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Thermal Performance of Falling Liquid Films in Vertical Channels with Intermittent Boiling

Misagh Mokhtari[1], Zohreh Shapoori[2]

Falling liquid films are widely used in vertical heat exchangers and compact evaporators due to their high surface area-to-volume ratio and enhanced phase change dynamics. Under transient operating conditions—such as power cycling in electronics or thermal fluctuations in industrial cooling—boiling in these systems becomes intermittent, leading to alternating nucleate and film boiling regimes. This unsteady phase transition behavior significantly impacts film stability, local dry-out, rewetting, and the overall heat transfer performance. Despite its importance in practical applications, the effect of intermittent boiling on falling film hydrodynamics remains poorly understood, especially under variable heat fluxes.

A 2D vertical channel was modeled using the Volume of Fluid (VOF) method coupled with a wall-boiling model implemented in ANSYS Fluent. Water was chosen as the working fluid. The wall heat flux was applied as a time-dependent function (square and sinusoidal pulses) to simulate intermittent boiling scenarios. Governing equations for mass, momentum, energy, and phase change were solved under transient conditions. Film thickness, temperature, vapor volume fraction, and local Nusselt number were monitored throughout the simulation. Cases with steady and intermittent boiling were compared to isolate the effects of pulsed heat input. Mesh independence and time-step sensitivity analyses were performed.

The results showed that intermittent boiling cycles significantly influence thermal performance and film dynamics. During the high-flux (on) phase, rapid bubble growth led to local film thinning and dry patches near the heated wall. In the off phase, rewetting was delayed due to residual vapor presence, resulting in a cyclic heat transfer coefficient pattern. Compared to steady boiling, intermittent conditions produced up to **18–25% lower time-averaged Nusselt numbers**, depending on pulsing frequency and amplitude. The vapor slug formation and collapse dynamics also influenced the film stability, especially in low-flow rate regimes.

This study demonstrates that intermittent boiling leads to complex, non-linear responses in falling film systems, which must be considered in the design of compact heat exchangers and thermally regulated surfaces. Further work, including experimental validation and optimization of pulsing profiles, is essential to maximize heat removal under cyclic operation.

Keywords: Intermittent Boiling, Falling Liquid Films, Phase Change Heat Transfer, Computational Fluid Dynamics (CFD).

References (examples):

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[1] Department of Mechanical Engineering, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran (e-mail: mokhtarimisagh4@gmail.com).

[2] Department of Mechanical Engineering, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran