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Thin liquid films interacting with gas jets

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Thin liquid films in contact with gas flows appear in many industrial applications, such as evaporators, distillation columns, or coating lines, in which the gas–liquid interaction critically influences the efficiency of the process. Surface waves at the interface enhance heat and mass transfer, yet under strong gas forcing the film can deform enough to alter the gas flow itself. A prime example is the turbulent impinging gas jet on a liquid film, which can produce fascinating coupling phenomena [1]. Capturing these bidirectional effects requires fully coupled two-phase CFD simulations, but their computational cost is prohibitive for most industrial-scale problems.

Such a two-phase numerical approach was used to understand in depth the feedback phenomenon that takes place in the jet wiping process, widely used in galvanization. In this process, a liquid film dragged by a substrate moving against gravity is impinged by a high-speed slot gas jet which acts as an “air knife”, reducing its thickness and generating a runback flow of excess liquid. The gas–liquid coupling was elucidated via high-fidelity CFD simulations [1], previously validated against lab-scale experiments. This interaction gives rise to large-amplitude waves in the runback flow, which in turn cause the jet to bend periodically. The oscillating jet then modulates wiping efficiency and imprints waves onto the final wiped film.

As an alternative to predict the dynamics of the liquid, Integral film models based on the long-wave approximation are orders of magnitude faster, but because they rely on externally supplied jet-induced stresses, they cannot capture the unsteady coupling between the gas jet and the liquid film. Building on this, we introduce the concept of a hybrid numerical solver, that couples a reduced-order integral model for the liquid film (BLEW, developed in the von Karman Institute [2]) with a standard Navier–Stokes solver for the gas phase. At each time step, the gas solver treats the film interface as a deformable wall: it computes the jet-induced stresses, passes them to BLEW to update the film profile, and then deforms its mesh in an Arbitrary Lagrangian–Eulerian framework to follow the new interface. After validating the film model against previous two-phase simulations, the hybrid framework successfully captures the dominant hydrodynamic mechanism in the gas-liquid coupling. In particular, the predicted wave frequency and flow features are in good agreement with the two-phase numerical data. This approach provides a flexible and computationally efficient tool to explore complex industrial gas-liquid configurations.

Keywords: Gas-liquid flow, coupling, CFD, thin films.

References:

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