ( $210 \text{ s} \leq t \leq 270 \text{ s}$ ):

$$\text{HRR}_{\text{av\_burner}} = \overline{\text{HRR}}_{\text{total}}(210 \text{ s} \dots 270 \text{ s}) \quad (5)$$

where

**HRR<sub>av\_burner</sub>** is the average heat release rate of the burner (kW);

**HRR<sub>total</sub>(t)** is the total heat release rate of specimen and burner (kW).

HRR of the specimen

In general, the HRR of the specimen is taken as the global HRR,  $\text{HRR}_{\text{total}}(t)$ , minus the average HRR of the burner,  $\text{HRR}_{\text{av\_burner}}$ :

For  $t > 312 \text{ s}$ :

$$\text{HRR}(t) = \text{HRR}_{\text{total}}(t) - \text{HRR}_{\text{av\_burner}} \quad (6)$$

where:

**HRR(t)** is the heat release rate of the specimen (kW);

**HRR<sub>total</sub>(t)** is the global heat release rate of specimen and burner (kW);

**HRR<sub>av\_burner</sub>** is the average heat release rate of the burner (kW).

During the switch from the primary to the main burner at the start of the exposure period, the total heat output of the two burners is less than  $\text{HRR}_{\text{av\_burner}}$  (it takes some time for the gas to be directed from one burner to the other). Formula (24) gives negative values for  $\text{HRR}(t)$  for at most 12 s (burner switch response time). Such negative values and the value for  $t = 300 \text{ s}$  are set to zero, as follows:

For  $t = 300 \text{ s}$ :

$$\text{HRR}(300) = 0 \text{ kW} \quad (7)$$

For  $300 \text{ s} < t \leq 312 \text{ s}$ :

$$\text{HRR}(t) = \max. \{0 \text{ kW}, \text{HRR}_{\text{total}}(t) - \text{HRR}_{\text{av\_burner}}\} \quad (8)$$

where

**max.[a, b]** is the maximum of two values a and b.

Calculation of  $\text{HRR}_{30\text{s}}$

In view of the calculation of the FIGRA index, the HRR data are smoothened with a 'flat' 30 s running average filter using 11 consecutive measurements:

$$\text{HRR}_{30\text{s}}(t) = \frac{0,5\text{HRR}(t-15) + \text{HRR}(t-12) + \dots + \text{HRR}(t+12) + 0,5\text{HRR}(t+15)}{10} \quad (9)$$

where

$\text{HRR}_{30\text{s}}(t)$  is the average of  $\text{HRR}(t)$  over 30 s (kW);

$\text{HRR}(t)$  is the heat release rate at time  $t$  (kW).

### 1.2.3.2 Calculation of THR(t) and THR<sub>600s</sub>

The total heat release of the specimen  $\text{THR}(t)$  and the total heat release of the specimen in the first 600 s of the exposure period ( $300 \text{ s} \leq t \leq 900 \text{ s}$ ),  $\text{THR}_{600\text{s}}$ , are calculated as follows:

$$\text{THR}(t_a) = \frac{1}{1000} \sum_{300s}^{t_a} \text{HRR}(t) \times 3 \quad (10)$$

$$\text{THR}_{600s} = \frac{1}{1000} \sum_{300s}^{900s} \text{HRR}(t) \times 3 \quad (11)$$

whereby the factor 1 000 is introduced to convert the result from kJ into MJ and the factor 3 stands for the time interval in-between 2 consecutive measurements,

and where

$\text{THR}(t_a)$  is the total heat release of the specimen during the period  $300 \text{ s} \leq t \leq t_a$  (MJ);

$\text{HRR}(t)$  is the heat release rate of the specimen (kW);

$\text{THR}_{600s}$  is the total heat release of the specimen during the period  $300 \text{ s} \leq t \leq 900 \text{ s}$  (MJ); (equal to  $\text{THR}(900)$ ).

### 1.2.3.3 Calculation of $\text{FIGRA}_{0,2\text{MJ}}$ and $\text{FIGRA}_{0,4\text{MJ}}$ (Fire growth rate indices)

The FIGRA is defined as the maximum of the ratio  $\text{HRR}_{\text{av}}(t)/(t - 300)$ , multiplied by 1 000. The ratio is calculated only for that part of the exposure period in which the threshold levels for  $\text{HRR}_{\text{av}}$  and  $\text{THR}$  have been exceeded. If one or both threshold values are not exceeded during the exposure period, FIGRA is equal to zero. Two combinations of threshold values are used, resulting in  $\text{FIGRA}_{0,2\text{MJ}}$  and  $\text{FIGRA}_{0,4\text{MJ}}$ .

