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MODELLING OF STANDARD FIRE TEST

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Abstract: *The paper describes an application of Computational Fluid Dynamics to the simulation of a furnace for fire-resistance tests following standard fire conditions. The model is based on an accurate representation of a real fire furnace of fire laboratory PAVUS a.s. located in the Czech Republic. It includes geometry of the real furnace, material properties of the furnace linings, burners, ventilation conditions and measurement devices. The model allows controlling of gas temperature and the static over pressure in the volume of the furnace as it is specified in requirements of European standard for fire resistance tests. The accuracy of the model is validated on results of a fire test executed in a horizontal furnace. The results of the virtual furnace illustrate the great potential for investigating the thermal behaviour of fire-resistance tests.*

Keywords: Fire-resistance test, Numerical model, Virtual furnace, FDS, Furnace.

1. Introduction

Testing by standard fire test is a common method of obtaining fire-resistance rating of structural elements, see (Buchanan, 2001). Fire resistance of a structural element is quantified as the time for which the element can meet certain criteria during exposure to a standard fire-resistance test. Despite fire-resistance tests are very common they can be quite time consuming regarding their planning, preparation and analysis of results of a test. The cost of the test is also very high. Because of these drawbacks, numerical model of a horizontal furnace is developed. The model takes advantage of great possibilities of Computational Fluid Dynamics (CFD) code Fire Dynamics Simulator (FDS).

First attempts to apply CFD modelling in standard testing are described in (Welch et al., 1997, Cayla et al., 2011, Auguin et al., 2013 and Cueff et al., 2014).

2. Fire resistance furnace

A horizontal furnace of fire laboratory PAVUS a.s. of dimensions 3.0 m x 4.0 m and 2.2 m high was chosen. The furnace is heated by 8 natural gas burners. Flue gas exhaust system is performed using a frequency fan placed in a conduit which is connected to the opening (500 mm x 800 mm) in the floor of the furnace. Ground plan and vertical section of the furnace are shown in Fig. 1a and Fig. 1b. Then, there is a sensor to control the furnace pressure and 14 holes 100 mm below the ceiling to place plate thermometers. The plate thermometers cooperate with gas burners and regulate the temperature inside the furnace. Walls of the furnace are made of blocks and mats of fire-resistant ceramic fibers, with the total thickness of 230 mm. Floor is composed of bricks of thickness of 256 mm. The ceiling may be closed by concrete panels or by a steel welded structure insulated with ceramic fibers.

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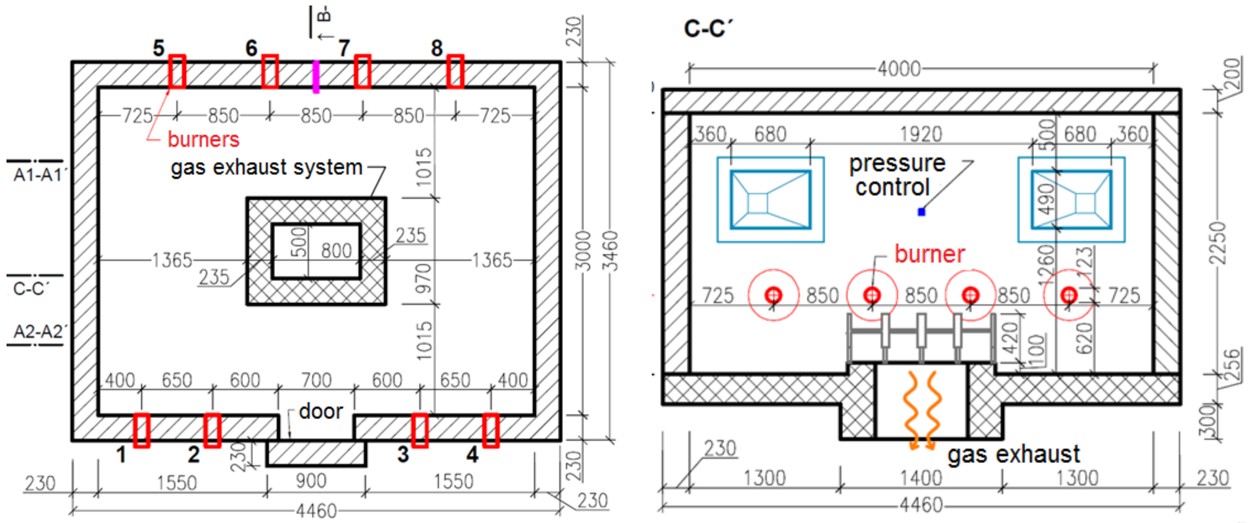


a) b)

Fig. 1: a) Ground plan of the furnace; b) Section of the furnace.

For standard fire testing it is important to meet requirements of European standard EN 1363-1:2013, which defines the conditions of fire resistance tests. Two constrains must be achieved in the real furnace as well as in the model:

1. The average temperature in the furnace is monitored and controlled to follow the relationship:

   $$T = 345 \log_{10} (8 t + 1) + 20 \tag{1}$$

   with T is the average temperature in °C, t is time in min.

