EGOLF
SBI THERMAL ATTACK MEASUREMENTS
ROUND ROBIN 2

Report reference : 27 ENF 6704/ CEMATE/1

<table>
<thead>
<tr>
<th>authors</th>
<th>checkers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valérie RUMBAU</td>
<td>Eric GUILLAUME</td>
</tr>
<tr>
<td>Eric GUILLAUME</td>
<td>Alain SAINRAT</td>
</tr>
<tr>
<td>Alain SAINRAT</td>
<td></td>
</tr>
</tbody>
</table>

Head of project : Christophe BLANC / Valérie RUMBAU (LNE/CEMATE)

Team: Michèle DESENFANT / Catherine YARDIN (LNE/DG)
Eric GUILLAUME / Christian MOLINIER / Alain SAINRAT (LNE/CEMATE)
Martin LIEVRE (LNE/CMSI)
# Table of contents:

I. **INTRODUCTION** ................................................................................................................... 5  
   A. Object.................................................................................................................................. 5  
   B. General principle ................................................................................................................ 5

II. **HFM CALIBRATION** ........................................................................................................ 6  
    A. Calibration Method .......................................................................................................... 6  
    B. Experimental conditions ................................................................................................. 7  
    C. Cycle of measurements ................................................................................................. 8

III. **TEST PROCEDURE** ........................................................................................................... 8  
    A. Measurement holes .................................................................................................... 8  
    B. Acquisition method .................................................................................................... 9

IV. **RESULTS** ........................................................................................................................ 10  
    A. Data File.................................................................................................................... 10  
    B. Results of heat flux measurements .............................................................................. 12  
    C. Statistical analysis ..................................................................................................... 12  
       1. Principle of the statistical analysis ............................................................................ 12  
       2. Results of this analysis ......................................................................................... 13  
       3. Explanation of these results .................................................................................. 14  
       4. Conclusion............................................................................................................... 15

V. **INTERPRETATION** ......................................................................................................... 16  
    A. Simulation study of SBI ............................................................................................ 16  
       1. Modelling tool ......................................................................................................... 16  
       2. Modelling options of SBI test ............................................................................... 16  
       3. Global validation ................................................................................................... 17  
       4. Local validation ................................................................................................... 18  
    B. Analyse of the results ................................................................................................. 21  
    C. Conclusion from the FDS simulation .......................................................................... 23

VI. **Conclusion** ..................................................................................................................... 24

Annexes :  

Annex A 1: Annex D2 of the EN 13823 ................................................................................. 26  
Annex A 2: Calibration certificate of fluxmeter n° 135051 .................................................. 27  
Annex A 3: Coefficients gave to the laboratory in function of time .................................... 31  
Annex A 1: Results (last 60 seconds) of every laboratories at each position ................. 35  
Annex A 2: Definition of statistical parameters evaluated in the analysis ...................... 39  
Annex A 3: Principle of Cochran’s and Grubbs’ homogeneity tests ............................... 40  
Annex A 4: New annex D2 of the EN 13823 ....................................................................... 42
Statement of tables, graphs, equation and figures:

Table 1: List of participating laboratories ................................................................. 6
Table 2: Results of initial calibration ........................................................................ 7
Table 3: Example of sheet data .................................................................................. 11
Table 4: Data send by the laboratories (W/cm²) ..................................................... 13
Table 5: Data used in the analysis ........................................................................... 14

Graph 1: HFM calibration curve ................................................................................ 7
Graph 2: Diagram of results ..................................................................................... 12

Equation 1: Regression line of the calibration .......................................................... 6

Figure 1: Points of measurements located on the large wing in SiCa at (x;y) .......... 9
Figure 2: Thermal picture long wing burner out (ceramic burner 30 kW) .......... 9

References:

HFCAL final report: title

Mandat CEN TC127/TG4

Previously documents:
  “EGOLF SBI Round Robin, thermal attack control”
  “EGOLF-CEPMC SBI RR2 exercise”

EN 13823: Building products excluding floorings exposed to the thermal attack by a single burning item

NF ISO 5725-2: Accuracy (trueness and precision) of measurement methods and results, Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method

ISO/Ts 14934-1:2002: Reaction-to-fire tests - Calibration and use of radiometers and heat flux meters - Part 1: general principles
I. INTRODUCTION

A. Object

This project is included into a global way of improvement of SBI test method which is realizing by the CEN TC 127/WG4. The objective of this CEN TC 127 is to propose amendments to the EN 13823. In order to reach this objective. Different items of improvements have been identified. One of them is the thermal attack measurement procedure which is described in “annex D2” (see annex A 1 of this paper) in the SBI standards (EN 13823). In order to improve the repeatability and the reproducibility of the SBI test method, some European laboratories assume that it is essential to control the heat flux level delivered by the main burner of the European test to the sample. Previously, a significant study has been realized, in 1998. Nevertheless an insufficient number of laboratories have participated to evaluate accurate repeatability and reproducibility.

The objective of this study is to organize a new round robin in order to verify the repeatability and the reproducibility of the SBI thermal attack and to determine which parameters can influence this measurement.

At the end of this study an improved protocol to check the thermal attack will be proposed and included in the “annex D2” of EN 13823 standard.

B. General principle

LNE managed the organisation of this project: procedure, heat flux meter, results checking and reporting.

Every laboratory checked the thermal attack of his own SBI bench according to the “annex D2” of the EN 13823 and to additional instructions (described in paragraph II-HFM calibration).

To measure the heat flux, a unique water cooled Gardon Gage heat flux meter of 25.5 mm diameter was send to all participating laboratories after a calibration in LNE (see annex A 2). After measurements, the HFM¹ was sent back to LNE with the tests results. A re-calibration of the HFM was done by LNE before its sending to the next laboratory. The routine was carried out for every participants’ laboratory. The list of the 10 participants is done in the table 1. There are 6 french laboratories and 4 foreign (Germany, Italy and Nederland).

¹ HFM : Heat Flux Meter
Table 1: List of participating laboratories

<table>
<thead>
<tr>
<th>LABORATORIES</th>
<th>CONTACTS</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASF</td>
<td>Joachim KOCH</td>
<td>Munster - GERMANY</td>
</tr>
<tr>
<td>CSTB</td>
<td>Bruce Le MADEC</td>
<td>Champs sur Marne - FRANCE</td>
</tr>
<tr>
<td>CTBA</td>
<td>Jean-Marie GAILLARD</td>
<td>Bordeaux - FRANCE</td>
</tr>
<tr>
<td>IFTH</td>
<td>Jean-Marc ORAISON</td>
<td>Lyon Ecully - FRANCE</td>
</tr>
<tr>
<td>KNAUF</td>
<td>Xavier ALLANIC</td>
<td>Ungersheim - FRANCE</td>
</tr>
<tr>
<td>LNE</td>
<td>Christophe BLANC Christian MOLINIER</td>
<td>Trappes Elancourt - FRANCE</td>
</tr>
<tr>
<td>LSF</td>
<td>Silvio MESSA</td>
<td>Montano Lucino (CO) - ITALY</td>
</tr>
<tr>
<td>MPA NRW</td>
<td>Sven KUHNEN Hendrik RADEMACHER</td>
<td>Erwitte - GERMANY</td>
</tr>
<tr>
<td>SME</td>
<td>Marie Claude THIBAUDET</td>
<td>Vert le Petit - FRANCE</td>
</tr>
<tr>
<td>TNO</td>
<td>Frans PAAP</td>
<td>Delft – THE NEDERLANDS</td>
</tr>
</tbody>
</table>

II. HFM CALIBRATION

The HFM is a water cooled Gardon Gage, model 64-10-20, without saphir window. Its serial number is Nr135051, manufactured by Medtherm Corporation (USA).

