VTT 22.6.2009 v.2

TRANSFEU

WP2 – Fire test for toxicity of fire effluents

Task 2.1.2 Development of small-scale test method for fire effluents

Step 1: Use of modeling

Plans according to DoW:

Movement of fire effluents in the test chamber will be simulated by **VTT** with an advanced simulation tool (FDS: Fire Dynamics Simulator) to give guidance for defining effecting parameters in the test chamber and for the sampling system. These parameters include sampling point, recycling, fresh air inflow points (if necessary) to check how to avoid disturbing the specimen combustion and the gas production, etc. This task will be carried out in close co-operation with experimental subtasks of task 2.1 to optimize the needs for experimental checks. The various proposals of positioning will be analyzed to choose the best.

Work done and first results

Smoke chamber modelling

Fire Dynamics Simulator, FDS, version 5.3.0 (3427) has been used to simulate the smoke chamber of ISO 5659-2. Some key measures are given below (more details of the smoke chamber are given in ANNEX 1):

- Internal dimensions of the chamber: 914 mm x 914 mm x 610 mm
- Two heat flux levels: 25 and 50 kW/m^2
- Chamber wall temperature 40 ± 5 °C for tests with the radiator cone at 25 kW/m^2 and 55 ± 5 °C for tests with the radiator cone at 50 kW/m^2

In the simulations the following assumptions have been used:

- Boundary Conditions (first approximations)
  - Insulated outer boundaries
  - Radiator cone has a prescribed temperature
    - 650 °C for 25 kW/m^2 heat flux at the centre of the specimen
    - 805 °C for 50 kW/m^2
    - 910 °C for 50 kW/m^2 with 50 mm specimen distance

- Due to simulation optimization, dimensions of the chamber have been rounded to 920 mm x 900 mm x 600 mm
- Grid resolution of 1 cm is used near the cone and sampling probe, specifically
  - from ceiling to 10 cm below the bottom of the cone and 3 cm away from each side except for the left side, where it extends 13cm to the left (covering the probe)
- Resolution of 2 cm is used elsewhere

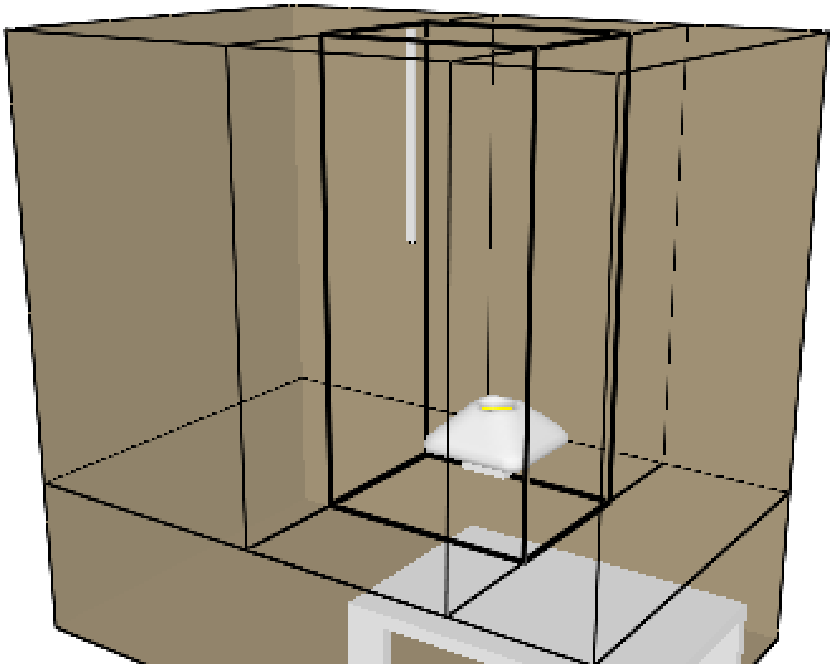


Figure 1: Boundaries of the simulation model meshes

- Because of 1cm grid resolution, the distance from the specimen holder to the radiator cone is reduced from 25 mm to 20 mm
- Sample modelled as fuel inflow boundary condition
- Methane is used as the reacting fuel
- Data needed for different materials
  - Soot yield
  - Heat of combustion of volatiles
  - Mass flux of volatiles

Results of grid resolution tests

To test the effects of grid resolution, the simulation was run with four different resolution settings:

- 1cm resolution everywhere
- 1cm near the cone and probe, 2cm elsewhere
- 2cm everywhere and the cone modelled with 2cm wide cells
- 1cm near the cone and probe, 2cm elsewhere and the cone modelled with 2cm wide cells

Results are shown in table 1. The comparisons were done with averages from 290 to 310 seconds with 50 kW/m^2 heat flux, insulated walls and 300 kW/m^2 heat release rate for the specimen.

Table 1: Results of different grid resolutions compared to the results of 1cm grid resolution

Grid resolution	**Heat flux**	**Temperature**	**CO_2 concentration**	**Ds**
1 cm	43.2 kW/m^2	127 °C	27000 ppm	397
1 cm and 2 cm, 1 cm cone	-5.1 %	-2.1 %	6.8 %	-20.1 %
2 cm, 2 cm cone	12.6 %	-6.8 %	-30.9 %	-26.4 %
1 cm and 2 cm, 2 cm cone	13.9 %	-7.5 %	-29.4 %	-43.9 %

As can be seen from the last two simulations, the significant loss in accuracy is mostly not due to the low grid resolution, but because not being able to model the cone accurately with 2 cm cells.
The mixed resolution was chosen for further simulations because of its reasonably good accuracy and 6-8 times faster speed. The measured values of the mixed resolution and the 1cm resolution simulations also behaved almost identically (same curve shapes) even though there were differences in absolute values (especially Ds).

Sensitivity of boundary conditions

The walls of the chamber are specified 1mm thick with steel as material.
Two simulations were run with 25 kW and 50 kW heat fluxes, the first with insulated backing of the steel sheets and the other with free convection and radiation boundary behind the steel sheets
The removal of insulation had no notable effect (less than 2 %) in measured CO_2, Ds and heat flux values – only the temperature changed significantly as shown in figure 1.

