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Local Flow Structure and Experimental Investigation of Interfacial Area Transport of Vertical Upward Air-Water Two-Phase Flow in an Annulus Channel

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1. Introduction

The formulation of the interfacial area transport (IAT) equation is based on statistical mechanics and its concept has been fully established (Ishii, 2006). However, the source and the sink terms of interfacial area due to bubble coalescence and breakup are still being developed. These are strongly dependent on flow conditions and geometries. So far, most experiments for interfacial area research have been performed in round tubes. There is very few data for the flow in an annulus. Hibiki et al. (2003) performed experiments in an annular channel, but their flow conditions were limited to bubbly flows. In this paper, an experimental study has been performed to investigate the interfacial area transport of vertical upward air-water two-phase flow in an annulus channel for a wide range of flow conditions.

2. Experimental Facility and Conditions

The annular test section consists of an inner rod of 19.1 mm diameter and an outer tube of 38.1 mm inner diameter. The test section is 4.37 m long.

Four-sensor conductivity probes were used at nine radial positions of three axial locations (z/D_H=52, 149 and 230) to measure the local flow parameters. These include the void fractions, interfacial area concentrations (IAC), and interfacial velocities for two groups of bubbles; spherical and distorted bubbles as Group 1, whereas cap and slug bubbles as Group 2. The boundary between the two groups is determined by the maximum distorted bubble diameter specified by Ishii and Zuber (1979), $D_{d,\max} = 4(\sigma / g\Delta\rho)^{0.5}$, where σ, g, and $\Delta\rho$ are the surface tension, gravitational acceleration, and the density difference between the two phases.

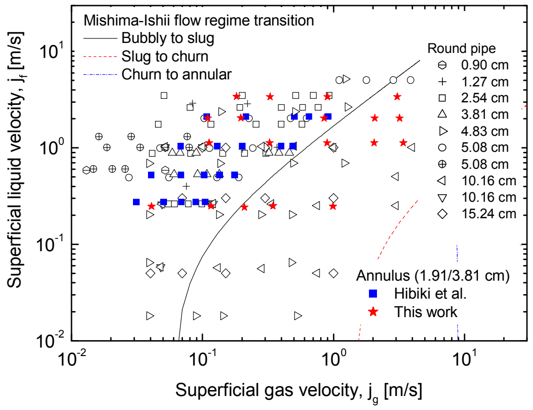

Figure 1. Experimental conditions for IAT research in round pipes and annuli: Inlet flow conditions are given.

Nineteen inlet flow conditions were selected so that a wide range of flow conditions can be covered, ranging from bubbly flows to churn-turbulent flows at the exit of the test section. The test conditions are compared with those of the existing IAT experiments in Figure 1.

3. Results and Discussions

The annulus gap size of 9.5 mm is smaller than the maximum distorted bubble diameter of ~ 10 mm and, as a result, it is difficult to distinguish the cap bubbles from slug bubbles. Thus, the flow regimes are simply divided into four categories (Juliá et al., 2007); bubbly (B), cap-slug (S), churn-turbulent (C), and annular regimes (A). In Figure 2, the flow conditions at z/D_H=52, 149, and 230 are marked with symbols, and the corresponding flow regimes are given. These flow regimes are based on both the visual observations and the area-averaged local flow parameters. It can be seen in Figure 2 that there are some entrance effects. This implies that a certain flow length is needed for a bubble growth and a flow regime evolution, which clearly shows the limitation of static flow-regime maps, especially for developing flows.

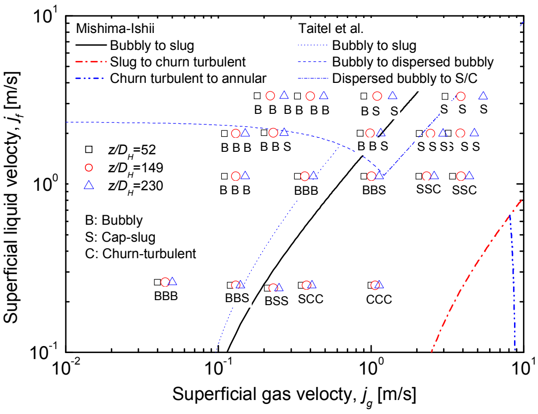

Figure 2. Flow regimes at z/D_H=52, 149 and 230: The local flow conditions are marked with symbols and the corresponding flow regimes are given with B, S, or C.

