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Lattice Boltzmann Simulation of Nucleate Pool Boiling in Saturated Liquid

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Abstract. A thermal lattice Boltzmann method (LBM) for two-phase fluid flows in nucleate pool boiling process is proposed. In the present method, a new function for heat transfer is introduced to the isothermal LBM for two-phase immiscible fluids with large density differences. The calculated temperature is substituted into the pressure tensor, which is used for the calculation of an order parameter representing two phases so that bubbles can be formed by nucleate boiling. By using this method, two-dimensional simulations of nucleate pool boiling by a heat source on a solid wall are carried out with the boundary condition for a constant heat flux. The flow characteristics and temperature distribution in the nucleate pool boiling process are obtained. It is seen that a bubble nucleation is formed at first and then the bubble grows and leaves the wall, finally going up with deformation by the buoyant effect. In addition, the effects of the gravity and the surface wettability on the bubble diameter at departure are numerically investigated. The calculated results are in qualitative agreement with other theoretical predictions with available experimental data.

AMS subject classifications: 76T10, 76M28, 80A22

Key words: Lattice Boltzmann method (LBM), two-phase fluid flows, heat transfer, nucleate pool boiling, wettability.

1 Introduction

Two-phase fluid flows with phase change are of great importance in science and engineering fields. In particular, flows with nucleate boiling can be found in many industrial

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applications because the efficiency of heat transfer is much higher than in single phase flows. In these applications, it is necessary to make correct predictions of heat transfer characteristics of two-phase fluid flows. However, most of the past studies on such nucleate boiling were related to collection of data for boiling process obtained as a function of any of the several independent variables: heater and flow conditions, system pressure, liquid/vapor thermophysical properties and so on (e.g., see reviews [1–3]). Thus, although the effects of these parameters on the heat transfer coefficient have been investigated and quite well established, the detailed mechanisms were not fully understood owing to its complexity. Nevertheless, with the current advance in precision measuring devices and high-performance computers, several experimental and numerical studies of these issues have recently been performed.

Main features of the nucleate boiling process that affect the rate of heat transfer during the ebullition cycle are the bubble radius at departure and the frequency at which bubbles are generated and departed. J. Kim and M. H. Kim [4] performed quantitative analyses of bubble departures during nucleate pool boiling and obtained dimensionless scales based on experimental data that had been previously reported in many studies. With regard to numerical researches, for example, Kunugi et al. [5] carried out direct numerical simulation of pool boiling phenomena by the MARS (Multi-interface Advection and Reconstruction Solver) method [6]. Mukherjee and Kandlikar [7] used the numerical model of Mukherjee and Dhir [8] to simulate vapor bubble growth on a heated wall by means of the level-set technique.

Whereas these simulations of boiling phenomena require some models for phase change such as the enthalpy method or temperature recovery method [9], an alternative approach has been proposed to simulate nucleate boiling without using any of the models. The method is based on the free-energy approach in nonequilibrium thermodynamics. Takada and Tomiyama [10] conducted numerical simulation of two-phase flows with phase change using a phase-field method. Seta and Okui [11] proposed a lattice Boltzmann method (LBM) [12, 13] with heat transfer to simulate pool boiling in two-dimensional flows. More recently, Hazi and Markus [14] also carried out lattice Boltzmann simulations of pool boiling phenomena and investigated bubble diameter at departure and release frequency under different gravity and various wetting conditions on a heated surface.

In the LBM for two-phase fluid flows, several models [15–18] have been developed and successfully applied to many kinds of issues such as phase separations, instability problems, droplet dynamics, bubble flows and so on. In particular, Inamuro et al. [19] proposed two-phase LBM, which enables the stable calculation of two-phase fluid flows with large density ratios of up to 1000. In the present paper, therefore, we incorporate the effects of heat transfer with nucleate boiling into the two-phase LBM proposed by Inamuro et al. to simulate the nucleate pool boiling on a heated surface. By using this method, the effects of the gravity and the surface wettability on the bubble diameter at departure are numerically investigated.