Development of the Multi-Sensor Probe Method to Measure an Interfacial Area Concentration and a Benchmarking by Using a Two-Dimensional Image Processing

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1. Introduction

Interfacial area concentration(IAC) is one of the most important parameters in the two-fluid model. Currently two types of probe methods have been used, which are the double- and the four-sensor method. The double-sensor probe method is useful in a dispersed flow regime with the spherical bubble shape assumption. The four-sensor probe method can predict the IAC without any assumptions of the bubble shape. [1] It still needs special treatment for the missing bubbles which bypass one or more of the rear sensors. Kim et al. (2000) developed a miniaturized four-sensor conductivity probe to reduce the missing bubble effect by minimizing the measuring area formed by the probe.[2] A five-sensor conductivity probe was proposed to improve the previous probe methods.[3] This study includes the development of an IAC measurement method with a slight change in the detailed part of Euh et al.(2004) and benchmarking tests in a rectangular visual channel by a comparison with the photographic method. Various other local parameters such as the void fraction, and bubble velocity were also compared.

2. Five-Sensor Probe Method

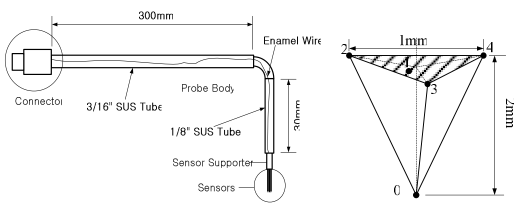

Figure 1. Five-Sensor Probe and the Tip Configuration

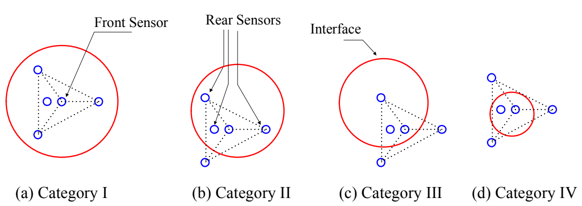

Figure 2. Bubble Passing Type through the sensors

Figure 1 shows the configuration and dimensions of the five sensor tips of the probe. Five-sensor method classifies the types of the interfaces passing through the sensors into four categories as shown in Figure 2. Among the categories, category IV includes small bubbles which can be assumed to be a spherical shape of which the size of the criteria is 2mm based on the chord length. The measurement method for each category of the interfaces is referred to Euh et al.(2004) except for the correction factors.

$$(\bar{a}_i^t)_k = (\bar{a}_i^t)_{k,0} I_k, \quad k = II, III, IV \qquad (1)$$

where

$$I_{II} = 0.63 + 0.37\exp(-(H'-0.11)/0.17)$$
$$I_{III} = 0.93 + 0.52\exp(-(H'-0.11)/0.14)$$
$$I_{IV} = (0.98 + 0.62H')(0.75 + 0.25*(D_{av}/D_{av0}))$$

In the above relations, H' means the measured bubble turbulent intensity ratio and D_{av0} is set as 3mm.

Figure 3 shows the performance of the five-sensor probe method for 5.0mm of an average bubble size based on the numerical simulation. The categorical results as well as the total IAC agree well with the exact values.

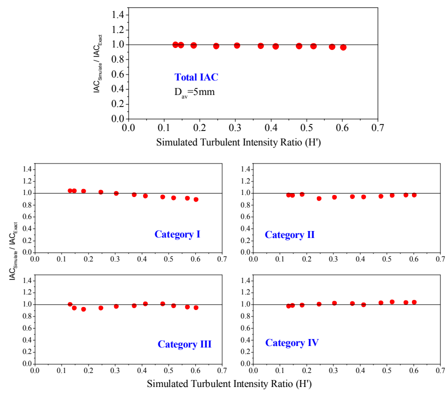

Figure 3. IAC Simulation Results for D_{av}=3.0mm

3. Photographic Method for a Benchmarking

Figure 4(a),(b) shows the visualization system. It has a test section which is made of acryl that has a 10mm X 10mm cross-section and a 1 m height. The probe is fixed at the center of the upper side of the test section. To take a side view of the bubbles, a mirror is installed at the side of the test section. The test conditions have the velocity range of 0.8~2.4 m/s. The imaging process is performed by using a NAC high-speed analog video camera of which the speed is 1000 fps. By using software, the boundary and position of the bubble are defined and the measured variables are coordinates of the bubble center, angles of an axis of an ellipsoidal, and the width and height of the box enclosing a bubble. Data acquisition of the probe signals and taking a picture is started simultaneously, and continued for the same period.