   According to Czech standard CSN EN 1363-1 tolerances for the temperature distribution in the furnace may vary up to ± 100 °C.

2. The furnace pressure relative to the pressure outside the furnace at the same height must be constantly monitored. The pressure in the furnace should not exceed 20 Pa. Sensor placement and the requirements for it are given in standard EN 1363 - 1.

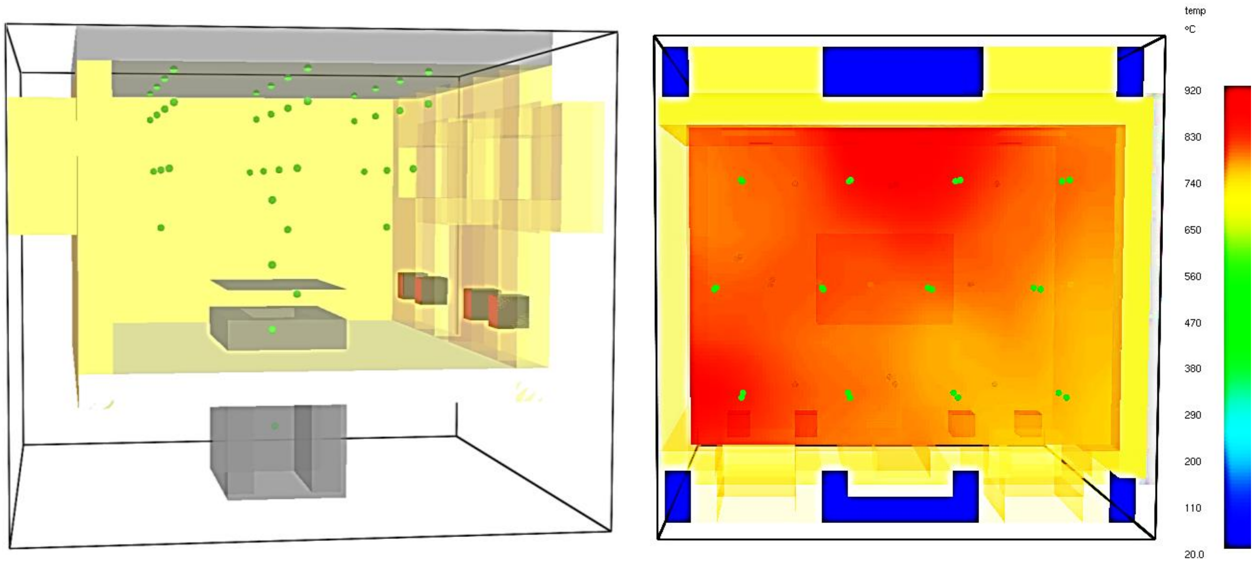
2.1. Model of the furnace

The model is created in the computational fluid dynamics code FDS (Fire Dynamics Simulator) version 6.4.0 (McGrattan et al., 2013). Geometry of the furnace, material properties of furnace linings, burners and ventilation conditions are created to correspond to the horizontal furnace of fire laboratory PAVUS a.s. described above.

Considering dimensions of the real furnace, time needed for numerical solution and sufficient level of accuracy of results, mesh size of 250 mm x 250 mm x 250 mm was selected. In the bottom part of the model the mesh is enlarged to simulate the conduit of the gas exhaust system, see Fig. 2a. In reality a hole leading into the conduit is protected with welded steel structures, while in the model there is a steel plate placed 250 mm above the hole. The plate can be seen in Fig. 2a. In Fig. 2a burners and niches of four visors may be also observed.

Material properties of the furnace linings are taken from data sheets of manufacturers. These include: density, specific heat capacity and thermal conductivity of high alumina bricks, thermally insulating bricks, calcium silicate boards, blocks of refractory ceramic fibres, steel and insulating refractory concrete. For detailed material properties see (Novotná, 2017 and Lišková, 2017).

In the model burners are simulated as eight square surfaces of type VENT of dimension 250 mm x 250 mm, which are located 0.5 m above the floor. The fuel in the real furnace is composed of the mixture of natural gas and air, just as it is in the case of virtual furnace, with the prescribed reaction of burning of this mixture. Power of the burners in the model is gradually increased in dependence on time according to the power of burners measured in a pilot fire test. In the model it is defined by a ramp function of heat release rate per surface area (HRRPUA). Details of reaction of burning and power of the burners are given in (Novotná, 2017 and Lišková, 2017).



a) b)

Fig. 2: a) Model of the furnace; b) Temperature resolution 100 mm below the ceiling in 15 min.

Unlike in the real furnace ventilation system in the model is simulated only by the rectangular concrete conduit with an opening at the border of the computational domain. This opening is created as a VENT of type OPEN, which allows natural exhaust of gases.

