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Isothermal and non-isothermal growth of a vapor bubble in pool boiling – Effect of translational velocity of bubble

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ABSTRACT

In the present work, we have numerically simulated the effect of bubble translation on the growth of a vapor bubble in a pool of superheated liquid based on the isothermal and non-isothermal model. The isothermal growth uses the ODE solver and the non-isothermal growth the PDE-ODE solver. The overall model at present considers the forces acting on the bubble to compute the bubble motion and the energy balance at the bubble surface to include the effect of bubble size on its motion. Thus, it computes equivalent bubble radius and bubble velocity simultaneously. The numerical simulation shows a remarkable improvement by our method over the previous numerical model while validating with the experimental and numerical results on bubble growth with the phase motion. The improved model has significantly reduced the deviation from the experiments reported in literature on the growth of a moving bubble. The aspect ratio of the bubble is computed to see the shape change of the bubble and is used to model the drag force accurately. It has been shown that the model of the isothermal growth can better explain the bubble growth at the initial stage, and the model of the non-isothermal growth at the final stage. The non-isothermal growth of bubble is accompanied by the slowdown of the bubble translation in the superheated liquid.

1. Introduction

The bubble translation essentially affects the spatial variation of temperature of liquid surrounding the vapor bubble, the temperature gradient at interface, and heat and mass transfer through the interface in the bubble growth [1–7]. Growth and translation of a vapor bubble in a boiling liquid is a two-phase flow with heat transfer. The rate of vaporization speeds up when a vapor bubble translates in the superheated liquid in the saturated boiling flow. The propagation of a rarefaction wave in the liquid causes a rapid vaporization (Prosperetti [4]). Thus, a large amount of vapor is used in power generation. The effect of bubble motion on the bubble growth and collapse are mostly studied experimentally and theoretically (approximate solutions). The experiments support that the complex dynamical change of the shape of a moving bubble makes the problem of bubble dynamics more complicated and interesting. Very recently, Paruya and Bhati [1,5] numerically simulated the effect of bubble motion on the bubble growth and collapse in pool boiling. The numerical model for the bubble motion was not adequate. They used a constant rise velocity of the bubble of a finite size. In experiments, the bubble gradually accelerates while growing or collapsing in a pool of liquid. The model neglected the effects of viscous drag, the momentum of vapor phase, the bubble size and the added mass due to the phase change. Thus, the numerical model gave rise to a high bubble radius initially compared to the experimental bubble radius. Growth and collapse of a vapor bubble rely on the heat transfer at the bubble surface. Thus, the effect of phase motion (convection) enhances the rate of heat transfer. The motion of bubble depends on the shape of the bubble. Consequently, the enhanced heat transfer, in turn, generates a feedback to the evolution of a growing or collapsing vapor-bubble.

Yang and Prosperetti [2] performed a theoretical study to find a fast collapse of the bubble in the isothermal subcooled liquid initially, caused by the inertia, due to a sudden exposer to the liquid. The bubble flattened on the orthogonal plane of the translational velocity and increased the added mass and consequently, slowed down. The collapse time for a spherical bubble did not differ significantly from that due to the bubble deformation. Legendre et al. [3] theoretically studied the effect of a steady and uniform mean velocity on the growth and collapse of a bubble, and showed that interfacial heat transfer depended on the ratio of the radial velocity to the translational velocity (streamwise velocity). If the ratio is approximately unity, the radial advection decreases and the thermal layer depends on the translational velocity. Ivashnyov

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