Analysis of surface wettability effect on nucleate boiling with a diffuse interface method

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Abstract

Multi-phase systems with phase-change phenomena, in particular boiling, are common in many industrial applications, including power generation plants and thermal management of high-power and high-dissipation-rate micro-devices which would burn out if not cooled properly.

Due to the non-equilibrium thermodynamics and the complexity of coupling the heat and mass transfer in phase-change and surface processes, these systems are difficult to describe accurately. Although experiments have been conducted to study boiling, its mechanisms and heat transfer characteristics are still not understood completely.

We simulate pool boiling using the diffuse interface method (DIM) embedded in our home-grown "TPLS" solver. This method allows the imposition of a boundary condition to prescribe wettability removing the stress singularity at the three-phase contact line, thus enabling us to analyse the role of surface features on heat transfer coefficient, bubble growth and bubble departures. Our framework also allows simulation of populations of bubbles and analyse bubble interactions at varied bubble sizes for different wettabilities as a function of superheat. We compare our simulations with our nucleate boiling experiments using FC72 on silicon surfaces.

Our simulations show the importance of surface tension on departure conditions, suggesting a higher heat transfer coefficient in hydrophilic cases. Conversely, we have found limited bubble growth rate on hydrophobic surfaces. In hydrophobic cases, the larger amount of residual vapour left on the heater surface after bubble departure limits the coolability of the substrate but it might promote the growth of forming bubbles subsequently.