Two-phase flow regime transition criteria of Staggered Mini Channel Printed Circuit Heat Exchanger

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1. Introduction

Heat exchangers are used for cooling and heating in various industries. Among them, Printed Circuit Heat Exchangers (PCHE) have high performance/high efficiency and are known to be the best heat exchangers developed so far. It is easy to manufacture tiny flow paths through chemical etching, and they are combined through a diffusion bonding method. There is an advantage of having high thermal efficiency by transferring heat through a tiny flow path, but on the other hand, it is necessary to consider an increase in pressure drop.

Experimental verification in the two-phase area is required to use high-efficiency PCHE as a Printed Circuit Steam Generator (PCSG). Prior to the heat transfer experiment, it is necessary to check the hydraulic performance of the channel in advance. In the case of Mishima et al. (1993), an experiment was conducted to identify flow characteristics using narrow gap duct channels, and Ide et al. (2006) experimented on a phenomenon that occurs as the diameter of the channel decreases in vertical and horizontal flows.[1, 2] It was experimentally confirmed that in channels with diameters of less than 5mm in horizontal flow, surface tension prevails over gravity and has symmetry in the flow direction. Hibiki and Mishima (2000) based Mishima and Ishii's (1984) model on flow regime transition criteria of vertical flow in narrow gap channels. [3,4] It was confirmed that transition criteria were appropriate for channels with a gap of 0.3 to 17mm. Xu(1999) experimented with a duct channel with a gap of 0.3, 0.6, and 1.0mm. [5] Flow patterns caused by surface tension becoming dominantly due to narrow gaps were defined as cap-bubbly, Slug-droplet, churn, and annular-droplet flow. In the past, various studies on mini-channel geometry have been conducted individually, but in recent years, the correlations studied have been focused on generalization.

2. Methods and Experimental apparatus

Fig. 1 is an experimental loop for conducting a two-phase flow experiment. The same staggered geometry was used in Hwang et al.(2021), and the void fraction was measured at the same experiment point. [6] A schematic diagram for measuring impedance is shown in Fig. 2. The input signal components were removed by measuring the signals passing through the test section electrode and dividing input signal components. Accordingly, an impedance value irrelevant to the component of the input signal can be obtained. Fig. 3 is a calibration result to ensure the validity of the manufactured impedance measuring circuit.

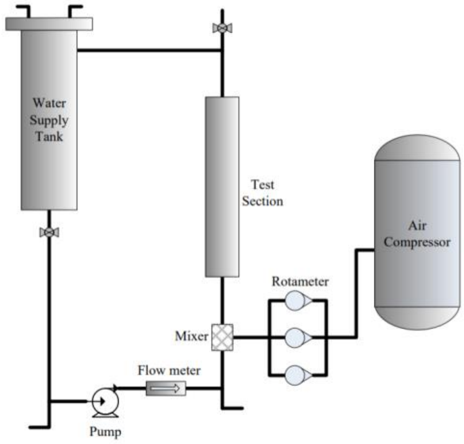


Fig. 1. Experimental system

The total length of the test section is 1700mm, and the electrode for measuring the void fraction is located at a height of 1000mm. Since the void fraction at the same experimental point as Hwang et al.(2021)was measured, the Reynolds number ranges are 422<Re_L<2955, 14<Re_G<570. The fluid used was water at room temperature and atmospheric pressure and air at 3 atmospheric pressure, and a total of 144 data were measured by selecting 12 points each.

