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Coupling of a pyrolysis model with CFD for flame spread simulations in case of fire

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Introduction

When trying to simulate fire scenarios in buildings, several physical processes must be properly accounted for. A key phenomenon, severely contributing to the impact of a fire hazard, is upward flame spread over vertical surfaces. In this case, a fire source (e.g. a burning paper basket) is located near a combustible wall that catches fire. The fire spreads rapidly, since the flame propagates in the same direction as the buoyant air motion. Fig. 1 depicts the upward flame spread scenario. The presence of a flame causes the combustible material to heat up, primarily due to radiative heat transfer. When the material's temperature is raised to a threshold temperature (*pyrolysis temperature*), the material degrades: its chemical structure changes and volatile components are released. The volatiles serve as a fuel in the gaseous flame combustion process, causing more heat to be released. This positive feed-back cause fires to spread very rapidly.

Because of the importance of the flame spread, a proper description of the interaction between the solid wall and the flame is necessary. The interaction requires well validated submodels both in the solid phase (pyrolysis) and in the gas phase (combustion). Also, the coupling strategy between the two phases is a point of interest.

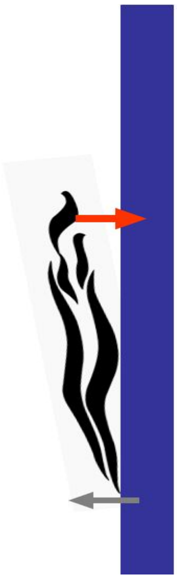

Figure 1 Upward flame spread scenario

Solid phase model

For the description of the heat transfer and pyrolysis process inside the solid material, a simplified enthalpy-based model [1-2] is applied, in which a single equation for enthalpy is solved. The pyrolysis process is endothermic, consuming an amount of energy (*heat of pyrolysis*), provided by conduction inside the material or by external radiation/convection. The model has successfully been applied to charring and non-charring materials, possibly containing moisture [1-2].

Figure 2 Solid phase degradation: the pyrolysis front separates the virgin material from the char

Here, we apply the model in a quasi two-dimensional formulation: heat conduction takes place in all directions, whereas in each row of cells in the computational mesh, the pyrolysis front (fig. 2) is parallel to the material surface and moves perpendicular to the surface. This is valid for thin walls, exposed at one side.

Gas phase model (CFD)

The gas phase phenomena are simulated using CFD (Computational Fluid Dynamics). Here, we use the commercial package ANSYS FLUENT, but the approach can be implemented in any CFD code. Models for radiation, combustion and soot formation are incorporated. In order to account for turbulence, the Unsteady Reynolds-Averaged Navier-Stokes equations (U-RANS) are solved. As the unsteadiness is primarily due to time-dependent boundary conditions, this approach is a good alternative for LES, with less severe conditions on grid spacing and the time step applied in the CFD calculations.

Coupling strategy

The equations in the gas phase and the solid phase are solved with separate codes. The CFD model takes the surface temperature and volatile mass flow rate as input and returns the heat transfer towards the solid phase. On the other hand, the pyrolysis model calculates the surface temperature and volatile mass flow rate for a given heat transfer. Gauss-Seidel iterations between both models are performed in each time step until they are in equilibrium.

Simulation results

Assessing the solid phase model and the coupling strategy

In order to check the proposed method, firstly simulations are performed, avoiding uncertainties related to gas phase modeling. The uncertainties are primarily due to the presence of turbulence and strong radiation. Therefore, a laminar test case without strong influence of radiation is considered. Downward flame spread over a sheet of PMMA is simulated. Chemical kinetics of PMMA and its volatile (MMA) are well known and therefore serve as an ideal test material. Upon external heat input, the material is ignited on top and the flame propagates downwards. Because of the downward motion, the lower virgin material does not really see the flame, which is tilted upwards, hence the radiation modeling can be excluded. A typical evolution in time of the flame is shown in figure 3 by means of temperature isocontours.

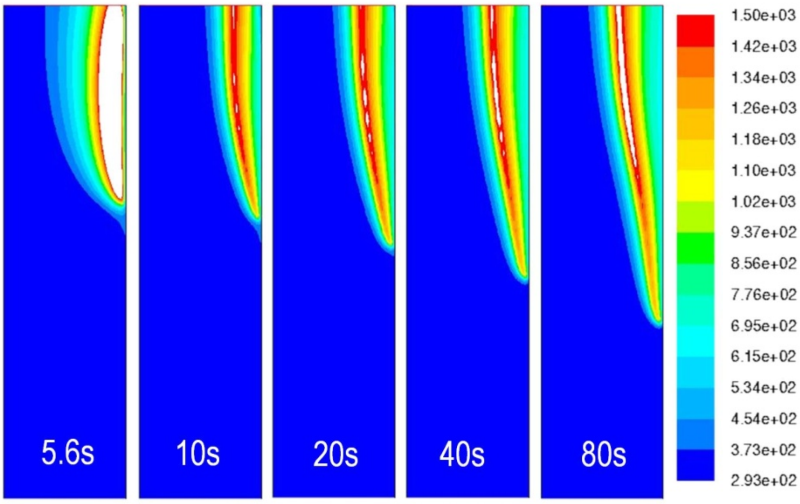

Figure 3 Ignition and downward flame spread [3]: isocontours of temperature at different times

Assessing the gas phase models

The ultimate goal is to simulate upward flame spread. Although, by means of the downward flame spread simulation and separate solid phase simulations [2] we are confident in the solid phase model and coupling strategy, up till now no satisfactory results for upward flame spread could be obtained. Reason for this is the inadequate modeling of the gas phase. Currently, buoyancy-modified turbulence models, validated soot models and its interaction with radiation are being investigated.

References

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