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Experimental studies of adiabatic flow boiling in fractal-like branching microchannels

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ABSTRACT

Experimental results of adiabatic boiling of water flowing through a fractal-like branching microchannel network are presented and compared to numerical model simulations. The goal is to assess the ability of current pressure loss models applied to a bifurcating flow geometry. The fractal-like branching channel network is based on channel length and width ratios between adjacent branching levels of $2^{-1/2}$. There are four branching sections for a total flow length of 18 mm, a channel height of 150 μm and a terminal channel width of 100 μm. The channels were Deep Reactive Ion Etched (DRIE) into a silicon disk. A Pyrex disk was anodically bonded to the silicon to form the channel top to allow visualization of the flow within the channels. The flow rates ranged from 100 to 225 g/min and the inlet subcooling levels varied from 0.5 to 6 °C. Pressure drop along the flow network and time averaged void fraction in each branching level were measured for each of the test conditions. The measured pressure drop ranged from 20 to 90 kPa, and the measured void fraction ranged from 0.3 to 0.9. The measured pressure drop results agree well with separated flow model predictions accounting for the varying flow geometry. The measured void fraction results followed the same trends as the model; however, the scatter in the experimental results is rather large.

1. Introduction

Boiling will occur for internal flows if the pressure drop along the flow results in a fluid pressure sufficiently below the vapor pressure for phase change to occur. Boiling in this case occurs without the addition of heat; thus it is described as adiabatic boiling. Adiabatic flow in capillary tubes has been utilized in refrigeration systems for many years to control the mass flow rate of refrigerant through the evaporator. These capillary tubes generally have inside diameters on the order of 1 mm and lengths on the order of 1 m, which implies a reasonably high pressure drop along the tube. As microchannel flow systems are being developed for energy and cooling systems an understanding of the adiabatic flow boiling process is needed to aid in model development used for design purposes. These flows generally start as single-phase subcooled liquid, then as the pressure falls below the saturation pressure some of the liquid flashes and two-phase flow ensues. Early studies by Whitesel [1,2] yielded empirically based relationships to predict the mass flow rate in capillary tubes given the geometry and the inlet and exit pressures. However, results were found to vary between −10% and +14%, indicating that there were significant flow rate variations for identical inlet and exit conditions. Mikol [3] and Mikol and Dudley [4] found that boiling does not occur immediately when the static pressure drops below the saturation pressure, but that the fluid remains in the liquid phase until the vaporization pressure is reached. Non-equilibrium phase change occurs for a small distance along the flow until the pressure, temperature, and quality asymptotically reach equilibrium conditions.

The region of the capillary where the pressure is below the saturation pressure is defined as the metastable region. Meyer and Dunn [5] studied the behavior of the metastable region as a function of the inlet liquid subcooling showing that for the same subcooling, the mass flow rate depends on whether the subcooling is approached from above or below. This difference in flow rate increases for smaller inlet subcooling values, and when approached from below, a lower mass flow rate occurs.

Bittle et al. [6] found similar results while showing that by providing nucleation sites, such as a small diameter wire or small holes in a tube wall, the variation in mass flow rate is significantly reduced. Bittle and Pate [7] examined a variety of fluids to predict the necessary vapor pressure conditions. Wong and Ooi [8] compared various homogenous two-phase viscosity models against data from other adiabatic capillary studies and found that the Dukler et al. [9] viscosity model matched the data best.

Predictive models for single- and two-phase flow through capillary tubes have been developed based on several studies such as

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