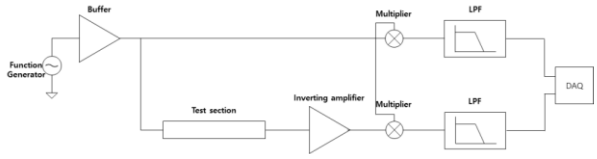


Fig. 2. Impedance measuring diagram

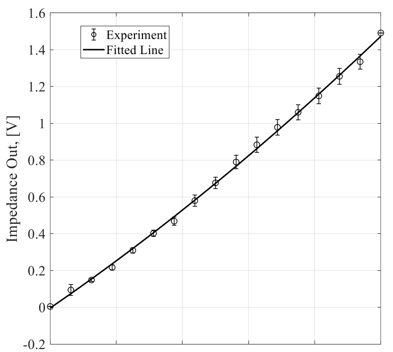


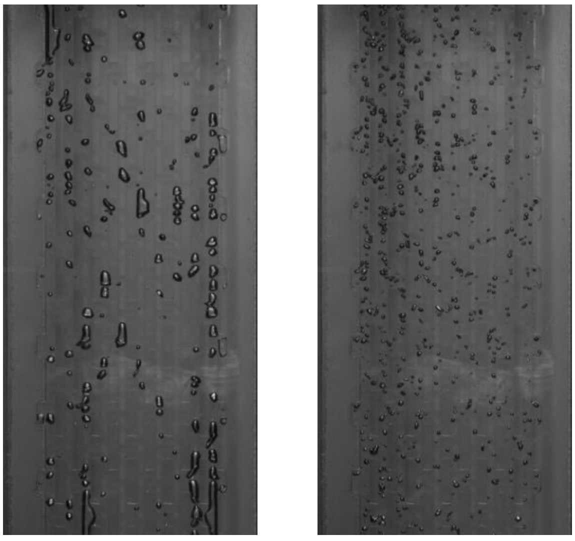
Fig. 3. Calibration result for Impedance meter

The flow pattern was measured using a high-speed camera. To remove the entrance effect, the measurement location of the high-speed camera was installed at a height of 850mm which is 400 times bigger than the hydraulic diameter based on the entrance to the test section. Through this, the flow regime map was defined after identifying the flow pattern according to the inlet flow rate condition.

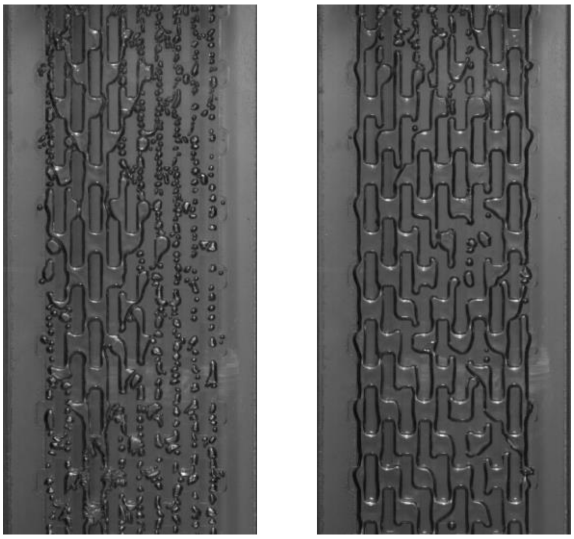
To confirm the validity of the region classification method used in the Staggered geometry, the analysis method was verified using a widely studied mini gap duct channel. The length of the test section is the same as 1700mm with a channel of 42x2mm. Through this, the reliability of the analysis methodology and results was confirmed.

3. Results and Discussion

The flow pattern observed in the Staggered geometry was classified into four categories as shown in Fig. 4. As previously studied, the bubble size is similar to the width of a single channel, and the tail is short. It can be seen in an area where the void fraction does not exceed 0.43 and is shown in Fig. 4-(a). The Finely Dispersed Bubbly flow is an area where bubbles are split and reduced in size by pins inside the channel. Liquid Reynolds number is turbulence region, and turbulence intensity is dominant, as shown in Fig. 4-(b). The Bubbly-Slug flow can be observed with a void fraction of 0.43 to 0.59 and is an area where the bubbly flow and the Slug flow are repeated as shown in Fig. 4-(c). Finally, the Slug flow region is a region with a void fraction of 0.59 or more and is switched from a value smaller than the regime transition criterion defined in the existing duct channel. As shown in Fig. 4-(d), most areas inside the channel are filled with bubbles. It can be observed the long tail as defined in the existing researched slug flow.



(a) Bubbly (b) Finely Dispersed Bubbly



(c) Bubbly-Slug (d) Slug

Fig 4. Staggered geometry flow pattern

The flow regime map according to the flow pattern area of Fig. 4 can be confirmed through Fig. 5. Thin dotted lines are the transition criterion previously studied in the duct channel, and thick dotted lines are the criterion in the newly defined Staggered geometry.

