A visualization of flow patterns during adiabatic two-phase flow of air-water mixtures in microchannel

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Abstract: - A visualization method using image processing to observe the flow pattern of air-water mixtures in microchannel is developed. A high-speed camera is used to identify the flow regimes. A 250-mm-long and 1-mm-inner diameter circular glass tube is used as the test channel. Air and water flow rates range from 0.01 to 0.1 L/min and 0.3 to 0.9 L/min, respectively. The results report that all observed flow patterns are annular. In addition, the comparison between the present experimental data and well-known two-phase flow pattern maps available in the literature is presented.

Key-Words: - Flow pattern map, air-water mixture, microchannel, annular flow, visualization method

1 Introduction

Because of global environmental issues, various technologies have been developed to curtail energy consumption and environmental pollution. The miniaturization has become the choice in these technologies, both for reducing the weight of the system and the fluid charge. However, the changeover from conventional to compact heat exchangers has not been completely ready. Particularly, a better understanding on the two-phase flow phenomenon in the microscale channels is necessary to optimize the design of each component in the system. On the other hand, the consideration on two-phase flow pattern in compact heat exchanger is the characterization of how the fluid flows through the microscale channels, which is relative to the thermal performance of heat exchanger.

Over the years, the publications concerning with the two-flow pattern in the conventional tube have been the subjected of some researchers. However, there has been very few works concerning with the observation of two-phase flow pattern in microchannel via image processing method available in the literature, which are summarized as follows:

Triplett et al. [1] performed the experimental study on the adiabatic air-DI water flowing through microchannels. The hydraulic diameter of microchannel was in the range of 1.1-1.5 mm. They observed that the bubbly, slug, churn, slug-annular, and annular flow patterns occurred in this study. Satitchaicharoen and Wongwises [3] observed the flow patterns of air-water flow in rectangular mini-channels. The test sections were placed vertically. A high-speed camera was used to capture the flow patterns in this study. The hydraulic diameters of rectangular mini-channels were in the range of 1.95 to 5.58 mm. The results revealed that the bubbly, cap-bubbly, slug, churn, and annular flow patterns were detected. The influences of liquid viscosity, size of gap, and width of channel on the transition of flow pattern were also examined in this study. The effect of working fluid on the two-phase flow pattern in the microchannel was investigated by Saisorn and Wongwises [4]. The diameter of microchannel was 0.53 mm. Four working fluids, i.e. nitrogen gas, air, water, and deionised water, were tested. They found that the data obtained from air-water flow was consistent with those of other fluids. Barreto et al. [4] study an adiabatic air–water upward flow in seven parallel microchannels. The results showed different air–water flow pattern in each channel, although approximately homogeneous conditions were verified in the inlet manifold for single-phase flows. Single-phase liquid and gas flow patterns were simultaneously found together with two-phase flow patterns: bubbly flow, slug flow, churn flow and annular flow. Finally, authors indicated that the current analysis can be accumulated to horizontal alignment or to other cross-section geometries of microchannel with hydraulic diameter around 1 mm.

Among several papers previously mentioned, the information on the two-phase flow pattern in microscale channels is still limited, and there remains room for further research. Therefore, an optical measurement technique using high speed camera is developed to observe the two-phase flow patterns in the microscale channel, which is important to have an effective method for thermal design.

2 Experimental apparatus and procedures

Fig. 1 displays a schematic diagram of the test rig used in this study. Air compressor was used to supply air and drive water from high pressure tank to the test section. The pressure supplied to the test section was fixed by a regulator at 4 bar, while the flow rates were measured and adjusted by a rotameter. The air and water flow rates ranged from 0.01 to 0.1 L/min and 0.3 to 0.9 L/min, respectively. Before entering the test section, air and water were mixed in the chamber. After the system reached the steady state condition, the flow rate of air and water, and flow pattern were recorded.

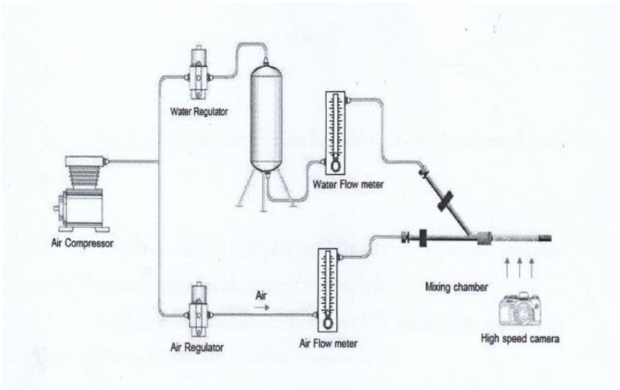


Fig. 1 A schematic diagram of the test rig

A 250-mm-long and 1-mm-inner diameter circular glass tube is used as the test channel. The air-water mixture from the chamber flows freely to the exit of the channel with the pressure close to 1 atm. The flow pattern is captured by the high speed camera (Fujifilm FinePix S7000) with shutter speed range of 1/15 to 1/10,000 s and a frame rate of 30 frames per second. After allowing the flow to fully developed, the camera then captures the image. The halogen lamp is installed under the test section to provide illumination for the flow visualization.

