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Surface Flow Simulation of Falling Films on a Vertical Plane

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Introduction

- The reactor containment in a nuclear power plant provides the principal barrier to prevent the release of radioactive materials into the environment.
- During a severe accident, analysis of water/steam behaviors plays a vital role in avoiding both a hydrogen explosion and steam overpressure in the containment.
- Accidents including the water spray and steam injections form a continuous liquid film on the surface of structures and components.
- Consequently, the liquid film dynamics affects the steam condensation on the cooling surface and becomes an important factor in ensuring the structural integrity of the containment.
- This study has estimated the FVM-based liquid film solver implemented in OpenFOAM. Numerical simulations are conducted for surface falling films on a vertical plate.

Numerical Method

- Since liquid film over solid surfaces is very thin, the liquid film solver has developed based on the following assumptions:
  - ✓ The surface-normal flow can be assumed to be negligible.
  - ✓ The surface-tangential diffusion of mass, momentum and energy are also insignificant compared to the surface-normal diffusion.
  - ✓ The velocity profile along the film is assumed to be quadratic.
- These assumptions simplify the 3D transport to the 2D surface flow by integrating the velocity distribution through the film. Thus, the governing equations can be written as follows:

<u>Continuity equation</u>

$$\frac{\partial \rho\delta}{\partial t} + \nabla_s \cdot [\rho\delta U] = S_{\rho\delta}$$

<u>Momentum equation</u>

$$\frac{\partial \rho\delta U}{\partial t} + \nabla_s \cdot [\rho\delta UU] = -\delta\nabla_s p + S_{\rho\delta U}$$

where

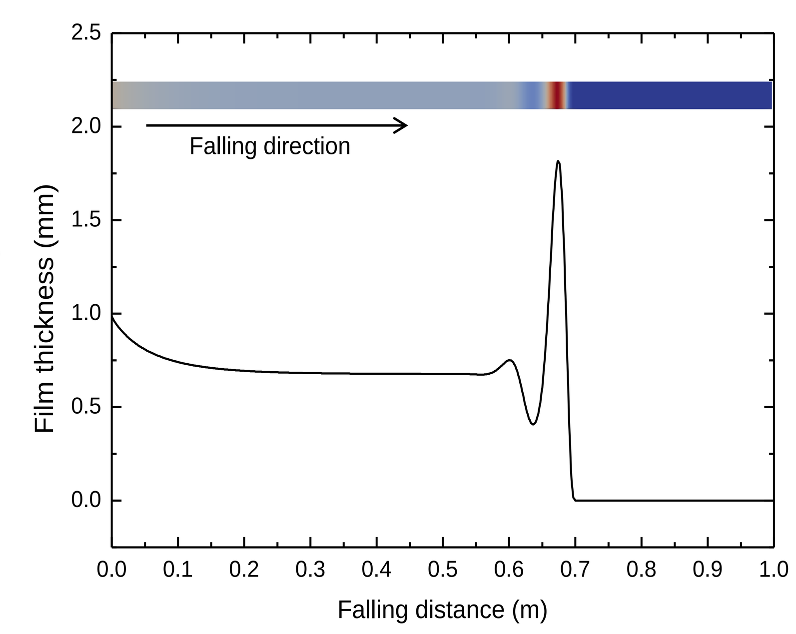
$$p = p_{imp} + p_{splash} + p_{vap} + p_\sigma + p_\delta + p_g$$

$$S_{\rho\delta U} = \tau_g - \tau_w + \tau_{mar} + \rho g_l \delta + F_\theta + S_{\rho\delta U,imp} + S_{\rho\delta U,splash} + S_{\rho\delta U,sep}$$