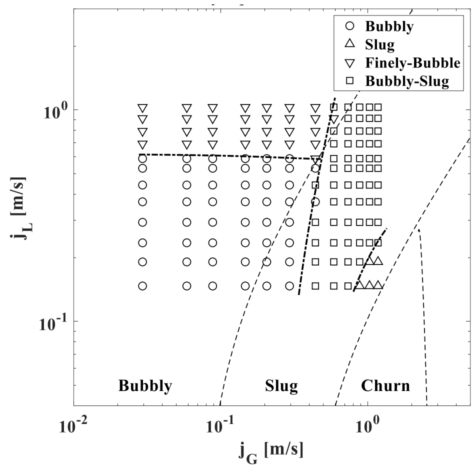
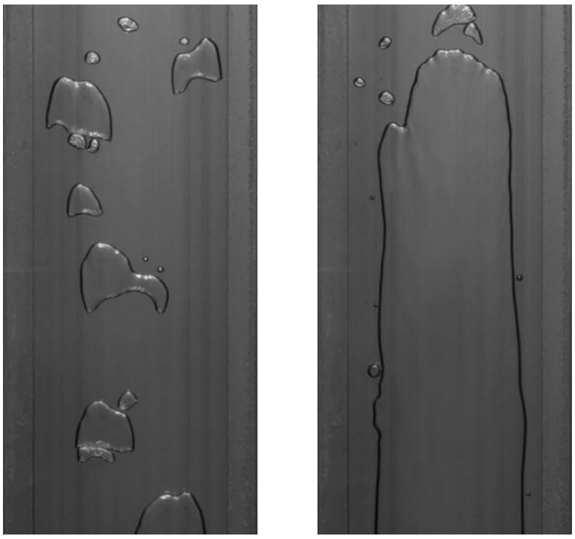


Fig 5. Flow Regime Map of staggered geometry

The flow pattern classification method was verified through the Mini gap duct channel. Fig. 6 shows the flow pattern observed in the mini gap duct channel. Bubbly flow and Slug flow could be observed within the experimental area. In the Bubbly flow, it can be checked several short tails and bubbles smaller than the width of the channel. Slug flow shows bubbles within a nose similar to the width of channel flow along with a long tail, followed by small bubbles at the front/back end.



(a) Bubbly flow (b) Slug flow

Fig. 6. Mini gap Duct channel flow pattern

Fig. 7 shows the flow pattern for each measurement point classified in this study and the previously studied flow pattern criterion. There are uncertain parts near the boundary line, but they are generally well classified. Through this. The validity of the classification method was confirmed.

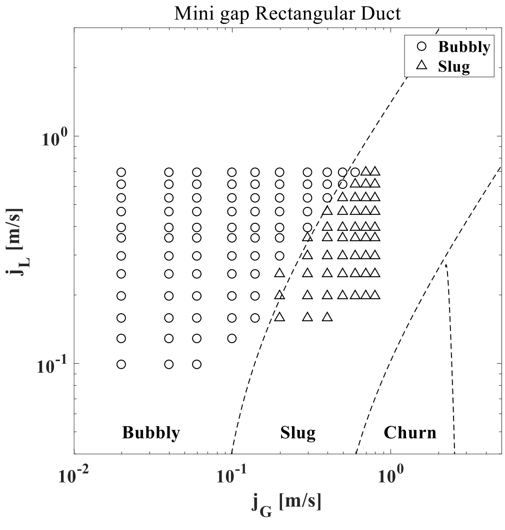


Fig. 7. Flow Regime Map of Mini gap Duc channel

4. Conclusions

Staggered geometry identified two-phase flow patterns. In order to define the flow regime map according to the patter area, an impedance meter circuit was designed and calibrated, and a flow pattern was observed with a high-speed camera. Through this, four flow patterns (Bubbly, Finely Dispersed Bubbly, Bubbly-Slug, Slug) and transition criteria were defined. In order to get the validity of the classification criteria, the existing research methods were followed using the previously widely studied mini gap duct channel.

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