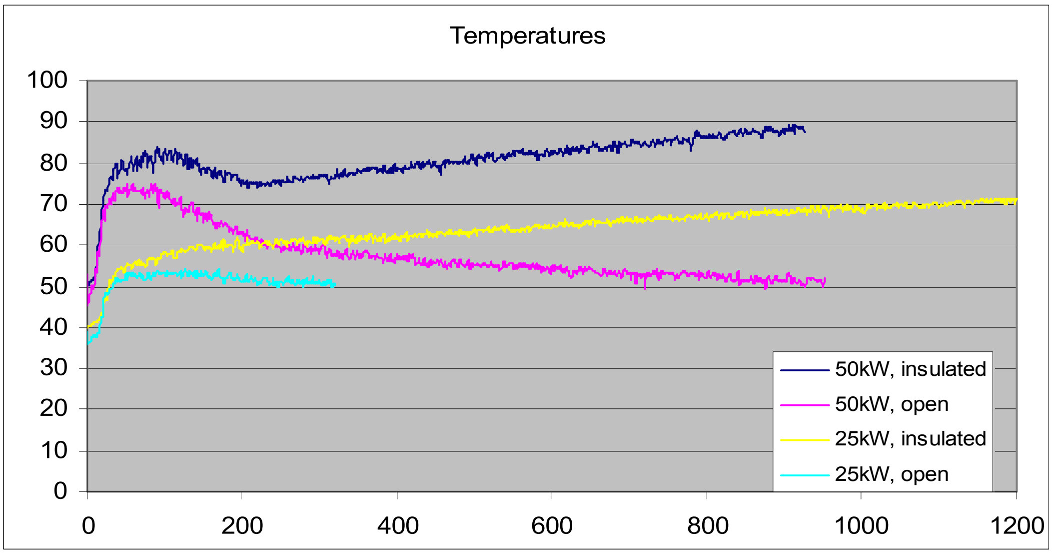


Figure 1: The temperature in the middle of the chamber with different boundary conditions

Surface temperature of chamber walls

Surface temperatures seen in figure 2 were measured after 600 seconds. 1cm grid resolution was used, walls were insulated from behind and 300 kW/m^2 heat release rate was specified for the specimen. The table and specimen holder temperatures were not modelled and measured. The ray effect seen on the walls is caused by inaccurate simulation and can avoided by increasing the number of radiation angles.

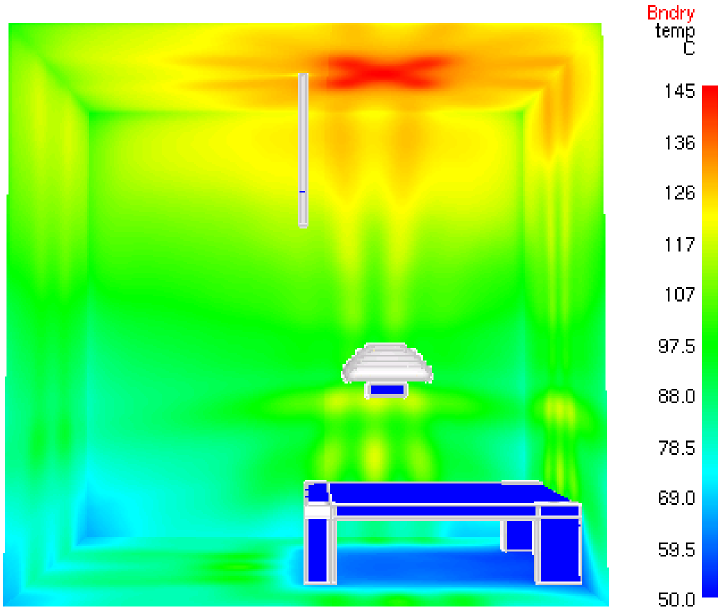


Figure 2: Surface temperature of chamber walls

Simulation of movement of smoke and fire effluents

Smoke density

When 1cm grid resolution was used, air pockets formed near the front and back of the chamber as demonstrated in figure 3. The pockets resulted in smoke density being a little higher near the centre and left side of the chamber than near the back where the measurement line is positioned.

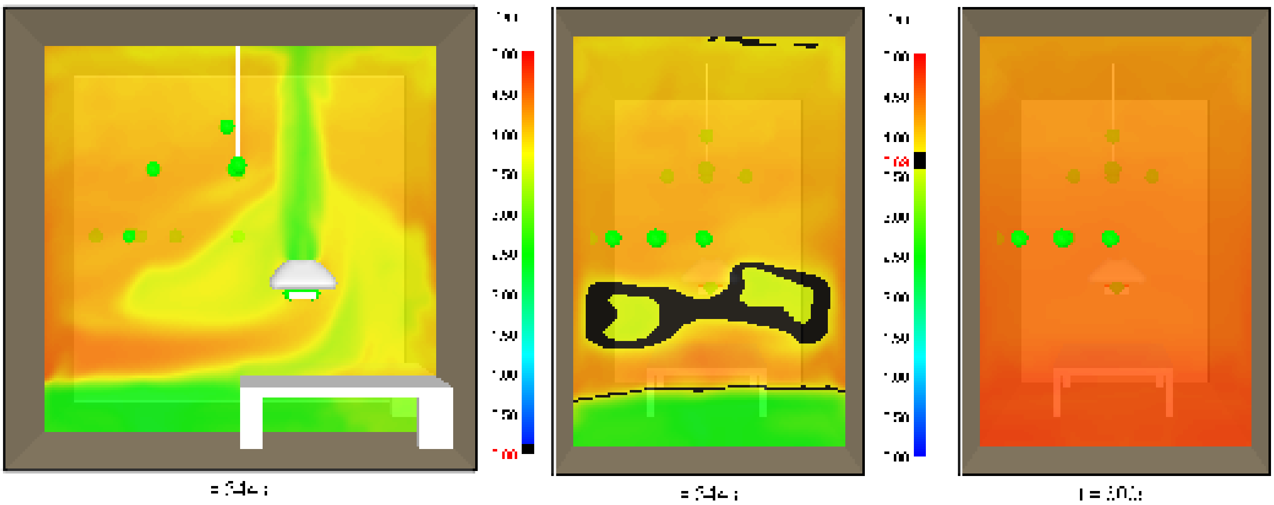


Figure 3: Smoke visibility after 344 and 600 seconds with 1cm grid resolution

However, the overall difference in Ds within 10 cm distance from the sampling line stayed mostly below 5 %, and the smoke started to even out after 7 minutes as can be seen from figure 4.

