Numerical simulation of EN 50399 standard test – Calibration and validation of a numerical virtual test

Bertrand GIRARDIN¹, Damien FLAMMIER² and Gildas AUGUIN³

¹ Efectis, Research & Innovation Direction, France
² Efectis, Laboratory, Fire resistance Testing Division, France
³ bertrand.girardin@efectis.com

ABSTRACT

Wires and cables have recently been included in the EN 13501-6 classification standard within the Construction Products Regulation (CPR). Thus they need to be tested according to the EN 50399 standard. It consists in a large scale test for classification of vertically mounted cables. This test represents a limit to the development of new flame retarded cable formulations because of time and material consuming. Moreover, all the developed formulations cannot be tested. A solution for the development and orientation tests phase could be to predict the fire behavior of cables inside the EN 50399 apparatus, thanks to CFD simulations carried out with the computational fluid dynamics code Fire Dynamics Simulator (FDS). Nevertheless, due to their particular geometries and the complex phenomenon cables undergo, it is difficult to simulate and predict how they perform in such large scale test.

So a first step is to evaluate the ability of FDS to reproduce quantitative results in terms of gas temperatures, velocity and heat fluxes distribution inside the test apparatus and in the cables environment for further evaluation of their fire performances. A numerical model of the test facility without burning cables is developed and assessed.

When experimental results are compared with numerical calculations, good agreement is found for gas temperature and heat flux. Temperatures with order of magnitude up to 1000 °C in front of the burner and up to 200°C are observed between 400 and 500 mm above the burner. For the thermocouples located 1.3 m and 2.6 m above the burner, the maximum gas temperature achieved are close to 100 °C. The proposed numerical model gives correct thermal loads in the vicinity of the ladder and the cables during calibration tests and can be used for further evaluation of combustible material on cables.

KEYWORDS

Modeling; EN50399; Cables; CFD; Validation; Flame spread
INTRODUCTION

Cables transmit energy and an ever growing amount of data. Numerous cables are installed to connect rooms and floors in buildings and installations. Low up to medium voltage cables, telephone and LAN cables are then part of all residential, industrial or public building. Independent from the conductor (mainly conductive copper wires), those cables generally contain polymer-insulation, sheathing or bedding. All types of cables can then produce a significant amount of fuel that can contribute to fires growth or propagation. As they need to pass through fire walls and are frequently located in horizontal and/or vertical ducting, they have significant potential to increase the fire hazard in a building spreading of fires.

However, a harmonization of the European fire safety test requirements for different building products, including cables have taken place in the frame of the European Construction Products Regulation (CPR) [1] since the last decades and cables now need to be CE-marked. The purpose is to ensure the free movement of all construction products within the European Union by harmonizing national laws with respect to the essential requirements applicable to these products in terms of health and safety. Cables are then classified in the so-called “Euroclass”. The EN 13501 [2] standard summarizes the criteria and the tests to be performed for the Euroclass of a cable. The Euroclasses are defined according to the results of either ISO 1716 [3], EN 50399 [4] and EN 60332-1-2 [5] tests.

One of the limitations when developing new materials for cables is the relevance of the tests performed for evaluating the fire performances of materials. Indeed, small-scale standard tests are generally not discriminant and large-scale tests are time and materials consuming. The development of new materials for cables implies then to test the materials themselves rather than the cables. These tests on the materials have then to be representative of the fire scenario involved when cables burn.

In that context, cone calorimetry is widely used even if it does not permit to examine flame spread. Some studies tried to investigate the lateral [6] or vertical [7] flame spread with a modified and/or inclined cone calorimeter with more or less success. Indeed, these studies considered forced and radiative burning conditions when the specimen are ignited with a flame in the EN 50399 apparatus or IEC 60332-1 apparatus. Moreover, the size of the ignition source (the heating cone) used in these studies is similar to that of the sample size (the size of the cone plaque). On the contrary, in the previously mentioned tests, the height of specimen is much larger than the one of the ignition source and thus allows studying flame spread.

In order to avoid massive cables production and time/materials consuming test that can’t be performed in the new materials development phase, one could use numerical modeling and virtual testing. Indeed, based on limited inputs and using such model could permit to predict the fire performance even in terms of flame spread in complex tests such as the EN 50399. To do so, a first step would be to simulate experiments performed without cable and with incombustible cable (flow obstruction) in order to validate the fire model in terms of gas temperatures, gas velocity and/or heat fluxes.