A. Calibration Method

The method consists to set successively a laboratory standard heat flux meter the heat flux meter to calibrated in front of a radiant source allowing to generate irradiances between 3.5 and 7 W/cm². Previously, the standard heat flux meter was calibrated using a reference blackbody cavity that was linked to the national standard temperature. In succession, the 2 HFM are put in front of a radiant emitter able to deliver flux from 3.5 to 7 W/cm² (see equation 1, Graph 1 and Table 2). For three time the reference unit output and the working unit output are successively measured for each level of incident flux. The calibration certificate is put in annex A.2.

Equation 1: Regression line of the calibration

\[ F = a + b*U = 0.9761*U \]
- \( F \): flux (W/cm²)
- \( a \): coefficient (W/cm²)
- \( b \): coefficient (W/[cm².mV])
- \( U \): tension (mV)
Graph 1: HFM calibration curve

![HFM calibration curve graph]

\[ y = 0.9761x \]
\[ R^2 = 0.9997 \]

Table 2: Results of initial calibration

<table>
<thead>
<tr>
<th>Density of incident flux (W/cm²)</th>
<th>Fluxmeter voltage (mV)</th>
<th>uncertainty of measurement = (2 * uncertainty-type) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.41</td>
<td>3.32</td>
<td>4.5</td>
</tr>
<tr>
<td>4.20</td>
<td>4.09</td>
<td>4.0</td>
</tr>
<tr>
<td>4.93</td>
<td>4.80</td>
<td>3.8</td>
</tr>
<tr>
<td>5.63</td>
<td>5.49</td>
<td>4.0</td>
</tr>
<tr>
<td>6.35</td>
<td>6.20</td>
<td>3.7</td>
</tr>
<tr>
<td>7.02</td>
<td>6.86</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The uncertainty-types was calculated in function of reference standard, calibration means, environmental conditions, contribution of calibrated material, repeatability…etc.

B. Experimental conditions

The geometric configuration (source-heat fluxmeter) is the same for the standard heat fluxmeter and the heat fluxmeter to calibrate.

The experimental conditions are:
- Source temperature is between 695°C and 880°C according to the irradiance levels
- Flux meter cooling temperature is 16°C ± 2°C
- Ambient temperature in the test room is 21°C ± 2°C.
- Relative humidity is 50 ± 5%
C. Cycle of measurements

For each irradiance level, the succession of operations is:
1) Reference voltage measurement using the standard flux meter
2) Voltage measurement of the calibrated flux meter
3) Reference voltage measurement using the standard flux meter.

The procedure is repeated 3 times per level. The levels 3.5 and 7 W/cm² are calibrated. The annex A3 give all the calibrations made on the HFM. The regression (see Equation 1) give the 2 coefficients “a” and “b” which are sent to the next laboratory for the future measures.

III. TEST PROCEDURE

A. Measurement holes

The SBI trolley was equipped with usual Calcium Silicate backing board (nominal density: 870 ± 50 kg/m³, thickness: 11 ± 2 mm, euroclass: A2) in standard corner configuration as described in the annex 1 of the report “EGOLF SBI Round Robin, thermal attack control” (instructions for the thermal attack measurement). Five experiments must be done for every 3 holes stipulated in the “annex 1” previously cited. During each experiment, a ceramic fibre plug (or mineral wool) shall be used to close the two unused holes. Before starting a test, the flux meter shall be connected with the acquisition data system used in the laboratory and with the water supply system; then it shall be inserted in the selected hole, from the back of the silicate board, with the black target side flush with the exposed face of the board.

Three holes have been choosing, in the long wing, to make heat flux measurements. Holes of diameter 25.5 mm have been done in the backing board at the 3 selected holes (see Figure 1).

- Position 1: 8 cm from the corner and 16 cm from the upper edge of the burner
- Position 2: 8 cm from the corner and 75 cm from the upper edge of the burner
- Position 3: 20 cm from the corner and 30 cm from the upper edge of the burner

The positions chosen were affected by the study of the improvement of burner-system. A thermographic measuring equipment was used during these previous work to locate the maximum irradiance spot on calcium silicate wings of the corner (see Figure 2). The localisation of the heartiest point has been done by operating burner at nominal propane flow until a steady thermal picture of the flame was seen. Then the burner was shut off and the warmest point quickly localised (using a pointer to mark).
Figure 1: Points of measurements located on the large wing in SiCa at (x;y)

Figure 2: Thermal picture long wing burner out (ceramic burner 30 kW)

This infra-red picture was taken just after the burner extension.

B. Acquisition method

The experiments are done in accordance with the following instructions:

1) Set SBI volume flow system in standard test conditions (0.60 ± 0.05 m³/s)
2) Control the temperature stability of exhaust duct using T1, T2 and T3 thermocouples
3) Ignite the pilot flames of both burners
4) Ignite the auxiliary burner at normal operating flow (647 mg/s propane mass flow), wait for 180 s
5) When 180 s are elapsed, start data acquisition system (step = 3s), ignite the main burner (the auxiliary burner is turned off) at normal operating flow and start time measurements, this is t=0
6) At t=0 + 300s stop the main burner and data acquisition system.

Five experiments are done for each of the 3 holes of the HFM. The acquisition is made during 300 seconds, and only the average of the 60 seconds are taken into account.
IV. RESULTS

A. Data File

After experiments, a copy of the data from $t = 0$ to $t = 300s$ is recorded and saved in the specific Excel sheets file (see Table 3). When all the tests are completed (5 replicates for each of the 3 spots), the data file is sent to LNE.
Table 3: Example of sheet data

<table>
<thead>
<tr>
<th>Sample Data in the order (0 to 300)</th>
<th>Result in the order (0 to 300)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0100</td>
<td>0.0011</td>
</tr>
<tr>
<td>0.0190</td>
<td>0.0012</td>
</tr>
<tr>
<td>0.0280</td>
<td>0.0013</td>
</tr>
<tr>
<td>0.0370</td>
<td>0.0014</td>
</tr>
<tr>
<td>0.0460</td>
<td>0.0015</td>
</tr>
<tr>
<td>0.0550</td>
<td>0.0016</td>
</tr>
<tr>
<td>0.0640</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

[Graph showing the data trend]
B. Results of heat flux measurements

The results are presented in Graph 2. The average heat flux level about the 3 measurements spots is given for each laboratory. The detailed results of experiments are given on Table 4 and annex A 4.

