ADAPTED FLASH-CAT METHODOLOGY TO MODEL HORIZONTAL CABLE TRAY FIRES USING COMPUTATIONAL FLUID DYNAMICS

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Abstract

Nuclear power plants (NPPs) use an extensive network of electrical cables that can catch fire and possibly lead to damage to the nuclear reactor core with widespread consequences. Therefore, accurately assessing the heat release rate (HRR) of cable fires is critical. Under OECD (Organisation for Economic Co-operation and Development) PRISME-3 project, IRSN (Institut de Radioprotection et de Sûreté Nucléaire) burned two cable trays in an open atmosphere to observe their fire behavior. Based on this, a computational fluid dynamics-based method was developed to model HRR through simulations. The method uses the modified FLASH-CAT model with the surface ignition temperature model of Fire Dynamics Simulator (FDS) software. Simulation matched the test HRR profile well. Such results provide confidence in using the outlined method in this paper.

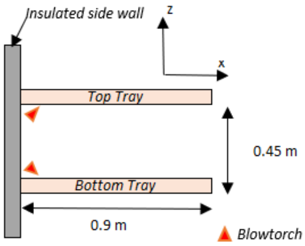

Figure 1. Insulated side wall, horizontal cable trays, and blowtorches. Tray length is 3 m and cable length are 2.4 m.

Introduction

Numerical simulation has been done using Fire Dynamics Simulator (FDS 6.7.7 [1]) software to replicate a cable fire test conducted by IRSN under OECD PRISME-3 project. Two horizontal trays (against an insulated wall as shown in Figure 1) having PE/PVC insulated electrical cables were burnt in an open environment under a large-scale calorimetric hood and fire related data like HRR, mass loss rate, emission factors (yields) etc. were collected and provided. The data from cone calorimetric tests along with the thermo-physical and chemical properties were also provided to be used in the simulation where FLASH-CAT model [2] was used in conjunction with FDS surface ignition temperature model. The FLASH-CAT model used properties such as linear mass density, plastic mass fraction, tray width etc. to calculate the effective combustible mass of cable surfaces in FDS. On the other hand, thermo-physical properties like thickness, thermal conductivity, density, specific heat, ignition temperature etc. governed the heat transfer into the cable surface in FDS and the resulting ignition (if any). PE (cable insulation material) and PVC (jacket material) were involved in the combustion. A single step mixing controlled gas phase chemical reaction was formulated by IRSN as:

$$0.32\,C_2H_3Cl + 0.68\,C_2H_4 + 2.213\,O_2 \rightarrow 1.53\,CO_2 + 1.26\,H_2O + 0.32\,HCl + 0.107\,C + 0.153\,CO + 0.211\,CH_4$$

The reaction and its related stoichiometric coefficients were used in the simulation to model the combustion. Bench-scale average HRRPUA (Heat Release Rate Per Unit Area) was provided for two different irradiance values (average HRRPUA 245 kW/m^2 and 314 kW/m^2 at an irradiance of 50 kW/m^2 and 75 kW/m^2, respectively) from the cone calorimeter tests of cables.

Adapted Approach

The approach used here is based on the research conducted by McGrattan et al. [2], Zavaleta et al. [3], Beji et al. [4], and Viitanen et al. [5]. By combining their findings, the approach was modified with a few new intermediate steps to address any shortcomings and minimize their prescriptive values like fixed values for vertical and horizontal fire spread rates for trays etc.

FDS's surface ignition temperature model has been used in the simulations. Under such approach, when a computational cell in FDS having fuel surface properties attains pre-assigned surface ignition temperature, it gets ignited. Then it follows a pre-defined burning rate as a function of the time, i.e., HRRPUA(t), as shown in Figure 2. Such computational cells burn for pre-calculated local fire duration (Δt_{fire}) at a given location on cable surface. In this work, the local fire duration has been calculated as

$$\Delta t_{fire} = \frac{6\Delta H_c\, n\, \gamma_p (1-\nu)\, m^{\prime}}{5\, \dot{q}_{avg}^{\prime\prime}\; 2W_{eff}}$$

where ΔH_c (MJ/kg) is the heat of combustion, n is the number of cables on each cable tray, γ_p is the plastic mass fraction, ν is the char yield, m' (kg/mm) is the linear mass density, W_{eff} is the effective width of the cable tray, and $\dot{q}''_{avg}$ is the average HRRPUA obtained from cone calorimeter. The "2"