The goal of this study is thus to present and validate the virtual model developed for the EN 50399 based on experimental data [8]. In a first part, the implementation of the EN 50399 apparatus using FDS v6 will be detailed, then critical aspects of the models such as the burner and the way cables can be implemented will be discussed. Special attention will be given in the temperature fields and impacting heat flux in the apparatus.

DESCRIPTION OF THE MODEL

Implementation of the EN 50399 cable test apparatus

The cable test apparatus was implemented according to the requirements in the standard EN 50399 (see Fig. 1). The inner dimensions of the apparatus are 1 x 2 x 4 m³ (width x depth x height). The inlet air is applied as volumetric flow rate of 0.133 m³/s injected vertically upward from a 0.8 x 0.4 m² opening in the floor. The extraction hood (0.5 x 1 m²) is placed 400 mm above the outlet of the cabin and a constant outlet flow rate of 1 m³/s is imposed.

After performing a mesh sensibility analysis, it was found that 25 x 25 x 50 mm³ mesh size was an appropriate cell size for the part of the test apparatus where the cable ladder is mounted. The size of the domain is extended to 4.5 m in height to take into account for the extraction hood. There is however a large volume of the test apparatus where there are no flames and where the cell size can be larger (50 x 50 x 50 mm³).
Implementation of the burner

As for the cables, the mesh size that can be used for CFD calculations is coarser than the burner size. Indeed, the burner in the EN 50399 apparatus consists of 242 holes of 1.32 mm diameter each throwing 1550 mg/s of air and 442 mg/s of propane. The total surface throwing gases is thus of around 331 mm² and the imposed mass flux are thus of 4.68 kg/m²/s of air and 1.33 kg/m²/s of propane. However, in FDS, the burner is described by a unique obstacle than cannot be larger than at least one grid cell (25 mm). When the mass flow of premixed gas leaves the holes of the burner the velocity is relatively high giving a horizontal flame that hits the rear side of the test apparatus. On the contrary, in the simulations the same mass flow leaving the 12500 mm² hole gives a much lower velocity and the flame becomes vertical. This obviously has implications on the heat transfer from the burner flame to the cables.

Different methods to numerically implement the burner are possible with FDS:

- Method 1: Adapt the mass flow per unit area of air and propane to the actual surface of the burner in the model so the burner power remains at 20.5 kW.
- Method 2: Maintain the total mass flux (6.01 kg/m²/s of gas) but decrease the mass flux of propane so the burner power remains at 20.5 kW.
- Method 3: Adapt mass flow of air and propane to the surface so the burner power remains at 20.5 kW but use the feature of FDS to “patch” the velocity and impose a horizontal velocity of 2 m/s in the vicinity of the burner.
- Method 4: Implement 242 particles with a total debiting surface of 331 mm² as for the real burner.
Implementation of the cables

One of the major limitations of FDS is the fact that the meshing should be lower than the diameter of the cables (10 or 20 mm for instance). This implies to have very long computational times. However, FDS code introduced the so called fixed cylindrical Lagrangian particle [10][11]. Using these features, sub-grid modelling of cylindrically symmetric cables can be performed on a coarser mesh. This allows detailed multi-scale modelling of fine objects, such as cables, in a much larger computational domain.

VALIDATION OF THE MODEL - COMPARISON OF SIMULATED TO EXPERIMENTAL DATA WITHOUT CABLES

In [8], Försth et al. conducted experiments in a cable test apparatus with a ladder without cable. Instead, thermocouples and plate thermometers (PT) were implemented on the ladder, around 430 mm, 1300 mm and 2600 mm above the burner location. At each location one thermocouple for gas temperature measurements and two plate thermometers were implemented (see Fig. 3). One of the PT was facing the burner and the front side of the cable test apparatus (Front) and one facing the rear side of the apparatus (Rear). The experiments were simulated using the four different methods. The numerical results in term of gas temperature and PT temperature are compared to the experimental measurements.