Graph 2 : Diagram of results

<table>
<thead>
<tr>
<th>Spot 1 (8x16cm)</th>
<th>Lab 0</th>
<th>Lab 01</th>
<th>Lab 02</th>
<th>Lab 03</th>
<th>Lab 04</th>
<th>Lab 05</th>
<th>Lab 06</th>
<th>Lab 07</th>
<th>Lab 08</th>
<th>Lab 09</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.47</td>
<td>5.23</td>
<td>6.38</td>
<td>5.30</td>
<td>5.50</td>
<td>5.16</td>
<td>5.47</td>
<td>5.46</td>
<td>5.13</td>
<td>5.69</td>
<td></td>
</tr>
<tr>
<td>2.30</td>
<td>2.12</td>
<td>2.39</td>
<td>1.85</td>
<td>1.98</td>
<td>2.03</td>
<td>2.35</td>
<td>2.20</td>
<td>1.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.35</td>
<td>1.53</td>
<td>1.25</td>
<td>1.60</td>
<td>1.46</td>
<td>1.36</td>
<td>1.26</td>
<td>1.42</td>
<td>1.19</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>dates</td>
<td>22/04/04</td>
<td>25/08/04</td>
<td>14/10/04</td>
<td>22/11/04</td>
<td>29/12/04</td>
<td>14/03/05</td>
<td>20/05/05</td>
<td>18/07/05</td>
<td>11/10/05</td>
<td>17/02/06</td>
</tr>
</tbody>
</table>

C. Statistical analysis

1. Principle of the statistical analysis

Statistical analysis is made according to the standard NF ISO 5725-2 (1994) : “Accuracy (trueness and precision) of measurement methods and results – Basic method for the determination of repeatability and reproducibility of a standard measurement method”.

This analysis determines a general mean \((m)\) from all laboratories and the fidelity (repeatability and reproducibility) of method. The repeatability is evaluated by the standard deviation of repeatability \((sr)\) and the limit of repeatability \((r: critical difference between two results from a single laboratory)\). The reproducibility is evaluated by the standard deviation of reproducibility \((sR)\) and the limit of reproducibility \((R: critical difference between two results from two different laboratories)\).

Definitions and calculated formulas of these quantities are quoted in annex A 5.

Mean and precision values are calculated from data after verification of their consistency. Two tests are used to check the consistency of the data : Cochran’s test and Grubbs’ test. These tests are presented in annex A 6.
2. Results of this analysis

The results are analysed separately for each position. They are given in the following Table 4.

After the use of the Cochran’s test and the double Grubbs’ test according to the NF ISO 5725-2 (1994) few results have been eliminated as explained after. The results means and standard deviations of the laboratories computed with the data kept in the analysis are presented in the table 5.

Table 4 : Data send by the laboratories (W/cm²)

<table>
<thead>
<tr>
<th>labo</th>
<th>position 1</th>
<th>position 2</th>
<th>position 3</th>
<th>Mean S. deviation</th>
<th>Mean S. deviation</th>
<th>Mean S. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.45</td>
<td>2.16</td>
<td>1.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5.35</td>
<td>2.43</td>
<td>1.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5.65</td>
<td>2.37</td>
<td>1.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5.49</td>
<td>2.25</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5.39</td>
<td>2.29</td>
<td>1.47</td>
<td>5.466</td>
<td>0.1161</td>
<td>2.3</td>
</tr>
<tr>
<td>1</td>
<td>5.06</td>
<td>2.22</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.56</td>
<td>2.08</td>
<td>2.19**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.98</td>
<td>2.12</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.36</td>
<td>2.05</td>
<td>1.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.19</td>
<td>2.13</td>
<td>1.34</td>
<td>5.23</td>
<td>0.2339</td>
<td>2.12</td>
</tr>
<tr>
<td>2</td>
<td>6.27</td>
<td>2.34</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.33</td>
<td>2.37</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.53</td>
<td>2.48</td>
<td>1.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.38</td>
<td>2.43</td>
<td>1.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.41</td>
<td>2.31</td>
<td>1.26</td>
<td>6.384*</td>
<td>0.0974</td>
<td>2.386</td>
</tr>
<tr>
<td>3</td>
<td>5.54</td>
<td>1.99</td>
<td>1.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.27</td>
<td>1.89</td>
<td>1.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.29</td>
<td>1.79</td>
<td>1.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.33</td>
<td>1.82</td>
<td>1.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.05</td>
<td>1.77</td>
<td>1.64</td>
<td>5.296</td>
<td>0.1746</td>
<td>1.852</td>
</tr>
<tr>
<td>4</td>
<td>5.47</td>
<td>1.86</td>
<td>1.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.63</td>
<td>1.87</td>
<td>1.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.52</td>
<td>1.81</td>
<td>1.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.55</td>
<td>1.73</td>
<td>1.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.35</td>
<td>1.74</td>
<td>1.56</td>
<td>5.504</td>
<td>0.1038</td>
<td>1.802</td>
</tr>
<tr>
<td>5</td>
<td>5.32</td>
<td>1.95</td>
<td>1.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.29</td>
<td>1.93</td>
<td>1.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.27</td>
<td>2.1</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.04</td>
<td>2.01</td>
<td>1.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.86</td>
<td>1.93</td>
<td>1.4</td>
<td>5.156</td>
<td>0.1993</td>
<td>1.984</td>
</tr>
<tr>
<td>6</td>
<td>5.56</td>
<td>1.82</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.56</td>
<td>1.98</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.55</td>
<td>2.14</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.35</td>
<td>2.11</td>
<td>1.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.32</td>
<td>2.09</td>
<td>1.29</td>
<td>5.468</td>
<td>0.1219</td>
<td>2.028</td>
</tr>
<tr>
<td>7</td>
<td>5.28**</td>
<td>2.27</td>
<td>1.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4.91**</td>
<td>2.39</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.39**</td>
<td>2.22</td>
<td>1.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>6.02**</td>
<td>2.68</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.72**</td>
<td>2.2</td>
<td>1.64</td>
<td>5.464</td>
<td>0.4245**</td>
<td>2.352</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>2.33</td>
<td>1.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5.15</td>
<td>2.31</td>
<td>1.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5.01</td>
<td>2.13</td>
<td>1.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5.19</td>
<td>2.12</td>
<td>1.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5.29</td>
<td>2.08</td>
<td>1.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.68</td>
<td>2</td>
<td>1.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.87</td>
<td></td>
<td>1.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.64</td>
<td>1.93</td>
<td>1.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.61</td>
<td>1.87</td>
<td>1.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5.67</td>
<td>1.92</td>
<td>1.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>5.481</td>
<td>2.095</td>
<td>1.379</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Data used in the analysis

Means of the laboratories (W/cm²)