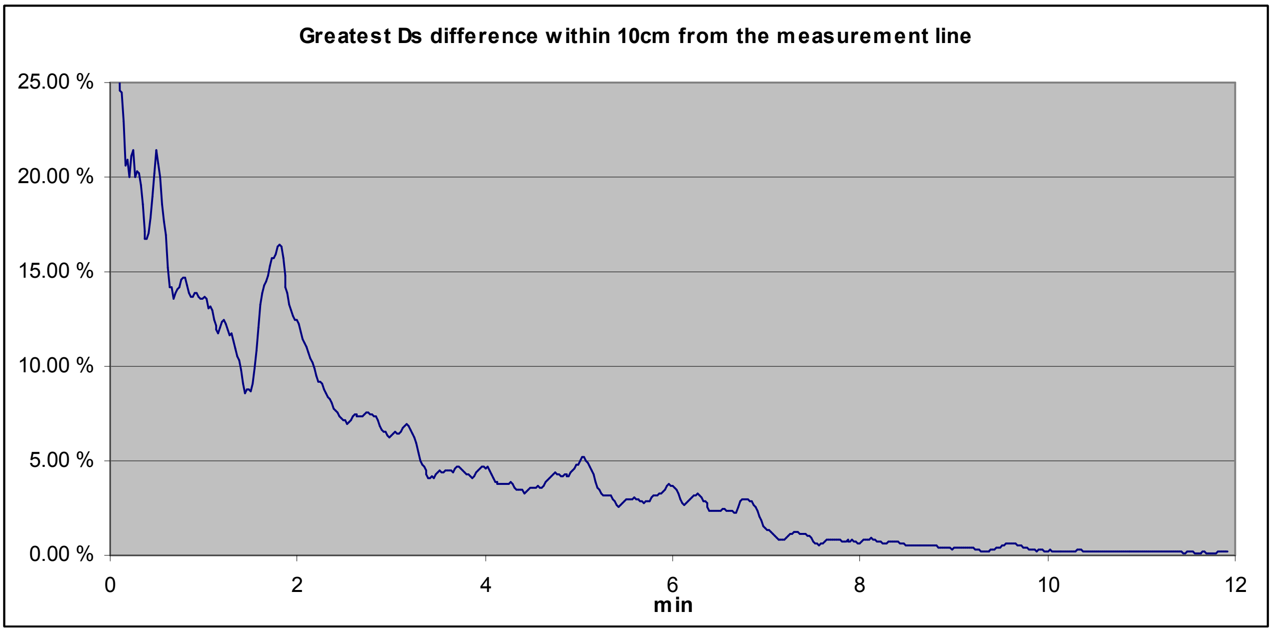


Figure 4: Greatest Ds difference with 1cm grid resolution, 50 kW heat flux and insulated walls

When 1 and 2cm mixed resolution was used, the difference in Ds stayed below 2 % after 4 minutes and below 1 % after 5 minutes. Similar results were achieved with non-insulated walls and both 25 and 50 kW heat fluxes, though with 25 kW the differences were below 5 % after 3 minutes and below 3 % after 6 minutes.

Gas concentrations

Greatest difference in CO_2 concentration within 10cm distance from the standard sampling point stayed very small after the first few minutes, as can be seen in figure 5.

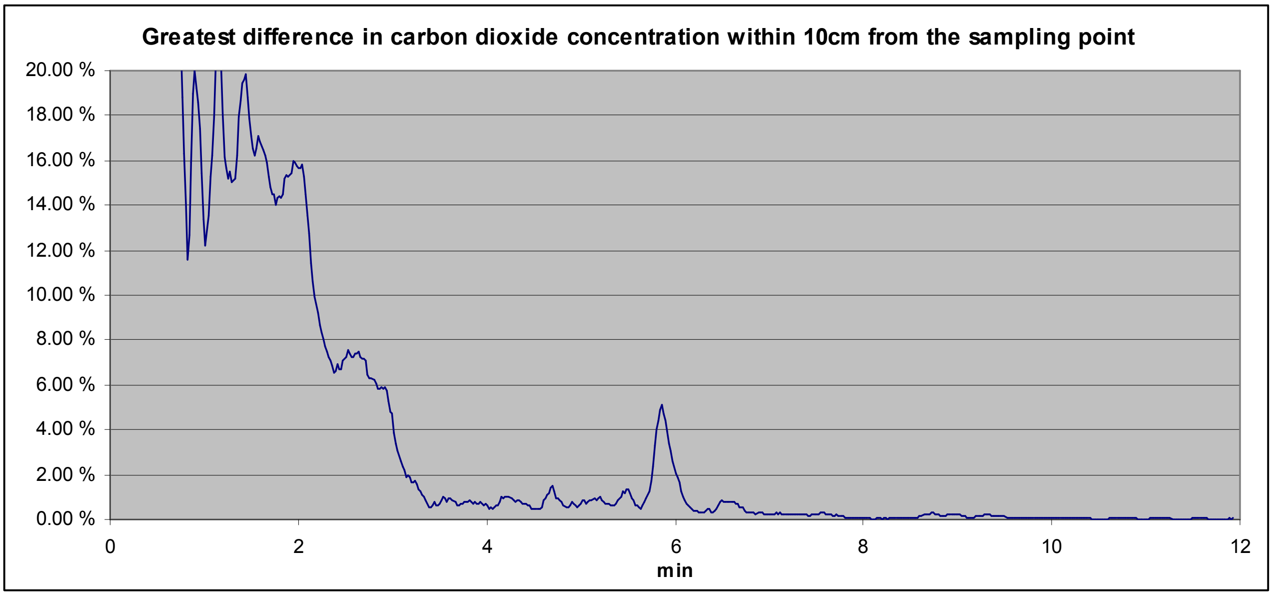


Figure 5: Greatest difference in CO_2 concentration with 1cm grid resolution, 50 kW heat flux and insulated walls

After 5 minutes only concentrations at points more than 10cm below the sampling point differed significantly from concentration at the standard sampling point, as seen in figure 6. As with Ds, wall insulation and heat flux seemed to have little to no effect on relative differences in CO_2 concentration.

