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INTRODUCTION

In the two-group interfacial area transport equation, bubbles are categorized into two groups, i.e., spherical/distorted bubbles as group 1 and cap/slug/churn-turbulent bubbles as group 2 [1]. The bubble rise velocities for both groups of bubbles may be estimated by the drift flux model [2] by applying different distribution parameters and drift velocities for both groups. However, the drift velocity for group 2 bubbles is not always applicable (when the wall effect becomes important) as in the current test loop of interest where the flow channel is confined by two parallel flat walls, with a dimension of 200-mm in width and 10-mm in gap. The previous experiments indicated that no stable slug flow existed in this test section, which was designed to permit visualization of the flow patterns and bubble characteristics without the distortion associated with curved surfaces [3]. In fact, distorted cap bubbly and churn-turbulent flow was observed.

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Therefore, it is essential to develop a correlation for cap bubble drift velocity in this confined flow channel. Since the rise velocity of a cap bubble depends on its size, a high-speed movie camera is used to capture images of cap bubbles to obtain the bubble size information. Meanwhile, the rise velocity of cap and elongated cap bubbles (called cap bubbles hereafter) is investigated by examining the captured images frame by frame. As a result, the conventional correlation of drift velocity for slug bubbles is modified and acceptable agreements between the measurements and correlation estimation are achieved.

EXPERIMENTS

The experiments are performed in a vertical air-water upward two-phase flow loop. In this loop, six sparger units are employed along the width direction to generate bubbles with uniform distribution at the inlet of the test section. The total length of the test section is 2950-mm. Detailed description of the experimental loop can be found in Reference 3. The cap bubbles are generated by a sudden increase of gas flow rate into either stagnant or flowing water in the test section. The images are taken by a high-speed movie camera at 500 frames per second at the location of $z/D_h \approx 92$. To avoid the wake effects of the preceding bubbles, only the first one or two (when rising parallel to each other) cap bubbles are used to estimate the rise velocity by measuring the bubble traveling distance and counting the frame number. Accounting for the error in distance measurement and the deformation of bubble interface, the overall measurement error for the cap bubble rise velocity is estimated within $\pm 10\%$.

ANALYSIS

From the drift flux model [2], the cap bubble rise velocity can be correlated by

$$\langle\langle v_g \rangle\rangle = C_o\left(\langle j_g \rangle + \langle j_f \rangle\right) + \langle\langle V_{gj} \rangle\rangle \tag{1}$$

where, C_o and $\langle\langle V_{gj} \rangle\rangle$ are the distribution parameter and drift velocity, and $\langle j_g \rangle$ and $\langle j_f \rangle$ are the gas and liquid volumetric fluxes. Jones and Zuber [4] suggested a value 1.2 for C_o, while Ishii [5] proposed the following equation for C_o in rectangular ducts:

$$C_o = 1.35 - 0.35\sqrt{\rho_g / \rho_f}\,, \tag{2}$$

where ρ_g and ρ_f are density for gas and liquid phases, respectively.

For the drift velocity in a rectangular channel, Griffith [6] claimed that the larger dimension of the channel was most important to determine cap/slug bubble velocity in a stagnant water column. Furthermore, the following drift velocity for large cap and slug bubbles in rectangular ducts was proposed:

$$\langle\langle V_{gj} \rangle\rangle = \left(0.23 + 0.13\,G/W\right)\sqrt{\left(\rho_f - \rho_g\right) g W / \rho_f} \tag{3}$$

where G and W are the gap and width of the flow channel, respectively ($W \geq G$). Note that the width of the flow ducts in his air-water experiments were smaller than 100-mm; therefore, it is possible to form slug bubbles whose base lengths are close to W. However, when equation (3) is applied for the current test section, unsatisfactory results are obtained because cap bubble size is not accounted for in the equation.

On the other hand, the following equation for a slug bubble in a circular pipe has been developed [7]

$$\langle\langle V_{gj} \rangle\rangle = 0.35\sqrt{(\rho_f - \rho_g) gD/\rho_f}\,, \tag{4}$$

where D is the inner diameter of the circular pipe. It is also known that the base diameter of a slug bubble, D_s, is usually considered similar to or larger than 3/4 of the pipe inner diameter, i.e.,

$$D_s \geq \frac{3}{4} D\,. \tag{5}$$

If the equal sign in the above equation is adopted, substituting it into equation (4) yields,

$$\langle\langle V_{gj} \rangle\rangle = 0.40\sqrt{(\rho_f - \rho_g) gD_s/\rho_f}\,. \tag{6}$$

