Proceedings of the Canadian Society for Mechanical Engineering International Congress 2022
CSME Congress 2022
June 5-8, 2022, Edmonton, AB, Canada

A Limited Nucleation Model to Simulate Liquid-Vapour Phase Change

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ABSTRACT

Development of a phase change model has important implications in industries such as oil and gas, automotive, nuclear and other major industries. Phase change can be modeled as occurring, either due depressurization or due to addition of heat, also termed as boiling. In the case of depressurization, most of the Computational Fluid Dynamics (CFD) models are developed for cavitation, where the phase change is localised and mass transfer rates are much lower, as compared to flashing, where there is a higher mass transfer and large complex liquid-vapour structures are formed. These features are not captured by conventional models, which treat the fluid as a mixture of phases. A more sophisticated Euler-Euler scheme, also called a Two-Fluid (TF) method is required to model the inter-momentum forces, such as lift, drag, virtual mass and turbulent dispersion forces, to better capture the flow field. The conventional methods also do not account for the delay in the formation of the initial vapour nuclei, which can lead to a pressure undershoot in phase change due to depressurization. This delay is caused by the initial critical size of the bubble being too large and the bubbles bursting before reaching this size and it results in the fluid remaining in the liquid state after crossing saturation conditions (superheated).

In this study, flashing of steam is simulated in a converging-diverging nozzle due to pressure drop, using the Two Fluid method, with full closure of inter-momentum forces. Standard models for lift, drag, virtual mass and turbulent dispersion forces are used to calculate the forces. The simulation results are compared with experimental results obtained from Brookhaven National Laboratories (BNL). The critical work of bubble formation is used as the criterion for the superheated liquid. This also allows to narrow down the nucleation/mass transfer regions in the domain, thereby achieving better compliance with experimental results. The mean sauter diameter is used to compute the mass transfer rate based on Newton's law of cooling. It is assumed that the nucleation bubble diameter is independent of the diameter of the flow field. The first bubble of vapour is observed just downstream of the throat near the wall, where the highest rate of depressurization is observed. The comparison with experimental data shows very good agreement for pressure and volume fractions. It is seen that the inter-momentum forces are essential to accurately predict transport of vapour fractions downstream of the nucleation region.