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Two-phase air–water flow in micro-channels: An investigation of the viscosity models for pressure drop prediction[☆]

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ABSTRACT

Adiabatic two-phase air–water flow is experimentally studied in this work. Two channels, made of fused silica, with different diameters of 0.53 and 0.15 mm are used as test sections. The void fraction data for both tubes are obtained by image analysis. For the larger channel, the void fraction is found to be a linear relationship with the volumetric quality. In the case of the smaller one, however, the non-linear void fraction is obtained. The measured frictional pressure drop data are compared with the predictions regarding the homogeneous flow assumption. Several well-known two-phase viscosity models are subsequently evaluated for applicability to micro-channels.

1. Introduction

Two-phase flow in micro-channel flow passages has been studied over the years. Clarification of micro-scale effects on two-phase flow and heat transfer characteristics has become more necessary due to the rapid development of microstructure devices used for several engineering applications including medical devices, high heat-flux compact heat exchangers, and cooling systems of various types of equipment such as high performance micro-electronics, supercomputers, and high-powered lasers.

Several investigators have proposed criteria to address the definition of a micro-channel. The proposed channel classifications are often based on different dimensionless parameters. For instance, arbitrary channel classifications based on the hydraulic diameter D_h have been proposed. Mehendale et al. [1] employed the hydraulic diameter as an important parameter for defining heat exchangers and Kandlikar [2] proposed criteria for small flow channels used in engineering applications.

Two-phase flow and heat transfer characteristics in small channels such as micro-channels and mini-channels are likely to be strongly dependent on surface tension effects in addition to viscosity and inertia forces, resulting in significant differences in two-phase flow phenomena between ordinarily sized channels and small channels.

In the past decade, a relatively small amount of publications have been available for both mini-channels and micro-channels compared to those for ordinarily sized channels.

Triplett et al. [3,4] studied adiabatic two-phase air-deionized water (DI water) flow characteristics in micro-channels with hydraulic diameters ranging from 1.1 to 1.5 mm. The flow patterns observed were bubbly, slug, churn, slug-annular, and annular. The measured void fraction and two-phase pressure drop in the relevant flow regimes were also investigated. The void fraction data were obtained based on image analysis.

Serizawa et al. [5] investigated the visualization of the two-phase flow pattern in circular micro-channels. The flowing mixture of air and water in channels 20, 25, and 100 μm in diameter and that of steam and water in a channel of 50 μm in diameter were studied experimentally. Two-phase flow patterns obtained from both air–water and steam–water flows were quite similar and their detailed structures were described. The study confirmed that the surface wettability had a significant effect on the two-phase flow patterns in very small channels.

Chung and Kawaji [6] performed an experiment to distinguish the two-phase flow characteristics in micro-channels from those in mini-channels. Four different circular diameters ranging from 50 to 526 μm were employed to examine a scaling effect on nitrogen-DI water two-phase flow. The results including the flow patterns, void fraction, and two-phase pressure drop were analysed.

A flow visualization study to clarify the flow patterns of a vertical upward gas–liquid two-phase flow in rectangular mini-channels with hydraulic diameters ranging from 1.95 to 5.58 mm was carried out by Satitchaicharoen and Wongwises [7]. Air–water, air — 20 wt.% glycerol solution, and air — 40 wt.% glycerol solution were used as working fluids. In the experiments, they employed various rectangular test sections: 20 mm × 2 mm, 40 mm × 1 mm, 40 mm × 2 mm, 40 mm × 3 mm, and 60 mm × 2 mm with an equal length of 1 m. The flow phenomena, which were classified as bubbly flow, cap-bubbly

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