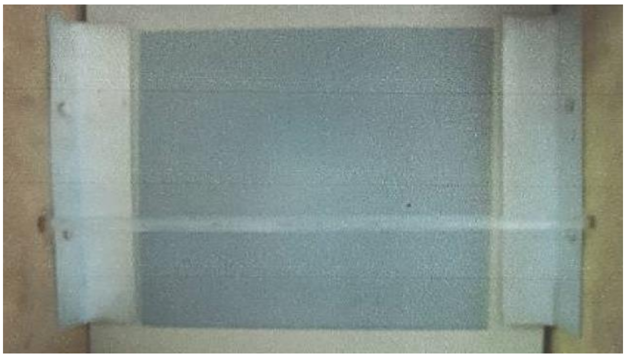


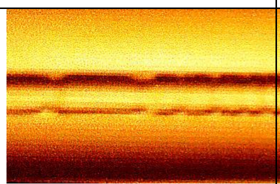
Fig. 2 A glass circular channel with inner diameter of 1 mm

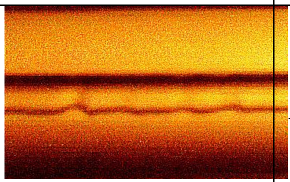
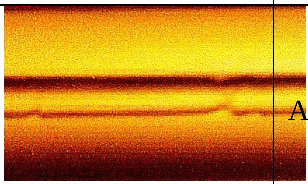
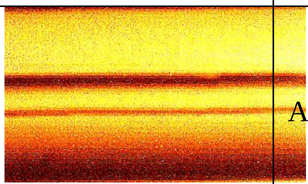
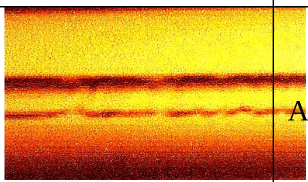
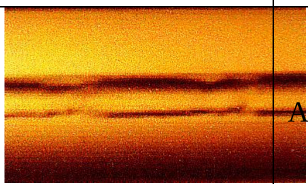
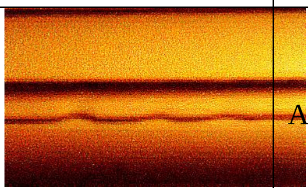
3 Results

3.1 Flow pattern image

In this present work, the two-phase flow pattern observations were carried out at air and water flow rates ranging from 0.01 to 0.1 L/min and 0.3 to 0.9 L/min, respectively. As the water flow rate was maintained to constant with a little increase in air flow rate, the flow pattern is captured via the camera and typical photographs are displayed in Table 1. Three types of annular flow were identified during the test, which are throat-annular flow, wavy-annular flow, and smooth annular flow. For an annular flow, a liquid film flows on the tube wall with a continuous central vapor axial flow. Liquid slugs are not observed in this study.

Table 1 The present flow pattern data

Water flow rate (LPM)	Air flow rate (LPM)	Result	
		Image	Flow pattern type
0.3	0.01		Annular
	0.05		Annular
	0.1		Annular

Water flow rate (LPM)	Air flow rate (LPM)	Result	
		Image	Flow pattern type
	0.01		Annular
0.6	0.05		Annular
	0.1		Annular
	0.01		Annular
0.9	0.05		Annular
	0.1		Annular

3.2 Flow pattern map

The Baker flow pattern map [5], which is for air-water in conventional channels with diameters not larger than 50 mm, was compared with the present data. The present flow pattern data were plotted as a map in terms of the phase superficial velocities. As shown in Fig. 3, most of the present data are located in the annular flow regime except for low superficial gas velocities range.

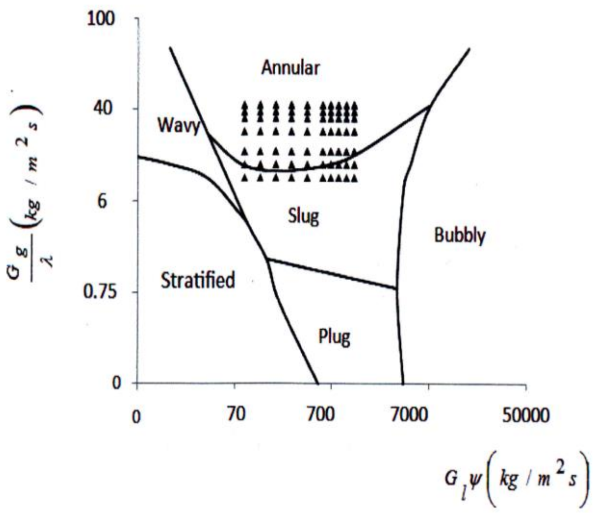


Fig. 3 Flow pattern prediction by Baker flow pattern map [5]

4 Conclusion

An optical measurement method based on image processing technique was developed to characterize the flow pattern of air-water flowing inside circular microchannel. A high speed camera allows determining whether liquid, vapor or liquid-vapor is present. The results under the experimental conditions report that all observed flow patterns are annular.

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