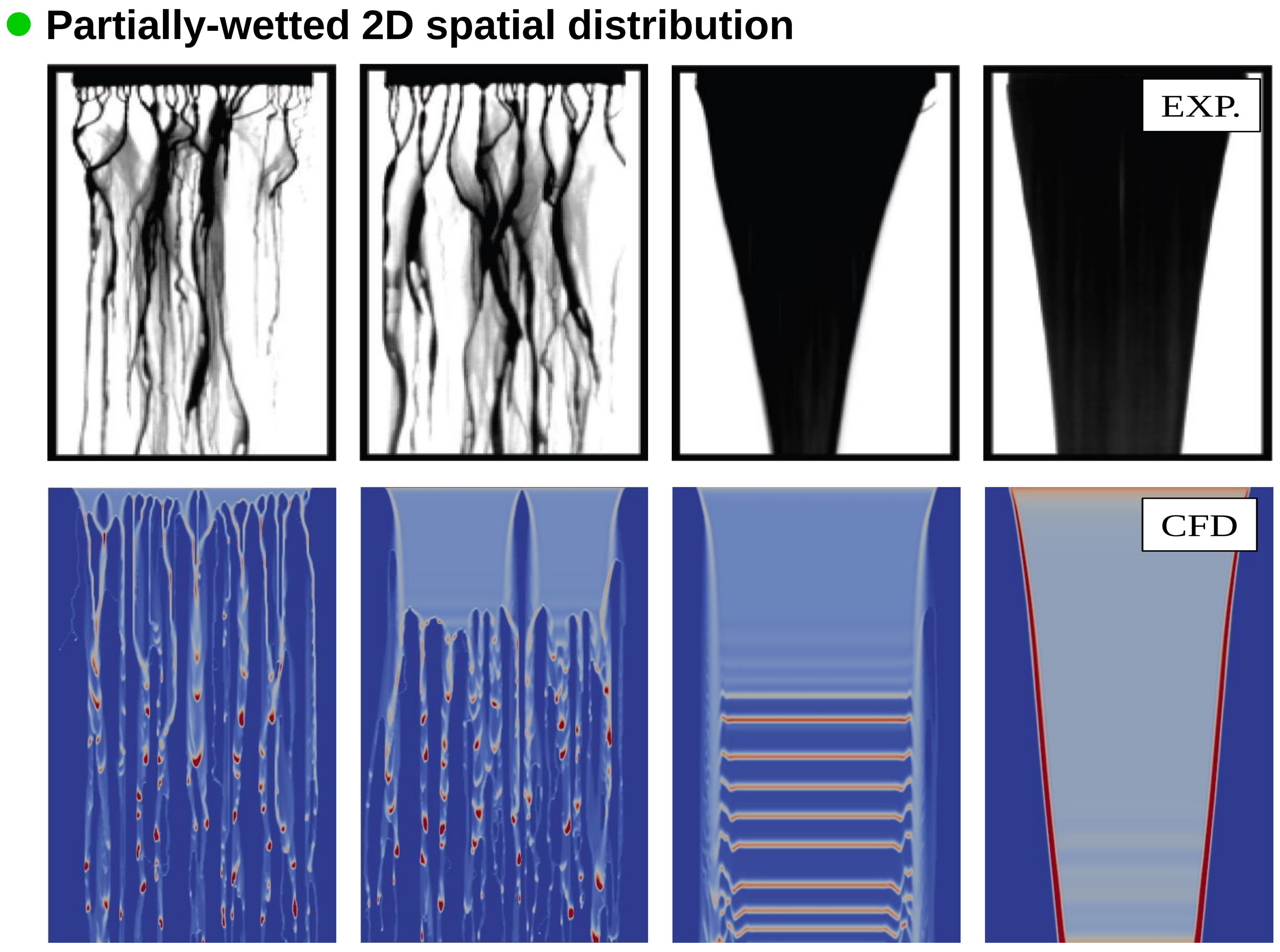
Validation

- 1D falling liquid film along a vertical plate
  - ✓ The falling liquid film provides a wrinkled curvature to overcome a contact force between the wet and dry regions

	Velocity (m/s)	Thickness (mm)
Nusselt theory	1.49909	0.677079
OpenFOAM	1.49942	0.677494



- Partially-wetted 2D spatial distribution



(a) Γ=73 g/m/s (b) Γ=125 g/m/s (c) Γ=212 g/m/s (d) Γ=505 g/m/s

Conclusion

- The liquid film solver implemented in OpenFOAM is validated by simulating falling films on a vertical plate.
- The simple 1D falling film reveals an oscillating curvature at the front section. The steady-state film velocity and thickness show good agreements with the Nusselt theory.
- The partially wetted flow is simulated to account for the 2D liquid film phenomena such as wet/dry separation, rivulet formation, isolated wet droplets, etc. The simulation appropriately predicts the formation of the rivulet flow and the reduction of the wetted area fraction.
- The present liquid film solver will be employed for the steam condensation analysis on the cooling surface in ensuring the structural integrity of the containment.

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