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Measurements of Interfacial Area Concentration in Two-Phase Bubbly Flow

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INTRODUCTION

Interfacial area concentration is an important parameter in the two-fluid model [1] for two-phase flow analysis, which is defined as the total interface area per unit mixture volume and has the following local time-averaged expression [1]:

$$\overline{a}^t = \frac{1}{\Delta T}\sum_j \left(\frac{1}{|\mathbf{V}_i \cdot \mathbf{n}_i|}\right)_j , \qquad (1)$$

where j denotes the j-th interface that passes the point of interest in a time interval ΔT. $\mathbf{V}_i$ and $\mathbf{n}_i$ refer to the bubble interface velocity and surface normal vector, respectively. To measure this parameter, the double-sensor probe technique is commonly used. Due to the influences of the bubble lateral motions, however, the measurement results should be interpreted via a certain statistic approach [2]. Recently, to take into account the effects of the probe spacing, Wu and Ishii provided the following new formula to correlate the measurable values to the interfacial area concentration [3]:

$$\overline{a}_i^t = \frac{2N_b}{\Delta T}\left(\frac{\overline{\Delta t}}{\Delta s}\right)\left[2+\left(\frac{1.2\sigma_{\Delta t}}{\overline{\Delta t}}\right)^{2.25}\right], \qquad \text{for} \qquad D = 1.2 \sim 2.8\Delta s, \qquad (2)$$

where N_b refers to the number of the bubbles that hit the probe front tip during time interval ΔT, Δs denotes the distance between the two probe tips, D is the bubble diameter, $\overline{\Delta t}$ represents the measured average time interval for a interface to travel through the two probe tips, and $\sigma_{\Delta t}$ is the standard deviation of Δt. The theoretical accuracy of this formula is within ±5% if the sample size is sufficiently large. The purpose of this study is to evaluate this method experimentally using an image processing method.

DESCRIPTION OF THE ACTUAL WORK

The tests were performed in an acrylic vertical rectangular duct with dimensions of 10 mm × 200 mm × 1800 mm (Fig. 1), and the air-water mixture flows through the duct upwards. A 100 mm wide, 62 mm high flow visualization window is positioned where the double-sensor probe is installed, at an axial location of 1140 mm from the duct inlet. The bubbly flow images in the window are recorded with a Sony 3-CCD camcorder at a shutter speed of 1/10000 s. The gas void fraction of the two-phase flow is controlled below 5% to prevent bubble images from overlapping. These images are then acquired on a personal computer for analysis. A computer code developed by Zhang and Ishii [4] is used to process these images for the information of the location and the diameter of each bubble. For a rectangular coordinate system (Fig. 1), the *yz*-plane area-averaged interfacial area concentration at any *x* position is given by:

$$a_i(x) = \frac{\pi \sum_j \left(D_b(x)\right)_j}{A_{yz}}, \tag{3}$$

where $D_b(x)$ is the bubble diameter at a x location and A_{yz} stands for the product of the image height and the duct depth. In this way, the parameter obtained from the image method is area-averaged in the yz-plane. Therefore, the local time-averaged parameter from a double-sensor conductivity probe should be line-averaged in the *z*-direction for effective comparisons. In the experiment, the conductivity probe traverses a half of the duct depth (5 mm) with 1 mm increment to obtain the *z*-directional profile. Afterwards, the equivalent *yz*-plane area-averaged parameter is given by:

$$a_i(x) = \frac{1}{L_z} \int_0^{L_z} \bar{a}_i^t \, dz. \tag{4}$$

RESULTS

A number of tests have been performed with different mixture velocities and gas void fractions. A typical result is illustrated in Fig. 2. The relative discrepancy of the results from the two methods is generally within ±10%. The data points at the image boundaries are eliminated because the window edge cuts some bubbles resulting in bubble fragments (Fig. 1) and non-realistic measurements. Moreover, as the total image number increases, the data fluctuations become smaller. For good statistic behaviors, the presented data set involves 200 images that contain roughly 20000 bubbles. It should be mentioned that the image method in this study is applicable for bubbles that are approximately spherical.

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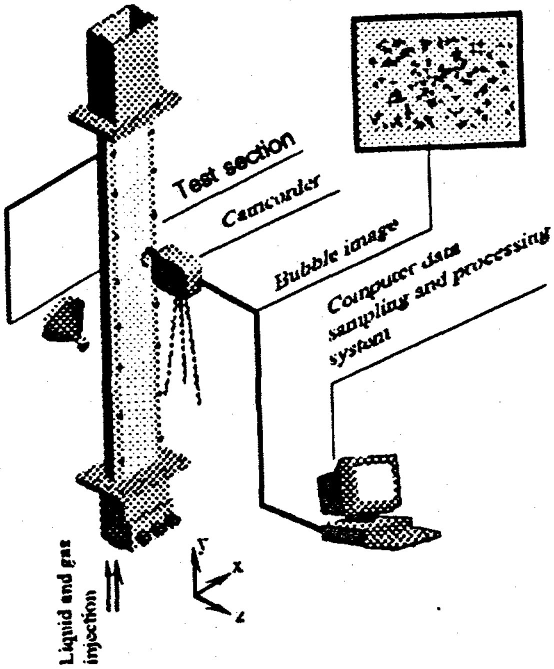

Fig. 1, Schematic of the test facility

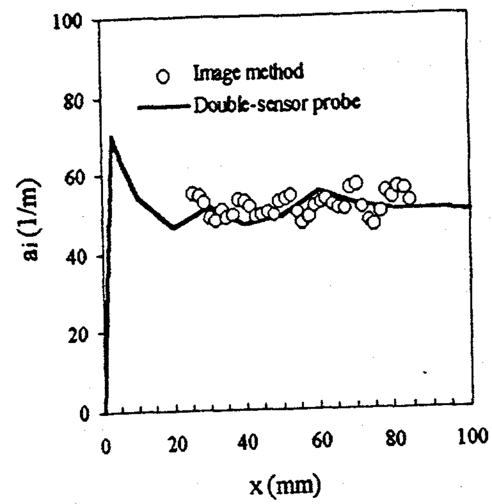

Fig. 2 Typical measurement result (j_g=0.023 m/s, j_f = 0.315 m/s)