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>position 1</th>
<th>position 2</th>
<th>position 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>5.466</td>
<td>2.300</td>
<td>1.356</td>
</tr>
<tr>
<td>01</td>
<td>5.230</td>
<td>2.120</td>
<td>1.365</td>
</tr>
<tr>
<td>02</td>
<td>6.384</td>
<td>2.386</td>
<td>1.250</td>
</tr>
<tr>
<td>03</td>
<td>5.296</td>
<td>1.852</td>
<td>1.606</td>
</tr>
<tr>
<td>04</td>
<td>5.504</td>
<td>1.802</td>
<td>1.460</td>
</tr>
<tr>
<td>05</td>
<td>5.156</td>
<td>1.984</td>
<td>1.356</td>
</tr>
<tr>
<td>06</td>
<td>5.468</td>
<td>2.028</td>
<td>1.264</td>
</tr>
<tr>
<td>07</td>
<td>-</td>
<td>2.352</td>
<td>1.416</td>
</tr>
<tr>
<td>08</td>
<td>5.128</td>
<td>2.194</td>
<td>1.188</td>
</tr>
<tr>
<td>09</td>
<td>5.694</td>
<td>1.930</td>
<td>1.528</td>
</tr>
</tbody>
</table>

Mean 5.481 2.095 1.379

Standard deviations of the laboratories (W/cm²)

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>position 1</th>
<th>position 2</th>
<th>position 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>0.116</td>
<td>0.105</td>
<td>0.193</td>
</tr>
<tr>
<td>01</td>
<td>0.234</td>
<td>0.064</td>
<td>0.048</td>
</tr>
<tr>
<td>02</td>
<td>0.097</td>
<td>0.069</td>
<td>0.027</td>
</tr>
<tr>
<td>03</td>
<td>0.175</td>
<td>0.090</td>
<td>0.095</td>
</tr>
<tr>
<td>04</td>
<td>0.104</td>
<td>0.065</td>
<td>0.090</td>
</tr>
<tr>
<td>05</td>
<td>0.199</td>
<td>0.073</td>
<td>0.087</td>
</tr>
<tr>
<td>06</td>
<td>0.122</td>
<td>0.131</td>
<td>0.033</td>
</tr>
<tr>
<td>07</td>
<td>-</td>
<td>0.198</td>
<td>0.138</td>
</tr>
<tr>
<td>08</td>
<td>0.123</td>
<td>0.117</td>
<td>0.094</td>
</tr>
<tr>
<td>09</td>
<td>0.102</td>
<td>0.046</td>
<td>0.038</td>
</tr>
</tbody>
</table>

Mean 0.149 0.105 0.098

3. Explanation of these results

- Position 1

The variance of the laboratory N°07 is too high in comparison with the other variances. Using the Cochran’s test, this variance is considered as an outlier. The data of this laboratory are removed from the analysis for this position.

The laboratories N°02 et N°09 give high means. These means are considered as straggler (not outlier) with the double Grubbs’ test. The two laboratories are retained in the analysis.
The average heat flux of the flame computed with 9 laboratories is $m = 5.481 \text{ W/cm}^2$.

The repeatability standard deviation is $\text{Sr} = 0.149 \text{ W/cm}^2$ and the limit of the repeatability $r = 0.416 \text{ W/cm}^2$ or 7.6% of the mean.

The reproducibility standard deviation is $\text{Sr} = 0.408 \text{ W/cm}^2$ and the limit of the reproducibility is $R = 1.142 \text{ W/cm}^2$ or 21% of the mean.

- **Position 2**
  The standard deviation of the laboratory N°01 is rather high compared to those of the other laboratories. This standard deviation is a straggler (not an outlier) with the Cochran’s test. Then the laboratory is retained in the analysis.

  The mean heat flux computed with 10 laboratories is $m = 2.095 \text{ W/cm}^2$.

  The repeatability standard deviation is $\text{Sr} = 0.105 \text{ W/cm}^2$ and the repeatability value is $r = 0.293 \text{ W/cm}^2$ or 14% of the mean.

  The reproducibility standard deviation is $\text{Sr} = 0.229 \text{ W/cm}^2$ and the reproducibility value is $R = 0.641 \text{ W/cm}^2$ or 31% of the mean.

- **Position 3**
  The standard deviation of the laboratory N°01 is higher than those of the other laboratories. It is due to an individual value 2.19 W/cm² considered as an outlier with the Grubbs’ test. This outlier 2.19 W/cm² is rejected then the mean and the standard deviation of the laboratory are computed with only 4 values.

  Also the laboratory N°00 gives a rather high standard deviation. This standard deviation is considered as a straggler (not an outlier) with the Cochran’s test.

  The mean heat flux computed with 10 laboratories is $m = 1.379 \text{ W/cm}^2$.

  The repeatability standard deviation is $\text{Sr} = 0.099 \text{ W/cm}^2$ and the limit of repeatability is $r = 0.276 \text{ W/cm}^2$ or 20% of the mean.

  The reproducibility standard deviation is $\text{Sr} = 0.157 \text{ W/cm}^2$ and the limit of reproducibility is $R = 0.440 \text{ W/cm}^2$ or 32% of the mean.

4. **Conclusion**

  Repeatability varies with the level of the heat flux. The relative repeatability is 20% at a heat flux of about 1.4 W/cm² and falls at 8% for a heat flux of 5.5 W/cm².

  A laboratory effect exists for all positions. The relative reproducibility varies to 32% at a heat flux of 1.4 W/cm² to 21% at a heat flux at 5.5 W/cm².
V. INTERPRETATION

The difference of the repeatability between the three positions of the fluxmeter can be explained by the stability of the flame of the burner or by the difficulty to measure the flux according to the level of the flux.

The difference of the reproducibility between the three positions of the fluxmeter can be explained by the difference of the shape of the flame between the laboratories or by the difficulty to measure the flux according to the level of the flux.

In order to validate these assumptions, CFD$^2$ simulations were performed. In the future, simulation should be run with a fine mesh to study the sensibility of the geometry of the apparatus (inside and outside of the room) as well as the air circulation condition on the flame shape.

A. Simulation study of SBI

1. Modelling tool

In this study, SBI test was modelled by Fire Dynamics Simulator (FDS) version 4.0.7. This tool is a Computed Fluid Dynamics model coupled with a chemical modelling of the combustion. The model allows solving Navier-Stokes low Mach number system of equations. In the options chosen for this study, turbulence was treated by a LES – fixed Smagorinsky number approach. In these conditions, turbulence bigger than grid cell is directly calculated and internal turbulence is modelled by a diffusive term based on a Smagorinsky constant.

Combustion was modelled following a Mixture fraction approach. This kind of simulation don’t provide acute view of heat generation in flames, but estimate it by considering that flame is at the interface between oxygen rich and fuel rich cells. In this case, heat generation is limited to a thin surface and fuel and oxygen cannot coexist in the same cell. This option provides a modelling of combustion in only one step and an infinitely fast reaction. It provides highest calculation times, but a bad spatial modelling of the flame.

2. Modelling options of SBI test

SBI was modelled considering that propane diffusion flame is applied on a calcium silica backing board, initially at 20°C. The propane diffusion burner produces a heat release rate of 30.7 kW during 300 seconds. Calculation domain chosen represents a volume of 1.04 m x 1.04 m x 1.75 m for 139 968 cells. In the zone of flame, cells are thin enough, so that their shape is cubic with a side of 2 cm. Exhaust system was reproduced too, in order to have comparable wind speeds in modelling and in real world.

