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Effect of Power Transients on Vertical Bubble Coalescence in Nucleate Pool Boiling:
A Computational Study

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Abstract

This study employs a validated Computational Multi-Fluid Dynamics (CMFD) solver based on a Ghost Fluid Method Sharp Interface Level Set approach to investigate the effect of power transients on vertical bubble coalescence in nucleate pool boiling from a single cavity site. Using a 2D axisymmetric domain with ethanol as the working fluid at a constant time-averaged heat flux of 10 kW/m², the work systematically characterises the role of excursion time, delay time, surface wettability, and fluid properties on boiling dynamics. A critical excursion time was identified as the minimum transience required to trigger coalescence, governed by the condition that the waiting time multiplied by the rise velocity of the preceding bubble must not exceed the seed diameter. Reducing excursion time below this threshold drives the system through a sequence of regimes — periodic, chaotic, and ultimately continuous chain coalescence — with bubble frequency increasing significantly and augmenting latent heat transfer. Introducing a delay time phase into the cyclic heat flux profile paradoxically raises the critical excursion time by inducing a pairing effect between alternate bubbles, while simultaneously suppressing chain coalescence even at very low excursion times, suggesting a pathway for transient Critical Heat Flux (CHF) enhancement. Parametric studies show that increasing contact angle (hydrophobicity) raises bubble diameter and lowers the critical excursion time, while methanol and water exhibit approximately 30% and 40% reductions in critical excursion time relative to ethanol, driven by differences in latent heat dissipation, surface tension, and specific heat. A non-dimensional power-law correlation linking critical excursion time to the combined parameter $Bo \cdot Pr^{-0.5}$ was developed to enable universal prediction across fluids and surface conditions. For pulse-based heating, coalescence is governed primarily by the heating time ratio and maximum heat flux, consistent with exponential heating findings, and the inherent long delay phase at low heating time ratios prevents chain coalescence entirely.