In the model gas temperature is calculated by devices of type THERMOCOUPLE and ADIABATIC SURFACE TEMPERATURE which allow later comparison with gas temperature measured during the fire test at coated thermocouples and plate thermometers. In visualization of the model location of temperature devices are displayed as green points, see Fig. 2a and Fig. 2b. Pressure in the virtual furnace is also calculated to control the requirement of EN 1363 – 1.

2.2. Results and validation

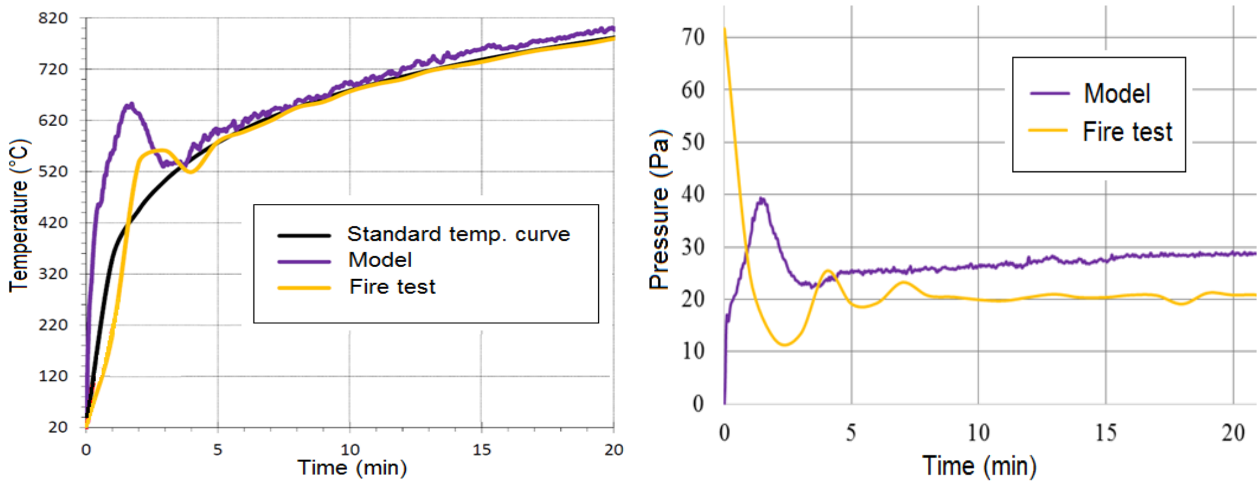
Spatial resolution of gas temperature below the ceiling of the virtual furnace in 15 min of the calculation is presented in Fig. 2b. A gradient in red colour indicates non-uniform temperature resolution ranging from 700 °C to 750 °C. Development of average gas temperature calculated from all devices simulating plate temperatures (PT), which were placed 100 mm below the ceiling, is shown in Fig. 3a. The development is compared with the standard temperature curve according to EN 1363 - 1. Based on the diagram it may be stated that after 5 min the temperature is within the acceptable tolerance given in EN 1363 – 1 (± 100 °C).

The furnace pressure calculated in the virtual furnace is compared to development of the pressure during the real fire test in Fig. 3b. Before 5 min big fluctuation may be observed. Then, the pressure evolution in the real furnace is maintained around level of 20 Pa. Despite this, in the model values are higher in range from 5 Pa to 10 Pa. This may be caused by simplified attitude of ventilation in the model. When improving the gas exhaust system with addition of forced vent, the temperature evolution in time may be in better correlation.

3. Conclusions

The paper presents the model of the horizontal furnace for fire-resistance tests. The model allows controlling gas temperature and the static over pressure in the volume of the furnace, so it can meet the requirements of European standard EN 1363-1:2013, which defines the conditions for fire resistance tests.

The accuracy of the model is validated to fire test executed in the horizontal furnace of fire laboratory PAVUS a.s. located in Czech Republic. The test of empty horizontal furnace helped to adjust the burners and check the total functionality of the model.



a) b)

Fig. 3: a) Gas temperature development 100 mm below the ceiling in the virtual furnace; b) Comparison of pressure in the virtual furnace and the fire test.

Certainly, further development is needed to improve the model. Namely, to improve the system of ventilation – in the real furnace a frequency fan placed in an exhaust duct draws hot gases out. Natural flue gas exhaust, which is used in this model, is not sufficient and therefore the pressure in the furnace is too high. Another point of planned improvement lies in material testing. These tests should provide accurate values of physical properties of materials that are used in the furnace. Finally, it is necessary to study sensitivity of mesh density in the model. With improved ventilation system, accurate material properties and finer mesh, more accurate results may be achieved.

In conclusion, the virtual furnace has a great potential for investigating the thermal behaviour of fire-resistance tests. A huge advantage inheres in the evaluation of the thermal effect throughout the volume of the furnace, which allows an accurate prediction of fire-resistance tests and evaluation of large number of technical alternatives and boundary conditions. It may be also used for optimization of settings of the real furnace in order to reach as uniform temperature resolution across the volume of the furnace as possible.

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