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An Experimental Study on the Onset of Gas and Liquid Entrainment of Horizontal Stratified Flow with Arbitrary-Angled Branches

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I. Introduction

A lot of industrial applications involve two-phase flow discharging from a stratified region through branch pipes. For instance, these applications include the flow through small break in horizontal cooling channels of a CANDU reactor during postulated loss-of-coolant accidents (LOCA) and the flow distribution at the header-feeder systems during accidents. Therefore, knowledge of the flow phenomena including the mass flow rate and quality of all discharging streams is obviously essential for the design and safety analysis of such systems.

The designs of the CANDU reactors are different from those of the light water cooled reactors (LWR). A total of 380 fuel bundles are divided into the four groups with 95 fuel bundles respectively and connected with the feeder pipes in order to transport the coolant for heat exchange. Especially, there are five-angled types at T-junctions between header and feeder pipes; 0°, -36°, -72°, -108°, -144° from the horizontal line. The geometrical characteristics between the header and feeder pipes of the CANDU reactor require different approaches from the existing offtake models restricted to top, bottom and side branches. Unfortunately, the researches for the offtake phenomena in the branch pipes with arbitrary angle were, however, hardly to find and there is no reliable correlation for this purpose.

In this study, to investigate the onset phenomena for a single branch with the arbitrary angle, onset experiments were carried out using the experimental facility of the horizontal pipe with 0°, ±30°, ±45°, ±60°, ±90° angled branch pipes.

The onset phenomena of gas and liquid entrainment at the branch entrance for stratified flow in the horizontal pipe are compared with the previous experimental results conducted by KfK [1] and UCB [2]. In addition, the onset phenomena at branch pipes with six specific angles (±30°, ±45°, ±60°) as well as three branches (top, side and bottom) are also described.

II. Experimental Apparatus

Although the inclined angles of feeder pipes from header horizontal line in CANDU6 reactor are 0°, -36° and -72°, in this study the branch angles are installed at 0°, ±30°, ±45°, ±60°, ±90° from the horizontal line to obtain general offtake correlations for arbitrary-angled branch pipes.

The onset experiments with liquid entrainment were performed at 0°, 30°, 45°, 60°, 90° branch pipes and those with gas entrainment were performed at 0°, -30°, -45°, -60°, -90° branch pipes using air and water as working fluids. The pressure is up to 700kPa and the range of temperature is from 15°C to 30°C.

To simulate the offtake phenomena in a CANDU-6 type reactor, the diameters of header and feeder pipes were scaled-down as 0.5 and 0.42 using the scaling law, respectively [3]. The diameter of horizontal pipe is 0.184 m, and those of branch pipes are 16, 20.7 and 24.8 mm by the scaling analysis. The air mass flow rate is up to 45 g/sec and the liquid mass flow rate is up to 3.2 kg/sec. In this experiment, there are no superimposed velocities and all of the gas and liquid flows injected to the test section are discharged through the branch pipe.

III. Experimental Results and Disscussion

3.1 Onset of Liquid Entrainment

The present experimental data of OLE (Onset of Liquid Entrainment) were plotted in Figure 1. The present experimental data at top and side branches are close to the onset correlations of KfK (D=206mm, d=6, 12, 20mm) and UCB (D=102.3mm, d=3.76, 6.32mm).

In addition to the above experiments, to grasp the angle effect, the OLE experiments for specific angled (30°, 45° and 60°) branches were carried out. In these cases, the onset phenomena have different patterns from previous onset models. In the cases of 30° and 45° angled branches, there were two onset phenomena for liquid entrainment: one is vortex and the other is vortex-free.

For relatively high Fr numbers, the liquid entrainment can involve a vortex formation in the entraining liquid spouts. For the vortex flow, the water crest is generated due to Bernoulli Effect and the liquid droplets entrained from the water crest are radially accelerated and only a small fraction reaches the branch inlet. The onset characteristics are different from the previous onset models, and the branch diameter effect (D/d) is obviously shown.

And for relatively low Fr numbers, the liquid entrainment is vortex free and a cone of liquid film is found to climb along the pipe wall until it gets dispensed into the break. In this case, the onset characteristics are similar with the previous side onset models.