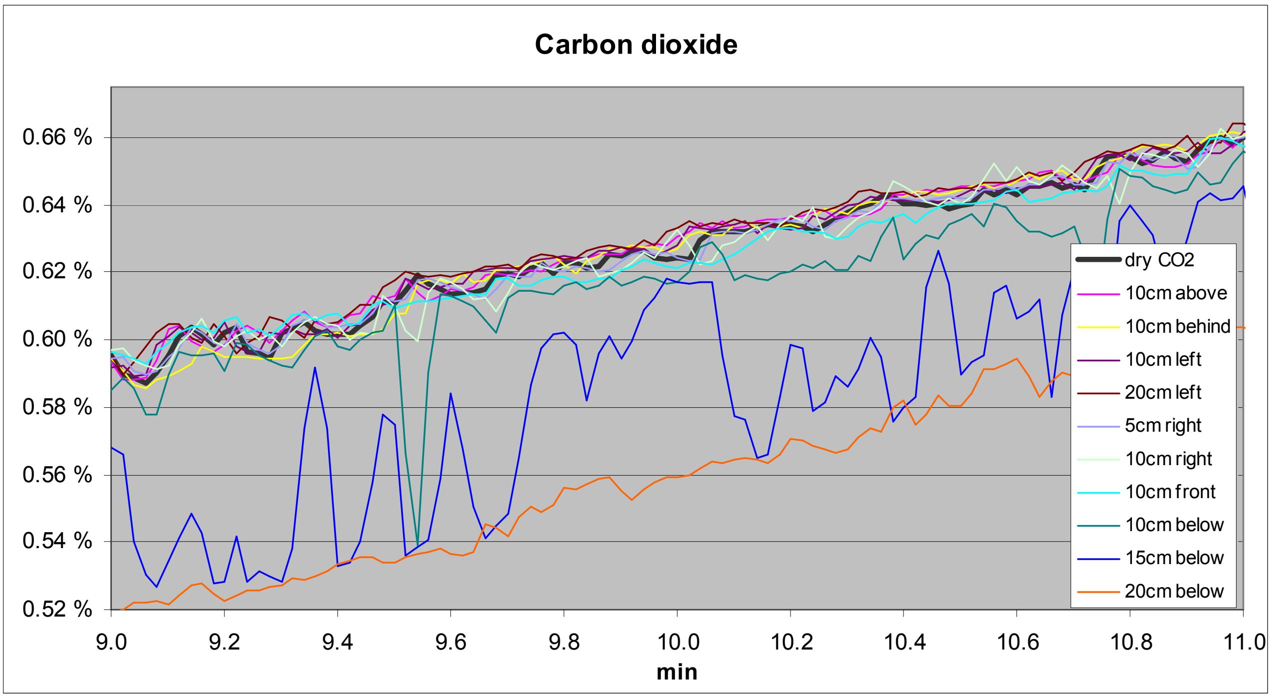


Figure 6: CO_2 concentration as a function of position relative to the sampling point with 1 cm and 2 cm mixed grid resolution, 25 kW heat flux and insulated walls

Results of different sampling probe air flow rates

To test the effects of the sampling probe, simulations were run with 0, 1 and 2 l/min air flow rates. No replacement air was introduced to the chamber. Initial parameters of the 50 kW heat flux simulation were used.
The results are shown in figures 7, 8 and 9 as comparisons to the simulation with 0 l/min flow rate.

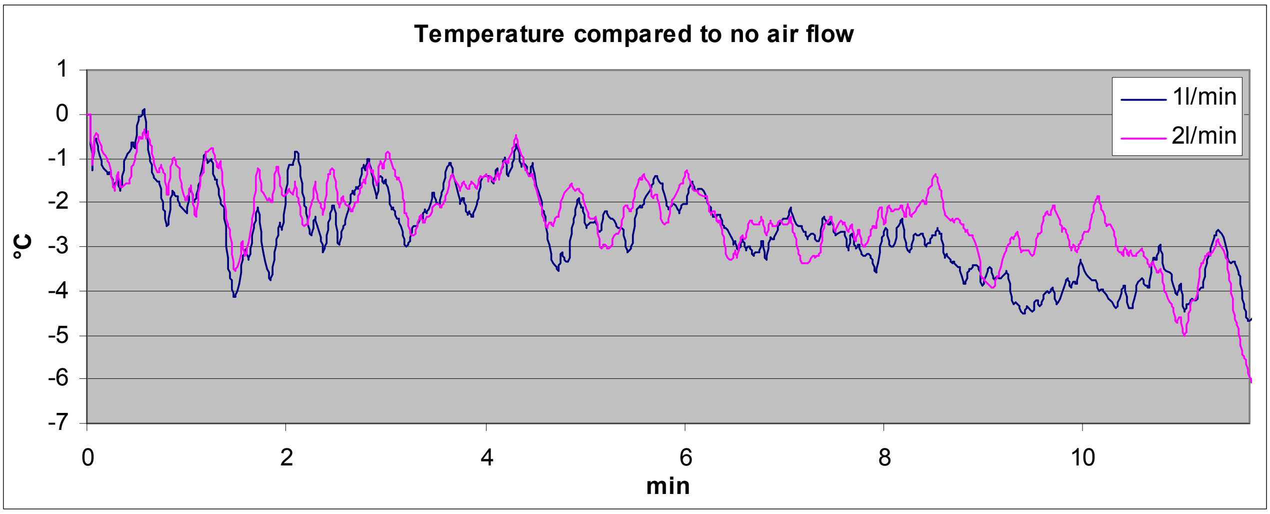


Figure 7: Sampling temperature difference with different sampling probe air flow rates