At the exception of the method 2, the results in terms of gas and PT temperature are similar to the experimental ones. Indeed, the experimental gas temperatures 430 mm, 1300 mm and 2600 mm above the burner are experimentally measured at 273±10 °C, 118±108 °C and 91±10 °C while they are predicted at 247±15 °C, 132±13 °C and 109±12 °C respectively with the method 3 for instance.

Table 1: Experimental and simulated gas and PT temperature.

| Method      | 430mm (°C) | 1300mm (°C) | 2600mm (°C) | 430mm (°C) | 1300mm (°C) | 2600mm (°C) |
|-------------|------------|-------------|-------------|------------|-------------|-------------|
| Experimental| 279 ± 10°C | 118 ± 10°C | 96 ± 10°C   | Front      | 185 ± 15°C  | 99 ± 15°C   |
|             |            |             |             | Rear       | 224 ± 15°C  | 107 ± 15°C  |
| Method 1    | 259 ± 15°C | 151 ± 15°C | 122 ± 14°C  | Front      | 225 ± 21°C  | 117 ± 19°C  |
|             |            |             |             | Rear       | 224 ± 18°C  | 123 ± 18°C  |
| Method 2    | 74 ± 4°C   | 83 ± 8°C   | 94 ± 11°C   | Front      | 70 ± 7°C    | 76 ± 12°C   |
|             |            |             |             | Rear       | 125 ± 13°C  | 89 ± 13°C   |
| Method 3    | 247 ± 15°C | 132 ± 13°C | 109 ± 12°C  | Front      | 197 ± 18°C  | 105 ± 17°C  |
|             |            |             |             | Rear       | 272 ± 18°C  | 121 ± 18°C  |
| Method 4    | 223 ± 13°C | 150 ± 15°C | 119 ± 14°C  | Front      | 229 ± 21°C  | 119 ± 19°C  |
|             |            |             |             | Rear       | 206 ± 18°C  | 122 ± 18°C  |

After performing such sensibility analysis, the experimental results were reproduced with the minimal errors using the Method 3 (“velocity patch”). Indeed, the model slightly over-predicts the PT temperature especially for the PT facing the rear side of the apparatus and 430 mm above the burner (260 °C with the model against 225 °C for the experiment). Apart for this point, the PT temperature prediction lies within ±15 °C. A visualization of the temperature and velocity field can be seen in Fig. 3 Gas temperatures up to 1000 °C are obtained close the burner, thus validating the measurements of Försth et al. [8] in front of the burner.
Fig. 3. Plate thermometer location [8] (left), simulated temperature (middle) and air velocity (right) in the cable test apparatus at the steady state.

IMPACT OF THE BURNER ON THE NUMERICAL BEHAVIOR OF THE CABLES

As shown in Table 1, the PT temperatures are different for the PT facing the burner than for those facing the rear side of the tests apparatus meaning that the impacting heat flux are different. Cables were numerically implemented to investigate the impact of the burner implementation on the ignition and heat release rate response of the model. The THIEF model [11][12] was used to model the heat transfer inside the cables. Namely, cables of 12 mm diameter were implemented and the results in terms of cable surface temperature after 1000 s of exposure are presented in Fig. 4.

Fig. 4: Temperature distribution along cables without cable ignition after 1000 s exposure to the burner.

It can be seen that the area where the temperature increases have different shapes depending on the burner type. Namely, the temperature increase is limited to around 400 °C on all the width of the ladder for the Method 1 when similar temperatures are obtained with the Method 4 but in a smaller area. The highest temperature (around 500 °C) is obtained for the Method 3 as well with an inversed V-shape. This behavior is typical of the EN 50399 testing where the highest damaged lengths are generally obtained at the middle of the ladder width.
CONCLUSION

The purpose of this study was to develop a numerical model to simulate the fire environment of the EN 50399 test facility. A comparison of experimental and simulated data using FDS v.6 showed that it is possible to predict the gas temperature and PT thermometer measured at different location of the EN 50399 apparatus. The optimum results were obtained when “patching” the velocity field in front of the burner. Furthermore, the anisotropy shown by Försth et al. [8] is well considered by the model. This validates the model developed in this study.

Further investigations on how to obtain reliable and meaningful data to be used as input data for numerical modelling of the flame spread along cables have to be carried out. Moreover, the model can be further validated by measuring the temperature field and also the velocity field inside the test apparatus.

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