In the case of 60° angled branch, there is no onset phenomenon for liquid entrainment with vortex-free flow and the onset phenomena are similar with the previous top onset model. And the branch diameter effect (D/d) is ambiguous.

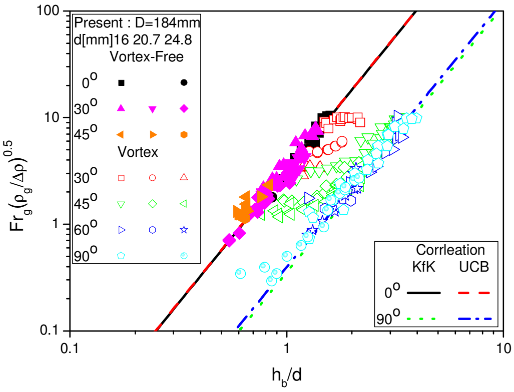

Figure 1. Onset of liquid entrainment at various angles

3.2 Onset of Gas Entrainment

The present experimental data of OGE (Onset of Gas Entrainment) were plotted in Figure 2. As for bottom branch, there are some differences in KfK, UCB and RELAP5 correlations. From the viewpoint of the definition of OGE, the vortex and vortex-free flow in KfK correspond to the first and continuous bubble pull-through in UCB, respectively. But there may be some differences between KfK and UCB due to the unstable nature of gas entrainment and the subjective criterion of investigator for OGE. In the present experiment, the definition of OGE was determined when the first thin gas hose reaches the bottom to eliminate the subjective of investigator. The present experimental data are similar with the OGE with vortex flow in KfK.

The present experimental data of OGE at side branch are located between KfK and UCB correlations.

In addition to the above experiments, to grasp the angle effect, OGE experiments for specific angled (-30°, -45°, -60°) branches were carried out. In the present experiment, OGE was determined when the first thin gas hose reaches -30°, -45° and -60° angled branches like bottom branch. In the cases of -30° and -45° angled branches, the onset phenomena have different characteristics from previous onset models. The experimental data of OGE at -30° and -45° angled branches are located between the bottom and side onset models. In the case of -30° angled branch, the branch diameter effect (D/d) is obviously shown. In the case of -45° angled branch, the branch diameter effect (D/d) is weakly shown and the experimental data of OGE are a little closer to the bottom onset model than the side onset model.

In the case of -60° angled branch, the experimental data of OGE were similar with the previous bottom onset model. And the branch diameter effect (D/d) is ambiguous.

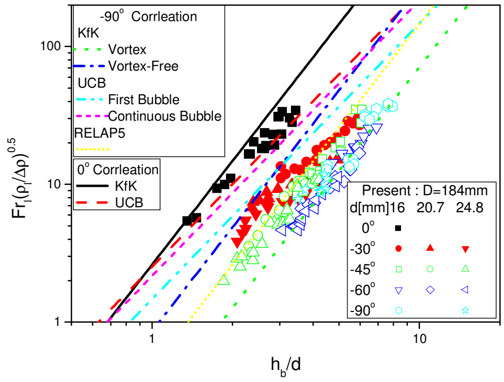

Figure 2. Onset of gas entrainment at various angles

IV. Conclusion

Through the present experiment for onset phenomena at top, bottom and side branch pipes, the present study reconfirmed the validity of the correlation of previous onset models of KfK and UCB.

The onset experiments at branch pipes with six specific angles (±30°, ±45° and ±60°) were also performed in addition to three conventional orientations (top, side and bottom). For the cases of 30° and 45° branch angles, there are two onset phenomena of liquid entrainment: One is vortex flow and the other is vortex-free flow. For the case of 60° angled branch, the onset phenomenon was always vortex flow. The onset phenomena with vortex-free flow are similar with the previous side onset models in KfK and UCB. But those with vortex flow have different entrainment characteristics from the previous onset models.

For the cases of -30°, -45° and -60° angled branches, the onset phenomena of gas entrainment were always vortex flow and had different entrainment characteristics with the previous OGE models.

In this study, no attempt was made to correlate the onset experimental data at arbitrary-angled branches. However the present onset data will supply the basis on the entrainment characteristics at arbitrary-angled branches and a data base for validation of existing numerical codes.

References

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