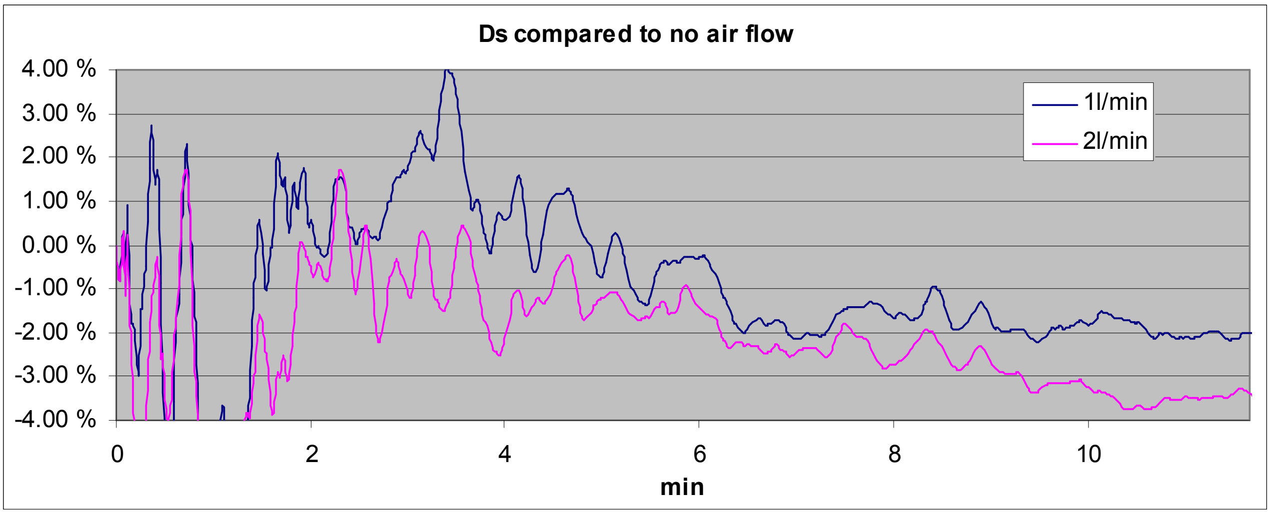


Figure 8: Ds difference with different sampling probe air flow rates

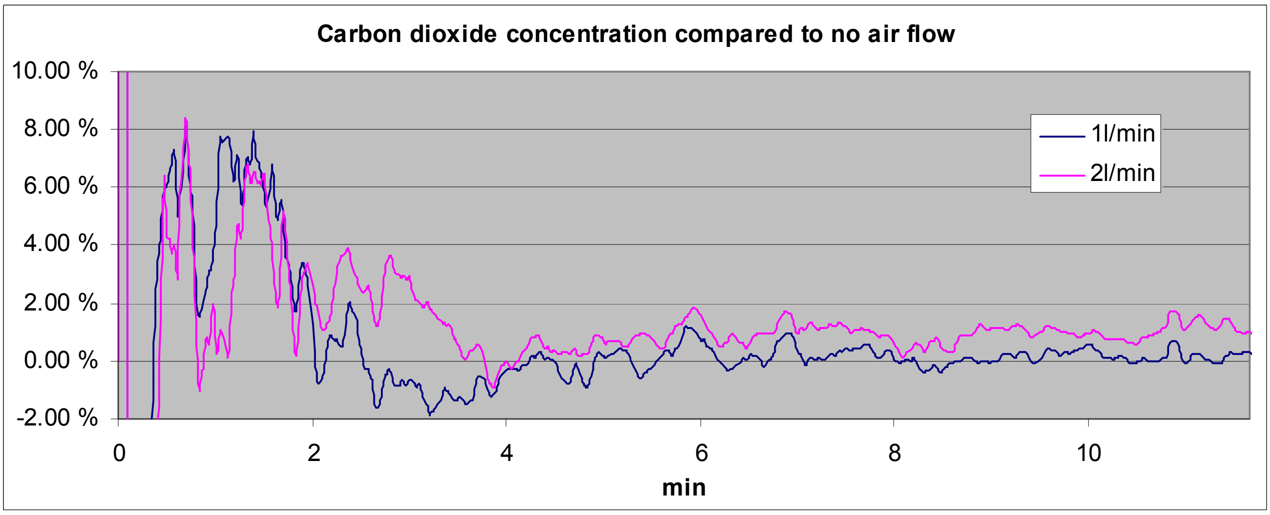


Figure 9: Carbon dioxide concentration difference with different sampling probe air flow rates

Results of higher cone temperature and 50 mm distance between cone heater and specimen

- As can be seen from figures 10 and 11, the higher cone temperature and 50 mm specimen distance caused gas concentrations to even out faster than with 25 mm distance and lower temperature.
- With 25 mm distance and lower temperature even after 10 minutes the gas concentrations were significantly lower 10, 15 and 20 cm below the sampling point than at the sampling point. However with 50 mm distance and higher temperature, after just 4 minutes the gas concentrations became virtually the same at the sampling point and 20 cm below it.