- a) The average of HRR,  $\text{HRR}_{\text{av}}$ , used to calculate the FIGRA is equal to  $\text{HRR}_{30s}$ , with the exception of the first 12 s of the exposure period. For data points in the first 12 s, the average is taken only over the widest possible symmetrical range of data points within the exposure period:

$$\text{For } t = 300 \text{ s: } \text{HRR}_{\text{av}}(300 \text{ s}) = 0 \quad (12)$$

$$\text{For } t = 303 \text{ s: } \text{HRR}_{\text{av}}(303 \text{ s}) = \overline{\text{HRR}}(300 \text{ s} \dots 306 \text{ s}) \quad (13)$$

$$\text{For } t = 306 \text{ s: } \text{HRR}_{\text{av}}(306 \text{ s}) = \overline{\text{HRR}}(300 \text{ s} \dots 312 \text{ s}) \quad (14)$$

$$\text{For } t = 309 \text{ s: } \text{HRR}_{\text{av}}(309 \text{ s}) = \overline{\text{HRR}}(300 \text{ s} \dots 318 \text{ s}) \quad (15)$$

$$\text{For } t = 312 \text{ s: } \text{HRR}_{\text{av}}(312 \text{ s}) = \overline{\text{HRR}}(300 \text{ s} \dots 324 \text{ s}) \quad (16)$$

$$\text{For } t \geq 315 \text{ s: } \text{HRR}_{\text{av}}(t) = \text{HRR}_{30s}(t) \quad (17)$$

- b) Calculate  $\text{FIGRA}_{0,2\text{MJ}}$  for all  $t$  where:

$$(\text{HRR}_{\text{av}}(t) > 3 \text{ kW}) \text{ and } (\text{THR}(t) > 0,2 \text{ MJ}) \text{ and } (300 \text{ s} < t \leq 1\,500 \text{ s});$$

and calculate  $\text{FIGRA}_{0,4\text{MJ}}$  for all  $t$  where:

$$(\text{HRR}_{\text{av}}(t) > 3 \text{ kW}) \text{ and } (\text{THR}(t) > 0,4 \text{ MJ}) \text{ and } (300 \text{ s} < t \leq 1\,500 \text{ s});$$

both using:

$$\text{FIGRA} = 1000 \times \max \left( \frac{\text{HRR}_{\text{av}}(t)}{t - 300} \right) \quad (18)$$

where:

**FIGRA** is the fire growth rate index

**HRR<sub>av</sub>(t)** is the average of HRR(t) as specified in a) (kW);

As a consequence, specimens with a HRR<sub>av</sub> not exceeding 3 kW during the total test have FIGRA values FIGRA<sub>0,2MJ</sub> and FIGRA<sub>0,4MJ</sub> equal to zero. Specimens with a THR not exceeding 0,2 MJ over the total test period have a FIGRA<sub>0,2MJ</sub> equal to zero and specimen with a THR not exceeding 0,4 MJ over the total test period have a FIGRA<sub>0,4MJ</sub> equal to zero.

## 2 Uncertainty

### 2.1 Introduction

According to EN ISO/IEC 17025 [3], which sets out the general requirements for the competence of testing and calibration laboratories, and EN ISO 10012 [7], which sets out the requirements for assuring the quality of measuring equipment, uncertainties shall be reported in both testing and calibration reports.

The general principles for evaluating and reporting uncertainties are given in the ISO Guide to the Expression of Uncertainty in Measurement (GUM) [6], but need to be applied to the specific case of fire testing. Due to the harmonization of fire testing in the European Community (EUROCLASSES; EN 13501-1 [21]) and the pressure on testing laboratories to operate under accreditation, this is becoming even more important.

It is of common knowledge that measurement results are never perfectly accurate. In practice the sources of systematic and random errors which can affect the results of measurement are numerous, even for the most careful operators. To describe this lack of perfection, the term 'uncertainty' is used. Although the concept of uncertainty may be related to a 'doubt', in the real sense the knowledge of uncertainty implies increased confidence in the validity of results.

The qualitative concept of accuracy is quantified by the uncertainty which varies inversely 'proportioned' to it. Accuracy consists of both trueness and precision as shown in Figure 1. A numerical measure for precision is the standard deviation, while trueness is expressed numerically by the systematic error or the bias.

It is considered good practice to eliminate any systematic errors. However, if the value of a systematic error is unknown it may be regarded as a random error. Random errors result in a spread of the values and can usually be reduced by increasing the number of observations. Its expectation or expected value is zero.