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COMPUTATIONAL MODELLING OF THIN FILM RUNOFF AND EVAPORATION ON SURFACES

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Rain impingement on building surfaces and the subsequent thin water film runoff are important moisture sources that influence the hygrothermal behaviour, durability, aesthetic appearance of building facades, and the leaching of biocides from the facades. Runoff of thin film fluid formed by droplet accumulation is particularly pronounced for smooth and semi-impermeable surfaces. There is, however, little knowledge on this phenomenon. Various studies, mostly performed through small-scale experiments and direct measurements on buildings, aimed to quantify the runoff process. Similarly, there were many experimental and theoretical studies focusing on droplets impingement mechanisms as well as thin fluid film dynamics. Computational modelling of the runoff on building facades is often performed by empirical equations due to the complexity in the mathematical formulations and numerical discretisation of the physical phenomena involved.

Recent advances in computational science have made it feasible to model these physical processes in a more detailed manner. However, such detailed approach has only been explored rarely within the building and environmental engineering communities.

In this study, a Eulerian unsteady Reynolds Averaged Navier-Stokes (RANS) method is developed and validated to simulate thin fluid film runoff on an impervious surface and the related physical phenomena occurring, i.e. wave formation, fingering, and film evaporation.

The kinematics of the thin film is resolved using the Eulerian unsteady RANS equation and a Finite Volume discretisation. A quasi-three-dimensional Volume of Fluid (VoF), is implemented in OpenFOAM (version 2.2.0). The quasi-three-dimensional implementation is achieved by evolving through time the continuity equation of the film thickness (h) in the x- and y- directions on computational cells, which is known as the long-wave approximation. Therefore, in this simplification, only a single computational cell is required in the z-direction to store the film thickness $h\ (x, y, t)$. The pressure in the z-direction can be calculated using the Laplace-Young boundary condition, such that $p(z) = -\sigma\kappa + p_{atm}$, where σ is the surface tension, κ is the curvature of the boundary and p_{atm} is the atmospheric pressure of the air region. This simplification is in accordance with the lubrication theory [Oron, et al. 1997, Kondic, 2003]. The momentum equation reads

$$\frac{\partial(\rho h\,\mathbf{u})}{\partial t} + \big((\rho h\,\mathbf{u})\ \cdot \nabla\big)\mathbf{u} = -\,h\,\nabla p + F_{sh} + F_{ca} + \nabla\sigma + \ \rho g h\,(\sin(\theta) - \cos(\theta)).$$

ρ is the fluid density, θ is the angle of plate inclination, and $\mathbf{u}$ is the velocity vector. The influences of surface shear F_{sh} and surface contact angle F_{ca}, which determine the evolution of thin fluid film, are parameterised in the model. Furthermore, the thermodynamics of the fluid film, such as Marangoni or thermocapillary force ($\nabla\sigma$), convection and evaporation to the air domain, have been included in the model.

Two validation simulations have been performed, namely, the hydrodynamics of film runoff on a narrow-width plate (0.08 m x 1.92m) with a slope of 45° (from the experiments of Moran, *et al.* 2002 and Ambrosini, *et al.* 2002), and the evaporation from a thin fluid film on a vertical (90°) narrow-width plate (0.3m x 1.0m) (Yan and Tsay, 1991). The first comparison focuses on the capability and accuracy of the model to quantify kinematic variables, such as film velocity, thickness, fluid wave spectrum, whereas the latter assesses the accuracy of the model to quantify evaporation and the associated latent heat transfer. Grid sensitivity studies have been performed for both validation cases in order to obtain optimal (mesh-independent) results.

The comparison of film thickness as well as velocity profiles for various Reynolds number suggest that the unsteady RANS model performs better in predicting the kinematic quantities, compared to the results from the Nusselt model, which is an empirical parametrisation of thin fluid film. Additionally, the model is able to detect the fingering dynamics and the waves that can occur in a thin film. A satisfactory result on the wave spectra has also been obtained when compared against the results of Ambrosini, *et al.* 2002. The validation simulation of evaporation and the associated cooling of the film runoff results in a very good agreement of interfacial heat and mass fluxes with the experiment. This developed model can now be utilised to quantify runoff due to rain impingement on building facades more accurately, for various geometry and surface properties. Furthermore, the model will be coupled to porous material models for building facades where absorption and biocide leaching are considered.

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