Numerical study of two-phase flow in vertical microtubes: Adiabatic flow pattern maps

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Abstract The current paper reports on a study of two-phase flow of liquid-vapour R134a in vertical circular channels with diameter of 1 mm using the Volume of Fluid (VOF) method. The purpose of these simulations was to develop a numerical flow regime map in order to identify the flow pattern boundaries. The vapour was injected using an annular (concentric) nozzle configuration. Two dimensional, axi-symmetry was assumed in order to save computational time and effort. Based on the numerical flow pattern maps developed in this study, four basic flow patterns were identified, namely: bubbly flow/confined bubble flow, slug flow, churn flow, annular flow. The present results were verified through comparison with the experimental flow visualization results and were shown to agree well. The study also showed that Computational Fluid Dynamics can be used to obtain a reliable two-phase flow pattern map.

Keywords: Two phase flow, flow pattern map, R134a, Computational Fluid Dynamics.

1. Introduction

Two-phase flow in microchannles has been studied extensively due to its wide range of applications in micro-electro-mechanical systems (MEMS) and systems designed to cool high heat flux electronic devices. Studies focused in two-phase flow in microchannels focusing on flow boiling and thus a significant number of reports on flow and heat transfer characteristics and empirical correlations were presented. Additionally, many researchers have conducted visualization of flow patterns in microchannels and presented flow patterns maps. Based on visual observations reported by previous researchers, the flow patterns or flow regimes that occur depend on the gas and liquid flow rates and can be affected by the micro passage geometry and flow parameters. The prevailing flows can be divided into three groups, namely surface tension dominant, inertia dominant and transitional regimes [1].

The study of flow patterns is important since the prevailing flow characteristics relate to the pressure drop and heat transfer rates in the channels. However, there is inconsistency in terminology of two-phase flow patterns, [1-3]. For example, slug flow, Taylor flow and bubble train flow as found in literature refer to the same flow regimes. One of the reasons for this discrepancy is the difficulty in classifying and analysing transitional flows. Therefore, there are morphological and flow pattern changes, and disagreements on flow patterns reported under the same flow condition [1]. In addition, in most works, there are no clear criteria mentioned for the transition from one regime to another, i.e. the transition boundaries were determined qualitatively and cannot provide sufficient accuracy, when experiments are repeated [4]. In this study, a numerical simulation was developed in order to determine transition boundaries between vapour-liquid two phase flow in a microchannel.

2. Computational model

A numerical flow pattern map for two phase flow in a vertical circular microchannel with a diameter of 1 mm under adiabatic conditions was produced by performing simulations for 82 different sets of flow conditions. The microchannel was modelled as a two-dimensional axisymmetric domain to save computational time and effort. The effect of gravity has been accounted for. The vapour was introduced at the centre of the channel inlet, with the liquid entering in an annulus around the vapour core. A pressure outlet boundary condition was applied at the channel outlet. The two-phase flow of R134a in the channel was assumed to be incompressible, adiabatic and to possess constant physical properties. This paper includes initial results for only one size of the gas inlet nozzle, i.e. d = 0.6 mm.

3 Results and Conclusions

In general, when the liquid superficial velocity is constant and the vapour superficial velocity increases, the flow patterns evolved, in sequence, from bubbly flow, to confined bubble flow, slug, churn (transition flow from slug to annular) and annular flow. The comparison of the numerical results (in colour) and the flow visualization results of Chen et al. [5] are depicted in Figure 1, with good agreement. Note the less chaotic nature of the churn flow of the numerical results. The flow pattern map of [5], modelled in [6] and the new modification developed by [7], predicted well the numerical data except the transition from the bubbly-slug and the slug-churn flow regime, see Figure 2. The study also proofs that the CFD method can be a feasible way to draw the two-phase flow patterns map. The nozzle size in relation to the channel diameter is important and can affect the resulting flow patterns. This is currently under investigation and may explain the partial differences between the current numerical work and the experimental results presented in [5-7].

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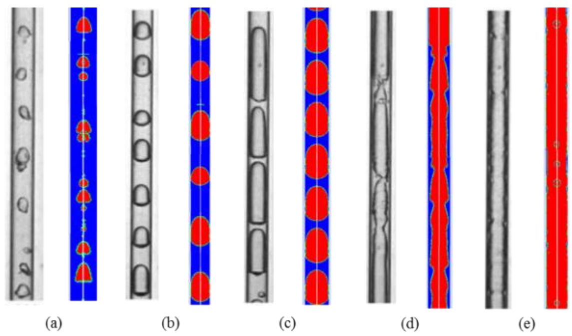

Figure 1. Comparison of visualization of numerical flow pattern results with [5] (a) bubbly flow, U_{gs}=0.17 m/s; U_{ls}=1.16 m/s (b) confined bubble flow, U_{gs}=0.02 m/s; U_{ls}=0.06 m/s (c)slug flow, U_{gs}=0.13 m/s; U_{ls}=0.07 m/s (d)churn flow; U_{gs}=0.76 m/s; U_{ls}=1.16 m/s (e) annular flow, U_{gs}=2.03 m/s; U_{ls}=1.16m/s

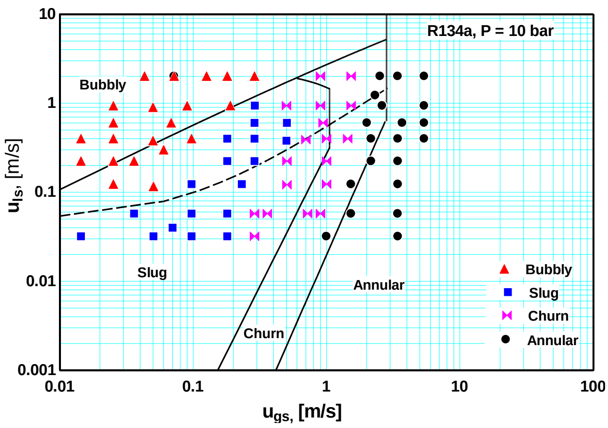

Figure 1. Comparison of numerical flow pattern with flow pattern map of [6] (solid lines) and the modification developed by [7] (dotted line).