Calcium silica properties were coming from LNE’s databases, with information on thermal conductivity and heat capacity of the product up to 800°C. The main difficulties of these simulations are:

- The usage of a Mixture Fraction model to represent a detailed shape of flame, because of the limitations cited of such model to represent thin flame details;
- The usage of a parallelepipedic numerical grid to represent a triangular burner, who produces geometrical approximations on burner modelling.

---

2 Computed Fluid Dynamics
SBI modelling, figuring burner, Calcium silica and measurement points of the RR is presented below:

3. Global validation

The preliminér validation is performed on global mass and energy balances. Burner modelised has to reproduce a total heat release rate of (30,7 ± 2,0) kW. Results and their comparison with measurements, are plotted hereunder:

![Graph showing total calorific flow comparison: experimental vs calculated values]

\[ \text{Débit calorifique total : comparaison essai / simulation} \]

In both numerical and experimental cases, averages are in the tolerance of the standard. Nevertheless, standard deviation on experimental measurement is more important than in simulation. Experimental HRR value is (29,8 ± 4,1) and numerical HRR value is (31,1 ± 2,0) kW. Simulation provides a good agreement with experimental and theoríc value, in spite of the problem of geometric discretization of the burner.

Note: In the experimental value, the burner shows a kinetic of increase of HRR value. This phenomenon is linked to the response curve of the oxygen analyser and to the gaseous diffusion between flame and sampling point. These both phenomenon are not corrected in experimental measures. Only a response time is considered and values are shifted for oxygen measurement.
4. Local validation

Local validation is given both on five points of temperature measurement and heat flux measurement. These points are placed on large SBI wing, as follows:

- Spot 1 is placed 8 cm horizontally and 16 cm vertically from the origin (Heat flux + temperature);
- Spot 2 is placed 8 cm horizontally and 75 cm vertically from the origin (Heat flux + temperature);
- Spot 3 is placed 20 cm horizontally and 30 cm vertically from the origin (Heat flux + temperature);
- Spot 4 is placed 8 cm horizontally and 30 cm vertically from the origin (Temperature);
- Spot 5 is placed 8 cm horizontally and 45 cm vertically from the origin (Temperature);

Measures are taken and compared to IR-thermography 30 seconds after the extinction of the burner. The corresponding IR-thermography picture was presented previously.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot 1:</td>
<td>(370 ± 10) °C</td>
</tr>
<tr>
<td>Spot 2:</td>
<td>&lt; 280 °C</td>
</tr>
<tr>
<td>Spot 3:</td>
<td>&lt; 280 °C</td>
</tr>
<tr>
<td>Spot 4:</td>
<td>(350 ± 10) °C</td>
</tr>
<tr>
<td>Spot 5:</td>
<td>(330 ± 10) °C</td>
</tr>
</tbody>
</table>

Observations:

The cold area in the bottom of the angle, near the burner, is linked to the absence of air in this region. In consequence, there is no combustion in this area. This phenomenon is well reproduced by the calculation. Validation of temperature is difficult for many points because of the uncertainties of measurement, but calculation shows a high gradient of temperature.
close to many points of measurement. Only spot 1, spots 4 and 5 are easily compared and reproduced by calculation. Spots 2 and 3 are in a region of high temperature gradient and can be reproduced with a bad accuracy because of spatial discretization.

Calculation of the temperature of calcium silica at the position of measurements, quantity experimentally not allowed, is presented hereunder.

This picture and this chart proves that thermal equilibrium of the calcium silica was not done for spots 1 and 3, where spot 2 seemed to be more stable. This data can have a big influence on round-robin results, because it shows the sensitivity to the initial conditions of temperature of backing boards during the experimental measurements.
Validation on heat fluxes measurement is done for the three points and analyzed in the table below. Experimental values come from present round-robin and after the statistic analysis. The uncertainty given is two times the reproducibility standard deviation. These values correspond to the average measurement of a water cooled gauge. The numerical data is the net heat flux for a cold wall at a temperature of 20°C. Both measurements are considered as averages between the 4th and the 5th minutes of a 5 minutes heating period.

<table>
<thead>
<tr>
<th>Experimental data</th>
<th>Calculated data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot 1</td>
<td>(54.81 ± 4.17) kW/m²</td>
</tr>
<tr>
<td>Spot 2</td>
<td>(20.95 ± 2.94) kW/m²</td>
</tr>
<tr>
<td>Spot 3</td>
<td>(13.79 ± 2.74) kW/m²</td>
</tr>
</tbody>
</table>

The uncertainty shown for experimental data is equal to 2.8 times the standard deviation of reproducibility.

Considering the uncertainty, the value measured on spot 1 is well reproduced, but this agreement decrease for spot 2 and is out of range for spot 3. These disagreements are linked to a choice of the measurement point close to the limit of the flame for the last two points, and to the bias generated by HFM measurements on fire conditions. It can partially explain the trueness and the reproducibility measured experimentally.
B. Analyse of the results

Analyse of numerical values provides information on repartition of heat between convection and radiation. It shows that trueness of the measurement is difficult to assume for spots 2 and 3. Especially in spot 2, convective part is important in comparison with calibration conditions. Figure below presents heat flux for a cold wall calculated for each point of the surface of the exposed panels of calcium silica.

Heat flux measured for a cold wall or a HFM at 300 s

Graduation marks are separated by 2 cm horizontally and vertically. This distance corresponds to the spatial discretization of the calculation. Calculation shows a thermal attack very variable in the space at the limits of the flame, and a central area of about 50 kW/m².

The numerical results can explain noise on the signal, especially for spots 2 and 3, because they are in the limit of the flame. They show that the maximum of the thermal attack is located close to the corner, forming two rectangular basis triangular shapes, approximately symmetrical in each wing. The hypotenuse of these shapes is variable because of flame movements, but the both other sides are stable.

Calculation gave a thermal attack of about 45 to 55 kW/m² in this area, and a surface impacted of about 0.22 m² per wing. An interesting think is that the thermal attack level is lower in the regions of the corner and of the position of the jointure (20 cm from the corner) chosen for the tests of some products families according to CPD.

The calculation can explain standard deviation of the measurements and so indicates a possible effect of bench more important for spots 2 and 3 than for spot 1. Trueness of the measurement can be questioned.

The quantities calculated are:
- Wall temperature $T_w$
- Radiative heat flux $q_r^r$
- Convective heat flux $q_c^r = h(T_g - T_w)$ with $T_g$: temperature of surrounding gas and $h$ given by $h = 0.95\left(T_g - T_W\right)^{1/3}$ for a vertical exposition
- Incident heat flux, given by: $q_{\text{incident}}^r = \frac{q_r^r}{\varepsilon} + \frac{q_r^g}{\varepsilon} + \sigma T_w^4$
- Gauge heat flux, given by: $q_{\text{fluxmeter}}^g = \frac{q_r^r}{\varepsilon} + \frac{q_r^g}{\varepsilon} + h(T_g - T_0) + \sigma(T_g^4 - T_0^4)$, with $T_0$ temperature of cooled face of the fluxmeter, chosen as equal to 20°C.
Net radiation and total convection are presented in figures below:

Radiation plot (net radiative flux for Calcium silica) shows that few regions of the walls contribute to the emission of radiation, because calcium silica is heated, in comparison with gauge heat flux measurement. Convective heat flux analyse shows that at the basis of the flame, wall is cooled by fresh air, and by propane in the region inside the flame. On the other parts, the sign of the convective flux is inverted.
Incident heat flux corresponds to levels comparable with gauge heat flux measured. Analyse of the ratios of convection and radiation, and other quantities from the 4\(^{th}\) minute to the 5\(^{th}\) are presented in chart and table below:

Values are averaged from 4\(^{th}\) to 5\(^{th}\) minute of the calculation. Calculation shows that for spot 1, about 85% of the net heat flux comes from radiation if calcium silica is considered.