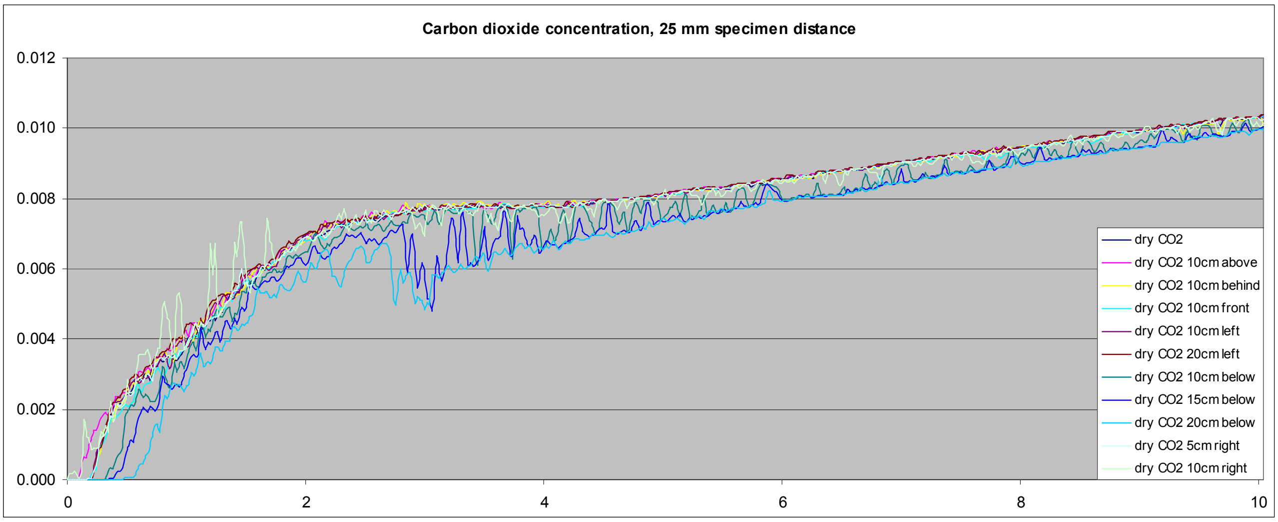


Figure 10: Carbon dioxide concentrations with 25 mm specimen distance

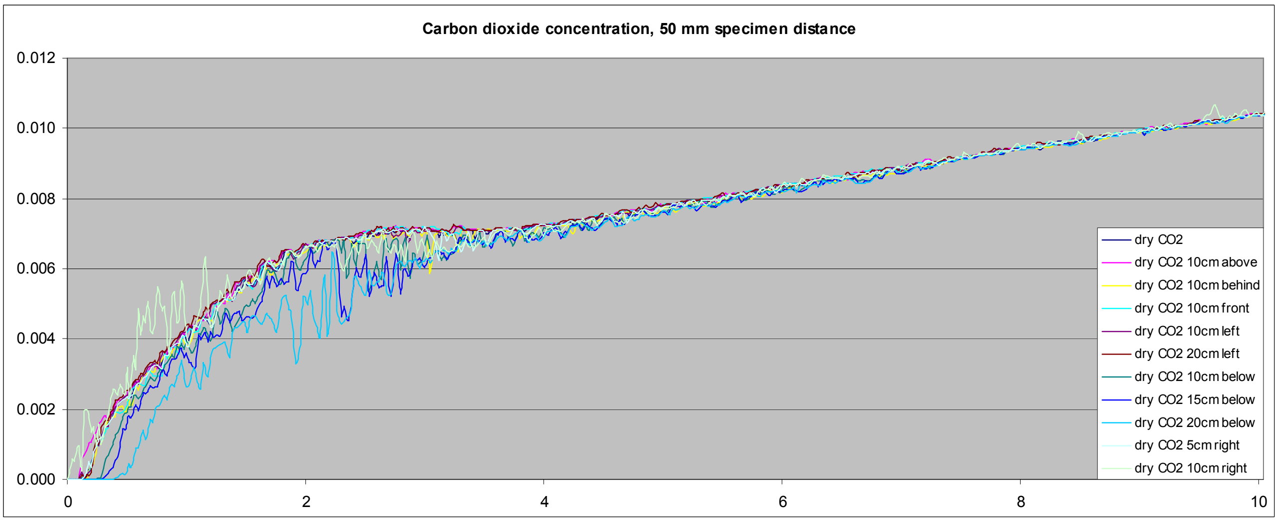


Figure 11: Carbon dioxide concentrations with 50 mm specimen distance

Summary of chosen initial parameters for simulations

- 2 cm grid resolution has to be used for most of the volume to be able to run simulations in reasonable time
- To be able to model the cone and probe accurately, 1cm grid resolution is used around them
- Because of 2 cm grid resolution and optimization of Fast Fourier Transforms, dimensions of the chamber have been rounded to 920mm x 900mm x 600mm
- The distance from the specimen holder to the radiator cone is set to 20 mm
- Ambient temperature is set to 40 °C for 25 kW and 55 °C for 50 kW simulations
- The chamber walls are modelled as being 1mm thick steel and insulated from behind
- The following heater temperatures were deduced for 25kW and 50kW heat fluxes
  - 650 °C for 25 kW/m^2
  - 805 °C for 50 kW/m^2
- The sampling probe is modelled as 10 mm x 10 mm x 610 mm rectangular pipe with air flow rate of 1 litre/min
- Methane is used as the reacting fuel and its SOOT_YIELD is set to 0.05
- Heat release rates of the specimens are modelled as shown in figure 12

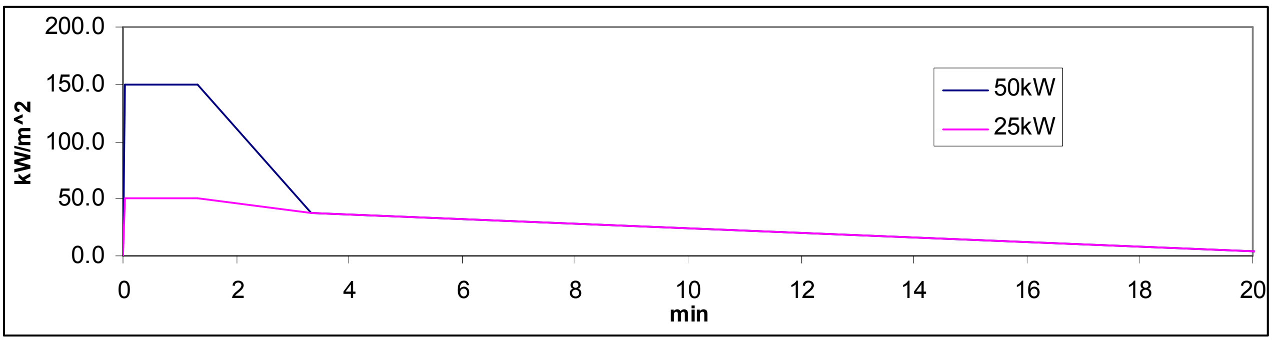


Figure 12: Specimen heat release rates as a function of time

Summary of present status

Main finding until now

- Boundary condition of the chamber walls seem to have little to no effect on CO_2 concentration and Ds, but do affect the gas temperature.
- After 7 minutes the smoke density evens out and stays virtually the same within 10 cm distance from the measurement line.
- The location dependence of gas concentrations diminishes fast and from 3 minutes onwards there are only little differences in measured concentrations within 10 cm distance from the sampling point. After 7 minutes the gas concentrations have evened out completely within 10 cm distance from the sampling point and virtually no differences can be detected.
- Higher cone temperature and 50 mm specimen distance reduces the location dependence of gas concentrations significantly when compared to 25 mm distance and lower cone temperature.