In the present study, the width of the test section is 200-mm, and no stable slug bubble can exist in this test section for air-water two-phase flow [3, 8]. However, if the base length of a cap bubble, $2a$, is considered equivalent to the slug bubble diameter, then the drift velocity for a cap bubble may be calculated by the following equation

$$\langle\langle V_{gj} \rangle\rangle = 0.40\sqrt{(\rho_f - \rho_g) g(2a)/\rho_f}\,. \tag{7}$$

RESULTS

Figure 1 shows the comparisons between the measured drift velocity and the estimation by equation (7) for cap bubbles in both stagnant and flowing water. The agreements are fairly acceptable, especially in the stagnant water condition. This comparison indicates that this correlation can be applied to calculate the cap bubble drift velocity for the current test section. Furthermore, in relation to the two-group interfacial area transport equation, the bubble velocity for group 2 bubbles may be estimated with acceptable uncertainty by equations (1), (2), and (7) for the confined flow channels where no stable slug bubbles exist.

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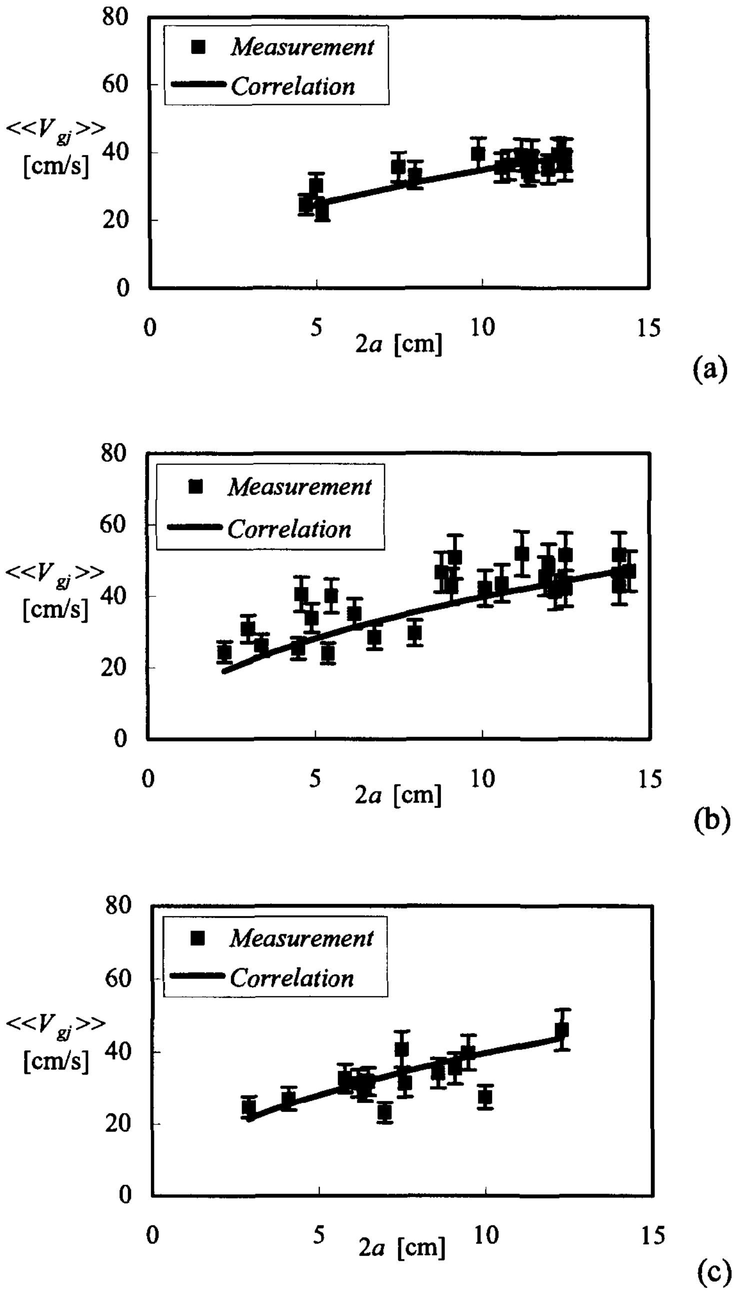

Figure 1. Comparison of the cap bubble drift velocity between the experiment and the estimation by equation (7) in (a) stagnant water, (b) $\langle j_f \rangle = 0.32$-m/s, and (c) $\langle j_f \rangle = 0.95$-m/s. Error bar: ±10%.