### C. Conclusion from the FDS simulation

These FDS simulations show that
- the good repeatability of the flux measurement on the position 1 is probably due to the good stability of the hottest zone of the flame.
- Its trueness is probably good because the stability of the hot zone and the heat is principally due to the radiation.
- The bad repeatability of the flux measurement on the positions 2 and 3 is probably due to the bad stability of the edge of the flame

\(^{(1)}\) For this spot, convection corresponds to a cooling of the calcium silica. Heating comes only from radiation
Its trueness is probably bad because the stability of the hot zone and a big part of the heat is due to the convection
- The good reproducibility of the flux measurement on the position 1 is probably due to the good reproducibility of the hottest zone of the flame between the laboratories
- The bad reproducibility of the flux measurement on the positions 2 and 3 is probably due to the bade reproducibility of the shape of the envelope of the flame.

VI. Conclusion

This study has shown that the thermal attack on the specimen from the flame of the burner has a very important thermal gradient from the centre of the flame to its envelope. But the size of the hottest zone of the thermal attack is sufficiently large to reach an acceptable stability of the temperature.

The stability of the temperature of the envelope of the flame is bad.

These observations explain why the level of flux in the centre (55kW/m²) of the flame is true and has good repeatability and reproducibility and why the level of flux near the envelope of the flame is not true and has a bad repeatability.

The bad reproducibility of the thermal attack near the envelope of the flame can be explained by a bad reproducibility of its shape.

This bad reproducibility can explain the bad reproducibility of the test results with SBI between the laboratories during the last Round Robin, principally for the products which have a joint at 20 cm from the corner. This distance correspond to the position 3 of the fluxmeter.

In order to improve this reproducibility there are two solutions.
- decrease the distance of the joint from the corner in order to put it in a part of the flame which is more stable
- to improve the stability of shape of the flame.

In order to improve this stability it is necessary to know the causes of the bad stability.

It can be explained by
- Difference in the air speed and turbulences inside the room,
- Condition of the air entry in the room, under the trolley, and the overall environment close to the room (free, close to a wall, …),
- Geometry of the room,
- Duct orientation (left, right, other),
- Packing down of the sand in the burner box.

A complementary study with FDS simulation could be useful to check these assumptions.

But actually it is possible to propose an improved procedure to measure the thermal attack which is described in “annex D2 of EN 13823.

This new procedure is described in *annexe A 7*
ANNEXES
Annex A 1: Annex D2 of the EN 13823

D.2 Check of the thermal attack on the specimens

D.2.1 General

The repeatability of the heat flux on the specimens should be checked after setup, maintenance, repair or replacement of the main burner or other major components that may influence the flames of the burner, by measuring the heat flux in the following three positions on the long wing:

- position 1: 8 cm from the corner and 16 cm from the upper edge of the burner;
- position 2: 8 cm from the corner and 75 cm from the upper edge of the burner;
- position 3: 20 cm from the corner and 30 cm from the upper edge of the burner;

For regular calibrations, or if there is a modification of the burner (for example: the old sand is replaced by a new sand), a measurement of the heat flux at position 3 is sufficient.

This check is performed with a large wing calcium silicate backing board (see 4.4.10) having three holes (diameter = 26 mm) at the positions given.

D.2.2 Procedure

Before ignition of the burner, place a heat flux meter in one of the holes in the long wing backing board (with the small wing backing board being also in place), and close the other holes.

Note The heat flux meter should be a 25,4 diameter Schmidt-Boelter which is calibrated between 0 kW/m² and 100 kW/m². The flux meter should be cooled by water at a temperature above 20°C. The flux meter black body surface should be on the backing board surface.

With the SBI apparatus working under normal conditions (see 8.2), record the heat flux for 5 min after the ignition of the burner. Then calculate the mean of the heat flux measured between 240 s and 300 s after ignition.

After set up, maintenance, repair or replacement of the main burner or other major components that may influence the flames of the burner, repeat the measure five times. Calculate the mean of the results of the five measurements for each position. The relative standard deviation should be less than 4%.

For regular calibrations (in position 3), one measurement is sufficient. If the deviation between this result and the mean of the measurement in five fold is more than 4%, check the burner or others parts of the apparatus and perform a measurement five times in the three positions.
Annex A 2: Calibration certificate of fluxmeter n° 135051

CERTIFICAT D'ETALONNAGE
N° E013625/1

Délivré à : LABORATOIRE NATIONAL D'ESSAIS
CEMAT 67
29 avenue Roger Hennequin
78197 Trappes Cedex

Date de la demande : Commande du 11/05/2004

INSTRUMENT ETALONNE

Désignation : Fluxmètre
Constructeur : Medtherm
Type : 64-10-20 N° de série : 135051
N° de référence :

Ce certificat comprend 3 pages Date d'émission : 25 mai 2004

Le Chef de la Division Thermique et Optique

Jean-Rémy FILTZ

Réalisation de l'Etalonnage

Thierry VALIN

La reproduction du présent document n'est autorisée que sous sa forme intégrale.
Il comporte 3 pages
1. IDENTIFICATION DE L'INSTRUMENT A ETALONNER

L'instrument à étalonner est un appareil de mesure de flux thermique de marque Modtherm, modèle 64-10-20. Le capteur nœud sans fenêtre est de type Gardon et porte le numéro de série 135051.

2. REPONSE DU FLUXMETRE DE 3,5 ET 7 W.cm²

2.1. METHODE D'ETALONNAGE

La méthode consiste à passer successivement devant une source rayonnante permettant de générer des éclairages entre 3,5 et 7 W/cm², un fluxmètre étalon du laboratoire puis le fluxmètre à étalonner. Au paravant le fluxmètre étalon a été étalonné à l'aide d'une cavité corps noir de référence, elle-même raccordée en température aux étalons nationaux.

2.2. MODE OPERATOIRE

2.2.1. Conditions expérimentales

Le fluxmètre à étalonner est fixé sur un plateau porte-fluxmètres. Il est positionné de telle sorte que la configuration géométrique (source-fluxmètre) soit successivement la même pour le fluxmètre étalon et le fluxmètre à étalonner.

La température de la source variait de 695°C à 880°C selon les niveaux d'éclairage.

La température de refroidissement des fluxmètres était de 16°C ± 2°C.

La température ambiante dans la salle d'essais était de 21°C ± 2°C.

L'humidité relative était de 50 ± 5 %.