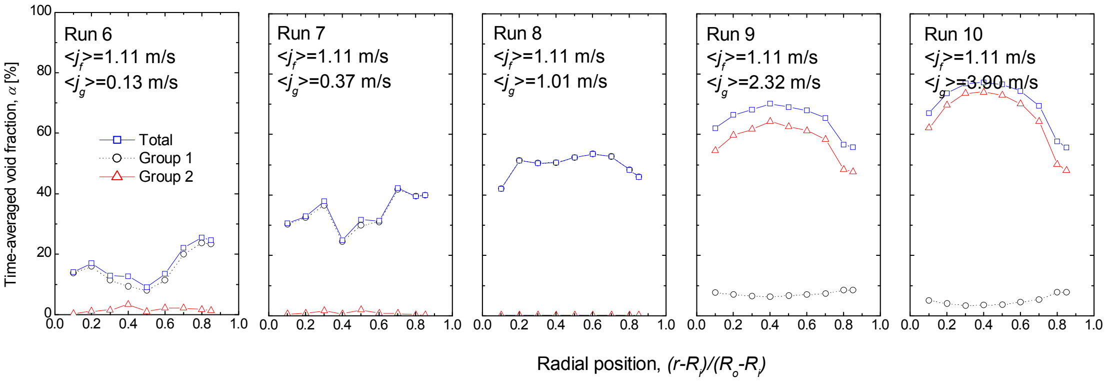

Figure 3. Radial distribution of time-averaged void fraction at z/D_H=149.

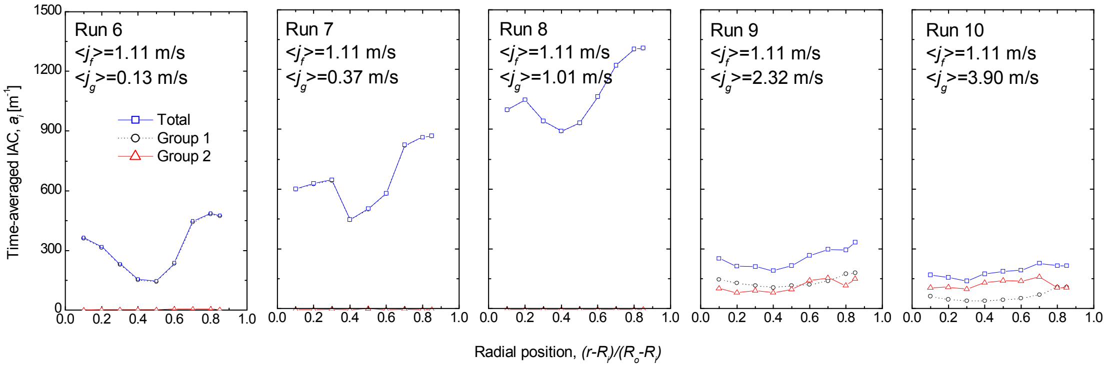

Figure 4. Radial distribution of time-averaged IAC at z/D_H=149.

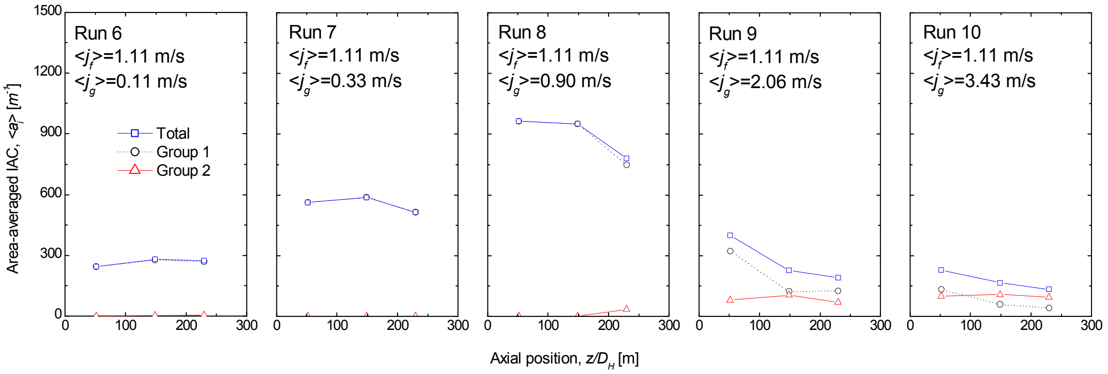

Figure 5. Axial profiles of area-averaged IAC: The flow conditions at z/D_H=52 are given.

Figures 3 and 4 show the radial distributions of the time-averaged void fraction and IAC, respectively. Since the contribution of Group 1 bubbles to total IAC is dominant, the total IAC is nearly proportional to the void fraction of the Group 1 bubbles. The slug and churn-turbulent flows are characterized by a high void fraction and low IAC, where the void fraction is core-peaked and the IAC is wall-peaked. Figure 5 shows the axial profiles of the area-averaged IAC.

4. Concluding Remarks

An experimental study on the interfacial area transport of vertical, upward, air-water two-phase flows in an annulus channel has been performed. Using the nineteen data set, the effects of j_g, j_f, and z/D_H on the local flow structure can be systematically analyzed. The data showed the limitation of static flow-regime maps.

The measured data can be utilized for the two-group interfacial area transport model, e.g., for the development and assessment of the bubble coalescence and breakup models. Some of the data can be used for the fine tuning of individual source and sink terms. The data is also suitable for the development of some closure models for computational fluid dynamics.

References

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