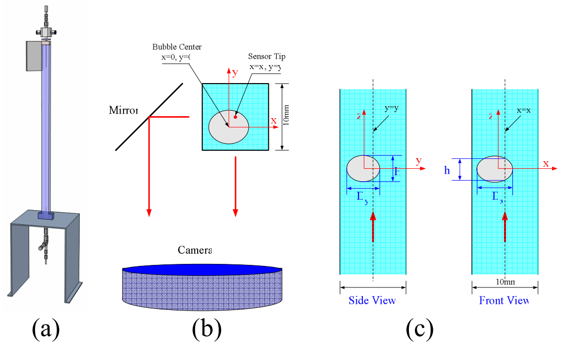

Figure 4. Visualization and Diagram for Image Processing

A bubble is assumed to be a rotated one which has the following ellipsoidal form.

$$\left(\frac{x}{a}\right)^2+\left(\frac{y}{b}\right)^2+\left(\frac{z}{c}\right)^2=1 \qquad (2)$$

The formula of a bubble surface function after a rotation can be expressed as the following formula by considering the rotated angles in the X-Z and Y-Z coordinates of Figure 4(c), which are defined as α and β respectively.

$$\left(\frac{\cos\alpha\cdot x+\sin\alpha\cdot z}{a}\right)^2+\left(\frac{-\sin\alpha\sin\beta\cdot x+\cos\beta\cdot y+\cos\alpha\sin\beta\cdot z}{b}\right)^2$$
$$+\left(\frac{-\sin\alpha\cos\beta\cdot x-\sin\beta\cdot y+\cos\alpha\cos\beta\cdot z}{c}\right)^2=1 \qquad (3)$$

From this formula, we can obtain the limit conditions of x, y, and z, which correspond to the box width and height enclosing the bubble in each direction.

For the upward flowing bubble, the local void fraction and interfacial area concentration at the position of the sensor tip can then be derived by

$$\alpha=N_b\left(\frac{h_i}{\mathrm{v}_b}\right) \text{ and } a_i=2N_b\left(\frac{1}{\mathrm{v}_b}\sqrt{1+\left(\frac{dz}{dx}\right)_i^2+\left(\frac{dz}{dy}\right)_i^2}\right). \qquad (4)$$

4. Results and Conclusions

The comparison plots of the probe data and image data for the bubble parameters are shown in Figure 5. The compared parameters are the velocity, bubble frequency, void fraction, interfacial area concentration, chord length, and the bubble Sauter mean diameter. The velocity, bubble frequency, void fraction and chord length agree well with 3.5, 8.3, 7.0 and 2.8% of an average deviation, respectively. Benchmarking for the four parameters illustrates that the interface perturbation effect by a piercing of the sensor tips and the validity of the converting procedures of the raw signals to a rectangular form are satisfactory. The average deviations between the two methods for the interfacial area concentration and the Sauter mean diameter are 9.9% and 8.8%, respectively. Since the two parameters are functions of the various variables, the errors can be induced from various reasons. However, the difference level is acceptable.

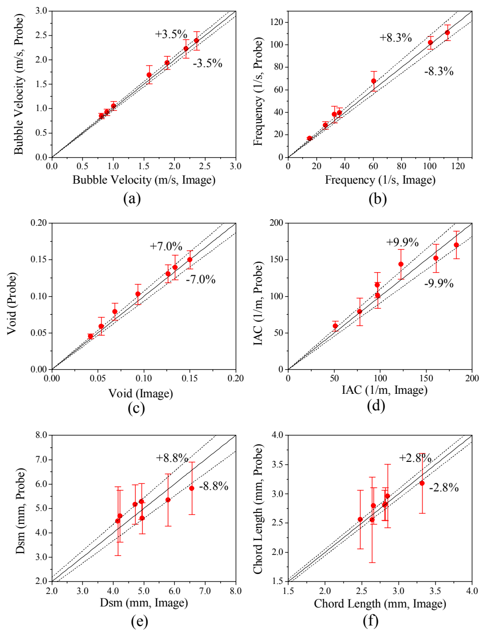

Figure 5. Comparisons of the Bubble Parameters

Acknowledgement

This work has been financially supported by the Ministry of Science and Technology (MOST) of Korean government under the national nuclear mid- & long-term R&D program.

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