2.2.2. Cycle des mesures

A chaque niveau d'éclairage, le cycle des opérations était le suivant :

- Mesure de la tension de référence à l'aide du fluxmètre étalon,
- Mesure de la tension du fluxmètre à étalonner,
- Mesure de la tension de référence à l'aide du fluxmètre étalon.

Cette procédure est répétée 5 fois par niveau.
3. RESULTATS

<table>
<thead>
<tr>
<th>Désignation</th>
<th>Fluxmètre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructeur</td>
<td>Medtherm</td>
</tr>
<tr>
<td>Modèle</td>
<td>64-10-20</td>
</tr>
<tr>
<td>Type</td>
<td>Gardon</td>
</tr>
<tr>
<td>N° série</td>
<td>135081</td>
</tr>
</tbody>
</table>

Date de l'étalonnage : Avril 2004
Étalonné par : Thierry VALIN
Rédigé par : Thierry VALIN

<table>
<thead>
<tr>
<th>Densité de flux incident [W/cm²]</th>
<th>Tension du Fluxmètre [mV]</th>
<th>Incertitude de l'étalonnage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,41</td>
<td>3,32</td>
<td>4,5</td>
</tr>
<tr>
<td>4,20</td>
<td>4,09</td>
<td>4,0</td>
</tr>
<tr>
<td>4,63</td>
<td>4,60</td>
<td>3,8</td>
</tr>
<tr>
<td>5,63</td>
<td>5,49</td>
<td>4,0</td>
</tr>
<tr>
<td>6,35</td>
<td>6,20</td>
<td>3,7</td>
</tr>
<tr>
<td>7,02</td>
<td>6,88</td>
<td>3,7</td>
</tr>
</tbody>
</table>

Les incertitudes étalonnées mentionnées sont celles correspondant à deux incertitudes-types. Les incertitudes-types ont été calculées en tenant compte des différentes composantes d'incertitudes, étalons de référence, moyens d'étalonnage, conditions d'environnement, contribution du matériel étalonné, répétabilité ...

Fin du certificat d'étalonnage
Annex A 3: Coefficients gave to the laboratory in function of time

- **June 2004 (Calibration capteur 051)**: $y = 0.982x$, $R^2 = 0.9998$
  ![Graph June 2004](image)

- **September 2004 (Calibration capteur 051)**: $y = 0.9547x$, $R^2 = 0.9997$
  ![Graph September 2004](image)

- **October 2004 (Calibration capteur 051)**: $y = 0.9146x$, $R^2 = 0.9989$
  ![Graph October 2004](image)

- **November 2004 (Calibration capteur 051)**: $y = 0.9201x$, $R^2 = 0.9987$
  ![Graph November 2004](image)
calibrage capteur 051  janv-05  
\[ y = 0.911x \]  
\[ R^2 = 0.9991 \]

Watt/cm\(^2\)

Watt/cm\(^2\)

calibrage capteur 051  mars-05  
\[ y = 0.9516x \]  
\[ R^2 = 0.9894 \]

calibrage capteur 051  Juin-05  
\[ y = 0.9289x \]  
\[ R^2 = 0.9994 \]

calibrage capteur 051  Sept-05  
\[ y = 0.9011x \]  
\[ R^2 = 1 \]
calibrage capteur 051 nov-05

\[ y = 0.9543x \]

\[ R^2 = 1 \]
Annex A 4: Results (last 60 seconds) of every laboratories at each position

Labo N°00

Labo N°01

Labo N°02
Labo N°06

Labo N°07

Labo N°08
Labo N°09
Annex A 5: Definition of statistical parameters evaluated in the analysis

**Repeatability conditions**: Conditions where the independent results are obtained by the same method on the same items in the same laboratory, by the same operator using the same equipment, and within a short interval of time.

**Repeatability standard deviation** ($S_r$): Standard deviation of testing results obtained under repeatability conditions.

**Repeatability limit** ($r$): Value under which is, with a probability level of 95%, the absolute difference between two test results, obtained under repeatability conditions.

**Reproducibility conditions**: Conditions where the independent results are obtained by the same method on the same items in different laboratories, by different operators using different equipments, and within a short interval of time.

**Reproducibility standard deviation** ($S_R$): Standard deviation of testing results obtained under reproducibility conditions.

**Reproducibility limit** ($R$): Value under which is, with a probability level of 95%, the absolute difference between two test results, obtained under reproducibility conditions.

**Intermediate conditions**: Conditions where the results are obtained when at least one of these factors is not constant: time, calibration, operator, equipment.

**Expression of statistical parameters evaluated in the analysis**

In the case of $p$ laboratories and exactly $n$ repetitions of measurement per laboratory, for a given level $j$

1 – mean: $m_j = \bar{y}_j = \frac{\sum_{i=1}^{p} \bar{y}_{ij}}{p}$ with $\bar{y}_{ij} = \frac{1}{n} \sum_{k=1}^{n} y_{ijk}$

2 – repeatability standard deviation: $S_{ij} = \sqrt{\frac{\sum_{i=1}^{p} S_{ij}^2}{p}}$ with $S_{ij} = \sqrt{\frac{1}{n-1} \sum_{k=1}^{n} (y_{ijk} - \bar{y}_{ij})^2}$

3 – reproducibility standard deviation: $S_{Rij} = \sqrt{S_{ij}^2 + S_{Lj}^2}$ or $S_{Rij} = \sqrt{\frac{1}{p-1} \sum_{i=1}^{p} (\bar{y}_{ij} - \bar{y}_j)^2 + \frac{n-1}{n} S_{ij}^2}$

with $S_{Lj}^2 = \frac{S_{ij}^2 - S_{Rij}^2}{n}$ (between-laboratory variance) and $S_{ij}^2 = \frac{n}{p-1} \sum_{i=1}^{p} (\bar{y}_{ij} - \bar{y}_j)^2$

4 – repeatability limit: $r = 2.8 \cdot S_r$

5 – reproducibility limit: $R = 2.8 \cdot S_R$
Annex A 6: Principle of Cochran’s and Grubbs’ homogeneity tests

In the case of \( p \) laboratories and exactly \( n \) repetitions of measurement per laboratory,

**Cochran’s test**
The Cochran’s test compares the variances of laboratories. It is performed first.

The test statistic \( C \) of Cochran’s test is:

\[
C = \frac{s_{\text{max}}^2}{\sum_{i=1}^{p} s_i^2}
\]

where \( s_{\text{max}} \) is the highest standard deviation in the set.

Then \( C \) is compared to the critical value at 1% and 5%.

**Grubbs’ test**
The Grubbs’ test is used basically to test the variability between laboratories but also the variability of results from outlier laboratories detected with the Cochran’s test.

NF ISO 5725-2 ; § 7.3.4.3 : “When analysing a precision experiment, Grubbs' test can be applied to the following.

a. The cell averages (table B of annex 6) for a given level \( j \), in which case \( x_i = \bar{y}_{ij} \) and \( p = p_j \) where \( j \) is fixed. Taking the data at one level, apply Grubbs’ test for one outlying observation to cell means. If a cell mean is shown to be an outlier by this test, exclude it, and repeat the test at the other extreme cell mean (e.g. if the highest is an outlier then look at the lowest with the highest excluded), but do not apply the Grubbs’ test for two outlying observations. If the Grubb’s test does not shown a cell mean to be an outlier, then apply the double-Grubbs’ test.

b. A single result within a cell where Cochran’s test has shown the cell standard deviation to be suspected.”