With constant air flows of 1 and 2 l/min through the sampling probe, a temperature decrease of 2-4 °C was measured after 10 minutes. In the same time, Ds decreased 2 % with 1 l/min air flow rate, and 3 % with 2 l/min rate. CO_2 concentration remained the same with 1 l/min flow rate, and an increase in order of 1% was measured with 2 l/min rate.

Proposals for further work

<u>List of proposed next steps:</u>

A. Checking possibilities to analyse differences in HCl and CO_2 mixing versus sampling point

B. Recycling/fresh air introduction?
- Volume flow?
- LNE/LSFire to describe in more details, if used

ANNEX 1

Smoke chamber details (ISO 5659-2)

7.2 Test chamber
7.2.1 Construction
7.2.1.1
The test chamber (see Figure 1 and Figure 2) shall be fabricated from laminated panels, the inner surfaces of which shall consist of **either a porcelain-enamelled metal not more than 1 mm thick or an equivalent coated metal** which is resistant to chemical attack and corrosion and easily cleaned.
The **internal dimensions** of the chamber shall be **914 mm ± 3 mm long, 914 mm ± 3 mm high and 610 mm ± 3 mm deep**.

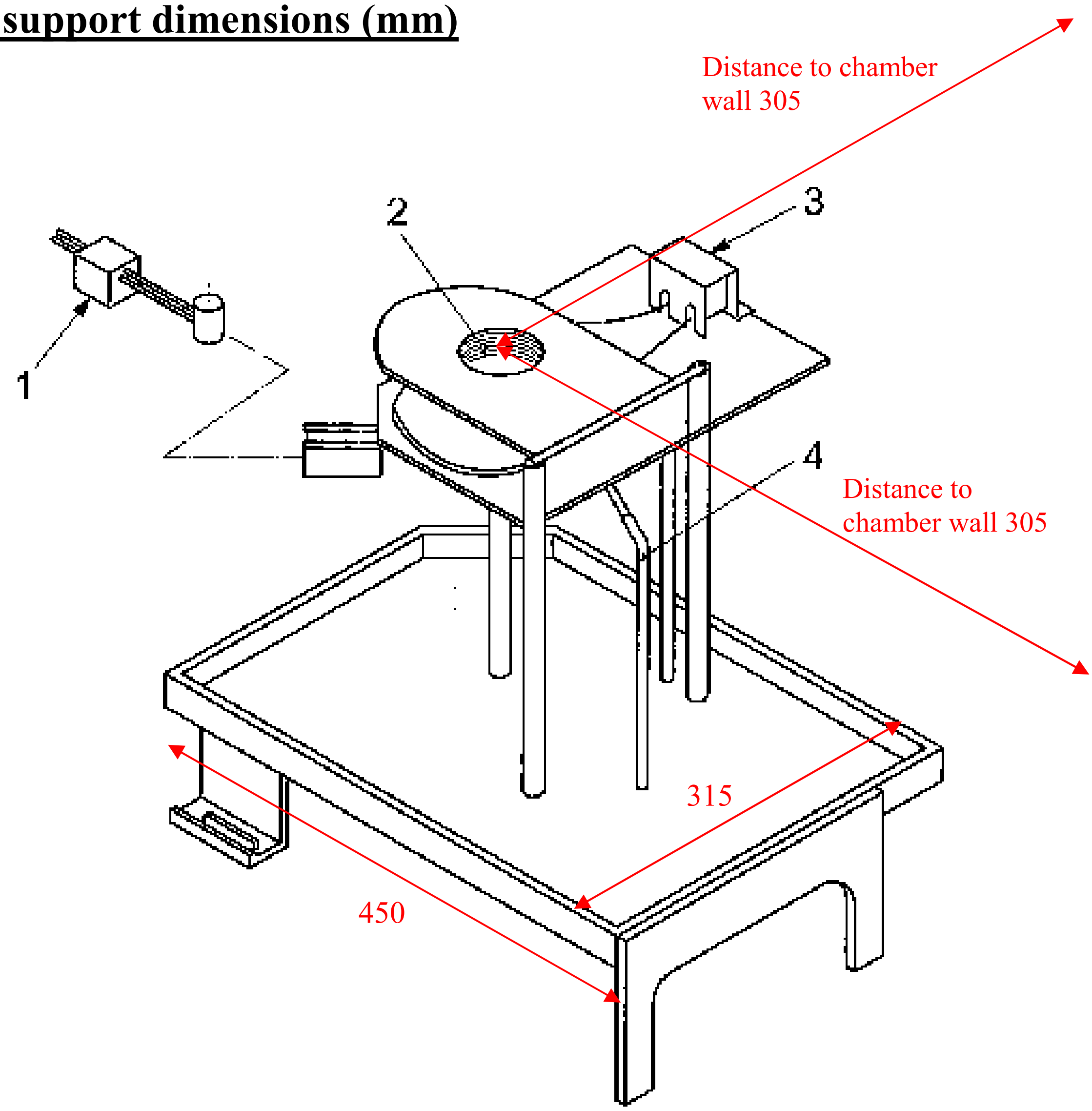
7.2.1.3
… **a positive pressure up to 1,5 kPa (150 mm water gauge)** above atmospheric pressure can be developed **inside the chamber** …
(Note: This limit may be exceeded in testing)

7.2.3 Chamber wall temperature
A thermocouple measuring junction, made from wires of diameter not greater than 1 mm, shall be mounted **on the inside of the back wall of the chamber, at the geometric centre**, by covering it with an insulating disc (such as polystyrene foam) having a thickness of approximately 6,5 mm and a diameter of not more than 20 mm, attached to the wall of the chamber with a suitable cement.