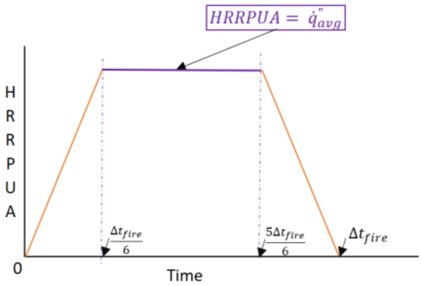

Figure 2. Idealized HRRPUA with respect to time

in the denominator was introduced by Zavaleta et al. in [1] to include both top and bottom areas of the cable trays against the original FLASH-CAT local fire duration formula which considered combustion only on one side of cable trays accounting for all the combustible mass. Moreover, cable surface built in FDS had openings based on the recommendation of Beji et al. in [4] and a stochastic approach to make simplified cable geometries for numerical simulations incorporating openings developed by Viitanen et al. in [5]. Obstructions in FDS representing the cable surface slab had randomly distributed openings, shown as black in Figure **3**. Such openings are holes having volume of a single cell allowing smoke and flame passing through them.

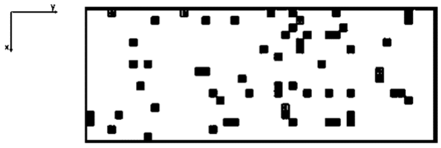

Figure 3. Randomly distributed openings on cable obstruction in FDS

Thus, the new effective width, W_{eff}, was calculated as: $W_{eff} = \frac{Area\ of\ the\ cable\ slab - Area\ of\ the\ openings}{Length\ of\ the\ slab}$

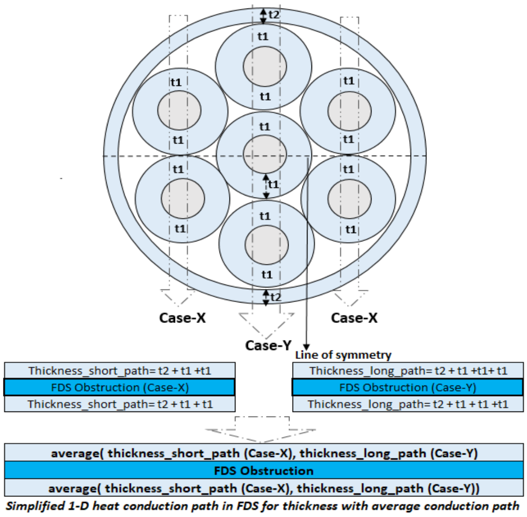

Figure 4. Idealized cable structure for one-dimensional heat transfer

Moreover, the internal structure of the cable was idealized for one dimensional heat transfer as shown in Figure 4 resulting into two different conduction paths with different thickness. To obtain a reliable estimate of the thickness for the symmetrical half of the idealized cable, the average value was computed from the "thickness_short_path" and "thickness_long_path" and used for cable surface thickness, as it is difficult to determine the actual path for one-dimensional heat transfer in the cable structure in a real fire.

Simulation and Result

The computational domain was 1.5 m x 4.4 m x 5.2 m in dimension with uniform mesh of grid size 0.05 m. The top and side boundaries were given OPEN boundary conditions and floor had concrete properties. Simulation with $\dot{q}''_{avg} = 245$ kW/m^2 led to slow fire growth, and another simulation with $\dot{q}''_{avg} = 314$ kW/m^2 led to fast fire growth. It is clear that not all the cable surface computational cells will receive irradiance having extreme values of 50 kW/m^2 or 75 kW/m^2 in the entire duration of the actual fire. A simulation with $\dot{q}''_{avg} = 279.5$ kW/m^2 (average of 245 kW/m^2 & 314 kW/m^2) produced the best (average) profile of HRR (Figure 5) close to the test. Peak HRR was underestimated by 4%, and time to reach peak HRR was overestimated by 5%.

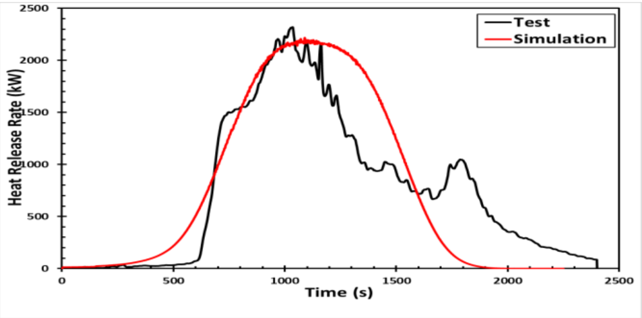

Figure 5. Heat release rate of test and simulation

Despite adapting the HRRPUA curve to the dynamic thermal feedback in the new FDS version 6.8.0 with min-max heat flux scaling, the results have not shown significant improvement especially in the decay phase. Further research is warranted at least on the choice of scaled heat flux limits.

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