**Simple-Grubbs’ test**
The Grubbs’ test statistic to test if the largest observation of a set is an outlier is

\[
G_p = \frac{(x_p - \bar{x})}{s}
\]

where \( \bar{x} \) is the mean and \( s \) the standard deviation of the set.

The Grubbs’ test statistic to test if the smallest observation of a set is an outlier is

\[
G_1 = \frac{(\bar{x} - x_1)}{s}
\]

where \( \bar{x} \) is the mean and \( s \) is the standard deviation of the set.

**Double-Grubbs’ test**
The Grubbs’ test statistic to test if the two largest observations of a set are outliers is
The Grubbs' test statistic to test if the two smallest observations of a set are outliers is
\[ G = \frac{s_{p-1,p}^2}{s_0^2} \]
where \( s_0^2 = \frac{1}{p} \sum (x_i - \bar{x})^2 \), \( s_{p-1,p}^2 = \frac{1}{p-1} \sum (x_i - \bar{x}_{p-1,p})^2 \) and \( \bar{x}_{p-1,p} = \frac{1}{p-2} \sum_{i=1}^{p-2} x_i \).

Then \( G \) is compared to the critical value at 1% and 5%.

General note about the result of the Cochran and Simple-Grubbs test (NF ISO 5725-2, § 7.3.2.1):
- If the test statistic is less than or equal to its 5% critical value, the item tested is accepted as correct.
- If the test statistic is greater than its 5% critical value and less than or equal to its 1% critical value, the item tested is called a straggler and is indicated by a single asterisk.
- If the test statistic is greater than its 1% critical value, the item is called a statistical outlier and is indicated by a double asterisk.
Annex A 7: New annex D2 of the EN 13823

INSTRUCTIONS FOR THE THERMAL ATTACK MEASUREMENT

D.2.1 GENERAL

The level of the heat flux on the specimens should be checked after set up, maintenance, repair or replacement of the main burner or other major components that may influence the flames of the burner, by measuring the heat flux in the following three positions on the long wing:

- position 1: 8 cm from the corner and 16 cm from the upper edge of the burner;
- position 2: 8 cm from the corner and 75 cm from the upper edge of the burner;
- position 3: 20 cm from the corner and 30 cm from the upper edge of the burner.

For regular calibrations, or if there is a modification of the burner (for example: the old sand is replaced by a new sand), a measurement of the heat flux at position 3 is sufficient.

This check is performed with a large wing calcium silicate backing board (see) having three holes (diameter ~ 26 mm) at the positions given.

D.2.2 TEST FACILITIES

D.2.2.1 Fluxmeter

One heat fluxmeter is used

It is a 25.4mm (diameter) Schmidtboelter Gardon which is calibrated between 0 and 100 kW/m².

D.2.2.2 Backing board

Two backing boards will be used.

They shall be calcium silicate boards with a density of (800 ± 150) kg/m³ and a thickness of (12 ± 3)mm.

Their dimensions are:

- For the short wing: (570 ± 5)mm x (1500 ± 5)mm;
- For the long wing: (1000 ± 5)mm x (1500 ± 5)mm

Three holes (diameter = 26mm) are made in the long wing at the following positions:

- Position 1: 8cm from the corner and 16 cm from the upper edge of the burner;
- Position 2: 8 cm from the corner and 75 cm from the upper edge of the burner
- Position 3: 20 cm from the corner and 30 cm from the upper edge of the burner.
D.2.2.3 Measurement equipments

Data acquisition system which measures mV, having an accuracy of 0.1% of full scale instrument output and 0.1s for the time.

The data acquisition system shall record and store the following quantities every 3 s (a data file sheet will be sent to each laboratory with the fluxmeter).

D.2.3 Conditioning

The both backing board are conditioned at (50 ± 5) % and (23 ± 2) °C.

D.2.4 Test Procedure

D.2.4.1 Preliminary checking of the symmetry of thermal attack

The symmetry of the flame attack by evaluation of the mark on the backing board according to the following procedure is checked as following.

Two backing boards without holes are placed in the trolley against the long U profile. The main burner is ignited during 5 minutes at normal operating level.

After the test, the both backing board are installed against a wall and are joined together.

The two distances (L1, L2) between the edges of the base of the triangle and its median, its high (H) are measured (see the figure 1).

![Figure 1](image)

L1 has to be equal to L2.

If not, check the burner (the size and the position of the sand for example) or the speed of air near the wing (see the protocol in annexe D.2.7).

D.2.4.2 Testing operations

These operations start if the symmetry of the flame has been checked and validated.

Before the ignition of the burner, place the both backing boards against the long U-profile on the trolley as described in the figure 2 of the EN 13823.
The heat fluxmeter is positioned in each of the three holes (position 1 and 2 and 3) made on the large wing calcium silicate backing board (see the description in chapter 2) of SBI (the small wing calcium silicate board being also in place) with the blacktarget surface on the backing board surface. The holes which are not used are closed with a ceramic fibre disc which has the same diameter. The heat fluxmeter is cooled at a temperature above 20°C.

In each position five measurements shall be done as following:

When the fluxmeter is installed in the hole, the SBI apparatus is working in normal conditions (see chapter 8.2 of the EN 13823), the principal burner is ignited during 5 minutes.

Record the heat flux for five minutes after the ignition of the burner.

After 5 minutes the burner is extinguished.

Calculate the average of the heat flux measured between 240s and 300s.

The next test can start when the fluxmeter is back at the initial conditions.

Repeat 4 measurements according to the same procedure.

The entire testing procedure from the installation of the both backing boards until the end of the five measurements shall be carried out within 2h of the removal of the specimen from the conditioning environment.

### D.2.4.3 Expression of results

<table>
<thead>
<tr>
<th>Number of test</th>
<th>Average of the thermal flux (kW/m²) between 240s and 300s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position 1</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
</tbody>
</table>

The thermal attack measurements will be recorded in a recorded sheet which is described in the annexe D.2.8.

### D.2.5 RELEVANT RESULTS

The results are considered as relevant if the following results are obtained.

Position 1: \(5.25 \pm 0.35\) kW/m²
Position 2: \(2.10 \pm 0.25\) kW/m²
Position 3: \(1.40 \pm 0.15\) kW/m²
D.2.6 checkings if the relevant results are not obtained

If the results are not relevant it is necessary to check if the following parameters satisfy the requirements of the EN 13823 standard

- **Burner:**
  - If the burner is conform to the descriptions of this standard (position of the burner according to the specimen,
  - the size of the sand and the homogeneity of its position in the burner
  - Thickness of layer (mm)
  - etc..

- **Distance (mm) between the long wing and the wall**

- **Position of the J of the extraction duct**

- **Position of the bottom plate (2), inox plate (8) in the collector (figure E.24 of EN 13823)**

These information will be recorded in the record sheet which is described in annexe D2.8

- **Calibrations according to the annexe C**