Simulation of transport, evaporation, and combustion of liquids in large-scale fire incidents

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Bio: Topi started working at VTT Technincal Research Centre of Finland in 2008 on Fire Safety Related topics. He defended his PhD in January 2018 at Aalto University in Finland. His research interests have been numerical simulation of fire phenomena, especially high-speed sprays and pool fires. He currently works as a consultant at Fire Safety Design and Consultants Markku Kauriala Ltd.

Abstract:

Combustible liquids are often present in large quantities in industrial facilities and in transportation. Leaks, vessel ruptures, transportation accidents and terrorist attacks involving liquids may lead to large scale fire incidents. Analyses of such incidents are needed in the safety analyses of nuclear power plants and other critical infrastructure. However, large scale incidents may be outside the area of validity of empirical models. Development and validation of numerical simulation methods are therefore needed.

This thesis has two objectives. The first is to develop and validate spray boundary conditions that can be used to model spray injection of water mist systems or for modeling liquid dispersal. The second is to predict burning rates of liquid pool fires starting from first principles. Large eddy simulation is used for the Eulerian gas phase solution and Lagrangian particle tracking for the sprays.

The spray model is developed and validated using data from experiments on high-pressure water mist nozzles and liquid-filled missile impacts. Suitable droplet size distributions and initial velocities for use in spray simulations are determined from experimental data. The spray structure and entrainment into the sprays are predicted with reasonable accuracy. The conclusion is that liquid dispersal from missile impacts can be simulated using the same spray models as for water mist sprays.

The burning rate of the liquid pool is calculated on the basis of vapor pressure and a mass transfer calculation at the liquid surface. One dimensional heat transfer by conduction and radiation within the liquid is considered. Effective absorption coefficients are determined for use with a one-dimensional radiation transport equation. An enhanced thermal conductivity model accounts for in-depth convective heat transfer. The conclusion is that inclusion of spectrally resolved radiation calculations and of lateral convection may be necessary for predicting the temporal development of the burning rate.

Finally, the models are applied to the full-scale simulation of an airplane impact on a nuclear island. The predicted fireball lifetimes and sizes compare favorably with available empirical

correlations. A significant amount of the fuel involved accumulates on the surfaces around the impact point.