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A Study on Identification of Transition Boundary between Intermittent and Annular Flow in an Inclined Two-Phase Flow

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1. Introduction

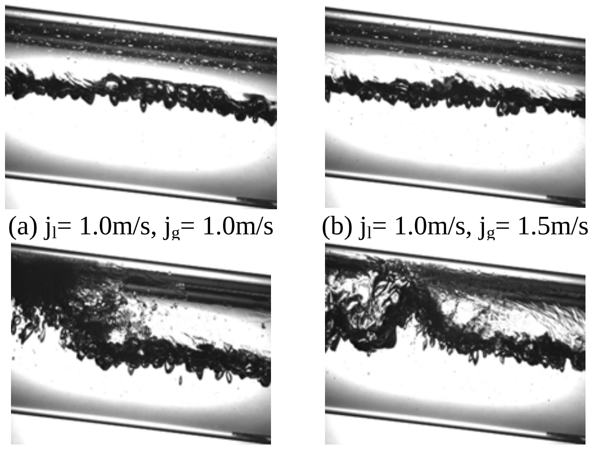
The identification of flow regime transition is very important part for nuclear safety analysis, improvement and design of mechanical system. There have been many theoretical and experimental attempts to demonstrate flow regime transitions in a horizontal and a vertical pipe, on the other hand, research for the inclined pipe has been rare. Taitel and Dukler proposed a theoretical model for predicting flow regime transitions in a horizontal and near-horizontal pipe [1]. Barnea et al. verified the Taitel and Dukler's model for various inclination angles, and observed that Taitel and Dukler's model well predict the flow regime transition up to inclination angles ±10°, but has limitation in classifying the transition boundary between the smooth and wavy stratified flow [2]. Barnea et al. intensively conducted experiment on the flow regime transition for the whole range of inclination angles from the horizontal to the vertical pipe [3]. Barnea later proposed a unified theoretical model predicting the transition between the annular and intermittent flow, and between the bubbly and intermittent which is valid for the whole range of inclination angles [4]. Also, Barnea summarized flow regime transition models and proposed a unified theoretical model applicable from horizontal to vertical flow [5]. This work, as a preparatory research, is motivated to classify the flow regime, in particular, transition between intermittent and annular flow in an inclined pipe which was constructed in order to describe the condensation heat exchanger in APR+ PAFS.

2. Experimental apparatus

The water from a main collection tank is lifted by a main pump whose capacity is 5HP. This pumped water flows through a pre-heater and a Coriolis mass flow meter whose measuring range from 0 to 400kg/min and accuracy is below ±0.15%, and then flows into the entrance. The air from compressor with 15HP flows through a Coriolis mass flow meter whose measuring range is from 0 to 15kg/min and accuracy is within ±0.2%, and then injected to the air entrance. These two fluids are then combined in the mixer and flow into the test section together. The test section consists of two inclined pipes, two elbow pipes connecting inclined pipes with the entrance and auxiliary collection tank, and a U-pipe connecting inclined pipes. The inner diameter of the inclined pipe is 44.8mm and its length form the entrance to the U-pipe is roughly 3200mm, and inclination angle is 3°. The radius of the U-pipe is 266mm. These dimensions are approximately equal to that of the condensation heat exchanger for the PAFS which belongs to KAERI.

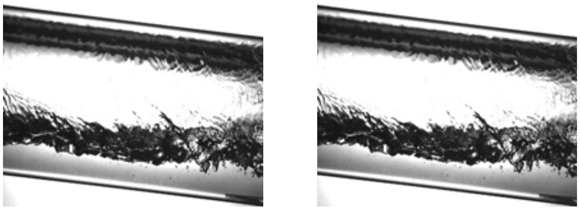
3. Experimental Results

For the investigation of flow regime transition in an inclination pipe with 3° inclination angle several experiments have been performed with respect to various liquid and gas superficial velocities under standard temperature and pressure. In order to classify the flow patterns this work adopts Barnea's classification based on visual observations [2] and electrical signal variations with phase distributions simultaneously. A high-speed camera which can monitor two-phase flow in maximum 198,000 fps has been employed for visual observations and this high-speed camera has been located at the point roughly 3000mm away from the inlet of inclined pipe for describing fully-developed condition. Figure 1 shows some examples for experimental observations obtained from high-speed camera for various liquid and gas superficial velocities.



(a) j_l= 1.0m/s, j_g= 1.0m/s (b) j_l= 1.0m/s, j_g= 1.5m/s

(c) j_l= 1.0m/s, j_g= 3.0m/s (d) j_l= 1.0m/s, j_g= 3.5m/s



(e) j_l= 0.3m/s, j_g= 10.0m/s (f) j_l= 0.3m/s, j_g= 13.0m/s

Figure 1: Flow regimes for given superficial velocities

Figure 1 indicates that when superficial gas and liquid velocities denoted by j_g and j_l are relatively small (first column), the wave on the interface does not grow and the resultant flow pattern is seen to be stratified flow; however, as gas accelerates the wave grows and this completely blocks the gas passage (second column). Further increase in superficial gas velocity makes liquid film around the pipe wall and the wave no longer blocks the gas phase due to the lack of the water amount which maintains a liquid slug (third column).

For verification, these visual observations were compared with theoretical models by Taitel and Dukler [1] and Barnea [4] as shown in Fig. 2. Figure 2 shows that experimental trend well match the theoretical predictions on the whole.

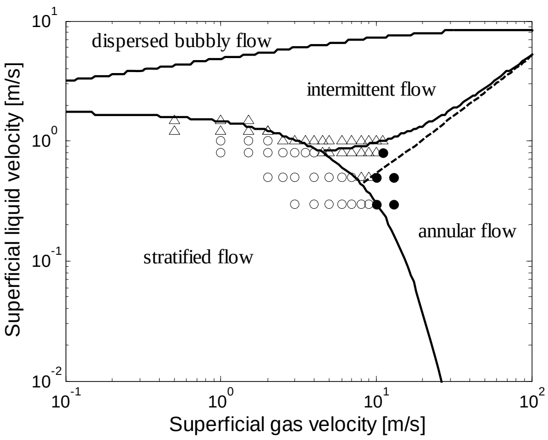


Figure 2: Comparison between experimental results and theoretical models; theoretical models (— Taitel & Dukler, --- Barnea), experiments (○ stratified, △ intermittent, ● annular).

4. Conclusions

As a preparatory research for identification of flow regime transitions in an inclined pipe, fundamental experiments have been conducted. A high-speed camera has been employed for visual observations. These visualization results have been compared with theoretical predictions based on typical flow regime classifications, in particular, for transition boundary between intermittent and annular flow, which is one of the most unobvious region to interpret, two existing theoretical models are introduced and these are successfully compared with experimental results.

ACKNOWLEDGMENTS

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