- **10.2.2:**
  - … the chamber wall temperature is within the range **40 °C ± 5 °C for tests with the radiator cone at 25 kW/m2** or within the range **55 °C ± 5 °C for tests with the radiator cone at 50 kW/m2**
  - *(For testing intumescent materials, the chamber wall temperature shall be within the range 50 °C ± 10 °C for tests with the radiator cone at 25 kW/m2 or within the range 60 °C ± 10 °C for tests with the radiator cone at 50 kW/m2;* ***This is not used according to CEN/TS 45545-2!****)*

7.3 Specimen support and heating arrangements
7.3.1 Radiator cone
7.3.1.1 The radiator cone shall consist of a heating element, of nominal rating 2 600 W, contained within a stainless-steel tube, approximately **2 210 mm in length and 6,5 mm in diameter**, coiled into the shape of a truncated cone and fitted into a shade. **The shade shall have an overall height of 45 mm ± 0,4 mm, an internal diameter of 55 mm ± 1 mm and an internal base diameter of 110 mm ± 3 mm**. It shall consist of **two layers of 1-mm-thick stainless steel with a 10 mm thickness of ceramic-fibre insulation of nominal density 100 kg/m3 sandwiched between them**. The heating element shall be clamped at the top and bottom of the shade.

Cone heater & support dimensions (mm)



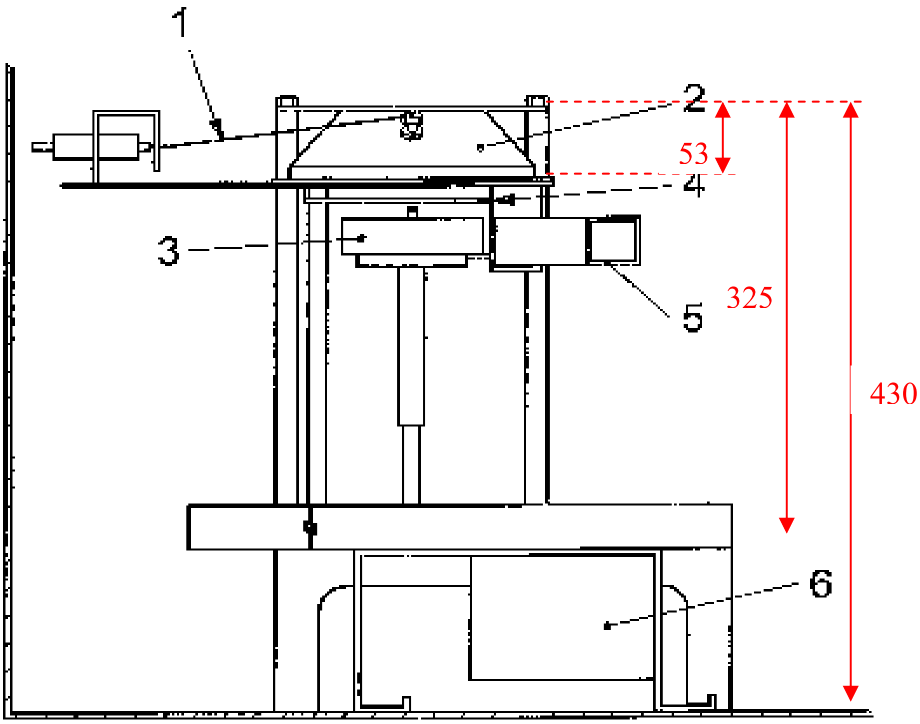
Key

1 heat flux meter and mount

2 heating element

3 thermocouple mount and shield

4 pilot burner



Key

1 thermocouple
2 radiator cone
3 specimen holder
4 radiator shield
5 heat flux meter holder
6 spark ignition housing

7.3.1.3
… an irradiance of **50 kW/m2** will be given by a heater temperature **in the range 700 °C to 750 °C** for the specimen position 25 mm below the edge of the heater

Heat fluxes
7.3.4.2
… heat fluxes of **25 kW/m2 and 50 kW/m2**

Specimen holder
7.3.5: Details of the specimen holder are shown in Figure 7.
- Note the exposure area of specimen: 65 mm x 65 mm

Chamber leakage rate test

9.6: The air-tightness of the test chamber shall be such that the **time taken for the recorded pressure to drop from 0,76 kPa to 0,50 kPa** (76 mm to 50 mm water gauge), determined using the timing device, **shall be not less than 5,0 min**.

Smoke chamber details (CEN/TS 45545-2)

Annex C

C.1 Introduction

Method 1: Smoke Chamber

This method is based on the exposure of a specified surface area for the test specimen. In this context, the test procedure is consistent with the methodology for measuring smoke density of railway products. **The test apparatus and conditions for Method 1 are described in EN ISO 5659-2 with additional gas analysis information provided in this Technical Specification.**

For large area products such as walls and ceilings, the test specimens shall be exposed to radiant heat flux conditions that simulate a developed stage of a fire; that is, heat flux of **50 kW/m2 without a pilot flame**. For floor coverings that generally receive lower levels of radiant heat during a fire, the test specimens shall be exposed to a radiant heat flux of **25 kW/m2 with a pilot flame**.

In Method 1**, the first gas samples** shall be taken so as to allow values **at time *t*1 equal to 240 s** to be determined. **The second gas samples** shall be taken so as to allow values **at time *t*2 equal to 480 s** to be determined.
See also C.8.2: The test period shall be always **20 min for smoke testing**.

C.3.2 Probe for sampling of effluents

… with a **stainless steel probe (5 mm inner diameter)** that is vertically **inserted from the centre of the ceiling** inside the smoke chamber. The sampling point shall be placed at **300 mm under the ceiling** of chamber (see Figure C.1). The thermocouple shall be placed at a maximum distance of 5 mm from the end of the probe.

C.4 Test environment

The test equipment shall be placed in a room with an atmosphere free from air draught, temperature between 15 °C and 35 °C, and a relative humidity between 20 % and 80 %. The test chamber shall be placed under a hood able to extract the smoke from chamber after the end of each test. The discharge valve of the test chamber should be connected to an exhaust fan.