Thin Liquid Film Modeling in OpenFOAM

Application to Fire Suppression

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Abstract

The ability to predict the transport of water over the surfaces of solid fuels is essential to simulating fire suppression. The goal of the current research is to develop and couple surface water transport modeling into a general framework established in OpenFOAM for simulating gas-phase combustion, condensed-phase pyrolysis, and sprinkler spray in a fire suppression scenario.

To this extent, an Eulerian, thin-film model has been developed. The basic equations for the wall film model are described in [1] and [2] with some submodels taken from [3]. The two main 'thin-film' assumptions are *a*) the velocity normal to wall is zero, and *b*) gradients in wall-tangential direction are negligible compared to gradients in the wall-normal direction. This is to say that heat conduction and shear stress are dominant in the wall normal direction. The transport equations are integrated in the wall-normal direction to obtain a set of equations for the film thickness (δ), the wall-tangential components of mean film velocity ($\mathbf{U}$), and the mean film enthalpy (h).

Thus, these equations are defined as

$$\frac{\partial \rho\delta}{\partial t} + \nabla_s \cdot [\rho\delta\mathbf{U}] = \dot{S}_{\rho\delta} \tag{1}$$

$$\frac{\partial \rho\delta\mathbf{U}}{\partial t} + \nabla_s \cdot [\rho\delta\mathbf{U}\mathbf{U}] = -\delta\nabla_s p_L + \boldsymbol{\tau}_g - \boldsymbol{\tau}_w + \rho\mathbf{g}\delta + \dot{\mathbf{S}}_{\rho\delta\mathbf{U}} + \mathbf{F}_\theta \tag{2}$$

$$\frac{\partial \rho\delta h}{\partial t} + [\nabla_s \cdot (\rho\delta\mathbf{U})\, h] = q_g'' - q_w'' + \dot{S}_{\rho\delta h} \tag{3}$$

Preliminary implementation of the model in OpenFOAM has been completed. The fundamental transport equations for the liquid film are solved on an extruded 2.5D surface mesh. The mesh is discretized in both directions tangent to the surface, but is only one cell thick in the direction normal to the surface. Further model details are awaiting implementation. Finally, a suggested plan for validation of the model is presented outlining what experiments are to be performed and what useful data might be obtained from them. The solution method and overall OpenFOAM code framework have been implemented in collaboration with OpenCFD (specifically Andy Heather, Henry Weller, and Mattjias Janssens).

Keywords: liquid film flow, thin film approximation

References

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