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Confined bubble growth during flow boiling in a mini-/micro-channel of rectangular cross-section part II: Approximate 3-D numerical simulation

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This Part II of the paper reports the three-dimensional (3-D) numerical modelling on bubbly flow in confined mini-/micro-channels using the volume of fluid (VOF) method in commercial CFD code FLUENT. The numerical simulation aims to provide detailed information of the fields of velocity, temperature and pressure so as to further understand the effect of bubble growth on the flow field and heat transfer from the channel wall.

In Part I, the experiment of flow boiling in a mini-/micro-channel of rectangular cross-section was carried out and a simple one-dimensional (1-D) model for the interaction of the pressure fluctuations during the growth of a confined bubble with various kinds of upstream compressibility was developed as an aid to the rational specification of inlet resistance. In Part II, the experimental observers and the theoretical model developed in Part I are tested by performing the 3-D numerical simulation of bubble growth from nucleation to full confinement. The simulation involves some approximations based on a concept of pseudo-boiling to avoid the well-known difficulties of modelling bubble generation and growth. During the simulation, the volumetric growth rate of the bubble is defined to match the experimental observations. At small times prior to bubble detachment, a vapour flow was injected through a small hole in the wall to simulate nucleation. Following partial confinement, vapour injection was stopped and growth was driven by the generation of vapour at a defined rate at the contact area between the bubble and the superheated wall. The 3-D simulation reproduces the experimental observations of the distorted profile of the bubble and its trajectory during partially confined growth and provides information about flow and heat transfer in the bulk liquid outside the thin film region. The 3-D and 1-D predictions of the development of axial pressure distributions during partially and fully confined growth are in satisfactory agreement.

1. Introduction

As an effective mode of heat transfer, channel nucleate boiling and flow boiling have widely been employed in various heat exchange systems [1–4]. Especially, with the development of the state-of-the-art micro-scale and micro flow technologies, the advantages of boiling in small hydraulic diameter channels are receiving increasing attention from both academia and industrialists [5]. Compared with conventional channels, evaporation in a small channel can provide higher heat transfer coefficient due to its larger contact area per unit volume of fluid. Much research work has been carried out to study the micro-channel boiling in recent years. Some comprehensive reviews on heat and fluid flow in micro-scale were offered by Kandlikar [6,7], Thome [8] and Agostini et al. [9].

Bubble nucleation and growth to confinement during flow boiling in heat sinks employing parallel micro-channels cause undesirable pressure fluctuations and flow reversals that may be suppressed by flow resistances and enhancement of nucleation at the entrance to every channel [10–13]. The study in Part I [14] provided a critical review of recent developments and experimental examples of confined bubble growth without and with flow reversal for different upstream conditions during flow boiling of water in a single channel 40 mm long and of rectangular cross-section 0.38 mm × 1.6 mm. A 1-D model for the pressure changes accompanying growth was developed as an aid to the rational specification of the inlet resistance required to suppress flow reversal. A novel feature was that growth was considered in two stages: partial confinement by the minor dimension of a rectangular cross-section, then full confinement by the major dimension.

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