Establishment of Stable Shear Flow for Measurement of Lift Force on the Bubble Interface using L-channel

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1. Introduction

Recently, efforts for 3-D CFD (Computational Fluid Dynamics) analysis of two-phase flow are actively in progress. In order to develop the 3-D CFD analysis for two-phase flow, correct models for interfacial forces which describe a bubble or a particle behavior against the working fluid are required. However, among the interfacial forces, lift force and turbulent dispersion force which are concerned in the lateral migration of bubbles or particles are still not clearly explained due to the lack of experimental data especially in low-viscosity systems. Therefore, in this study, lift force on single air bubbles was measured under the stable shear field generated by L-channel to improve the understanding of lift force in low-viscosity systems such as air-water system.

2. Experimental Methods

2.1 Experimental Facility

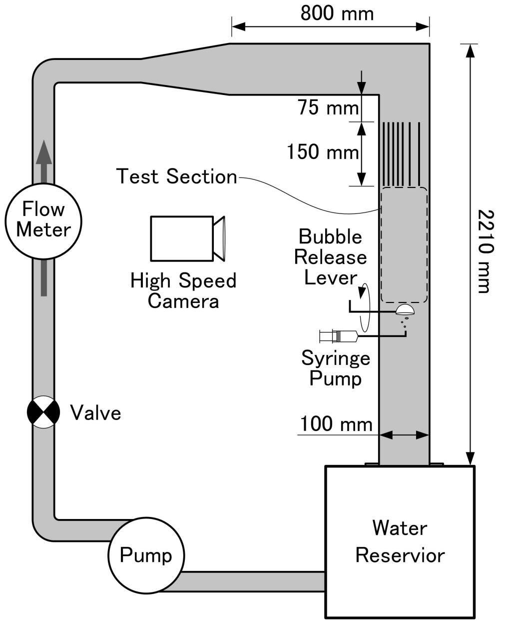

Fig.1. Schematic of the experimental apparatus

The schematic of the experimental apparatus is shown in Fig. 1. The test channel was fabricated in L-shape with the cross-sectional area of $100\times100\ mm^2$, the height of 2210 mm and the width of 800 mm. All parts of the channel are made of transparent acrylic plates to trace the bubble trajectory. Diffuser with angle less than 7° is inserted to avoid the large losses associated with separation occurred in the diverging section between the channel and pipe. In order to minimize the turbulence term and make the flow uniform, aluminum honeycombs (with the length of 45mm) and stainless steel mesh screens (with the size of 4 mm) are placed at each terminal of the diffuser.

2.2 Shear Generation

Unlike previous method which used a belt to develop the shear flow (Tomiyama et al., 2002), L-channel closed loop system was developed to generate the shear flow in low-viscosity system which utilized the feature of non-uniform flow that occurs when flow changes its direction rapidly. In order to stabilize the shear flow, the length of each vertical partition in the channel is designed to be 150mm with CFD analysis. This geometry has high linearity and maintainability of velocity profiles. The flow velocity profiles were measured by using UVP (Ultrasonic Velocity Profiling) method with Met-Flow SA UVP-DUO UVP measurement system. The linear shear flow was observed in the L-channel for various inlet flow rates. Fig. 2 shows the measured velocity profiles at the test section with the flow rate of 67.5 lpm.

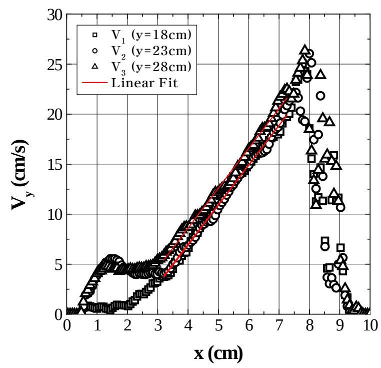

Fig. 2.UVP measured velocity profiles of 67.5 lpm

The shear angles of the velocity profiles were calculated by linear regression. The average shear angle is $3.98s^{-1}$ for 67.5 lpm. Standard error and adjusted R-square values for the linear regression are 0.0476 and 0.99197, respectively.

2.3 Bubble Injection and Trajectory Tracing

Since air-water system has low viscosity, large bubbles can be separated into several bubble segments. For the purpose of preventing the bubble separation before the measurement process, the bubble holding cap of hemisphere-type (4mm in diameter) was installed.

After the bubble is released, each bubble trajectory was traced using high-speed camera, Photron Fastcam Ultima 512.

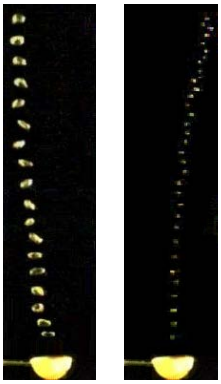

Fig. 3. Trajectory of single bubble released by holding cap, frame rate: 50 ms, (a) large bubble (d_b = 11.45 mm), (b) small bubble (d_b = 3.98 mm)

3. Results

Tomiyama et al., (2002) assumed the form of lift force caused by slanted wake and shear-induced are same, so that the net transverse lift force is given by

$$\begin{aligned} \boldsymbol{F}_L &= \boldsymbol{F}_{SL} + \boldsymbol{F}_{WL} \\ &= -(C_{SL} + C_{WL})\rho_l \frac{\pi d_b^3}{6}(\boldsymbol{v}_g - \boldsymbol{v}_l) \times rot\, \boldsymbol{v}_l \\ &= -C_L \rho_l \frac{\pi d_b^3}{6}(\boldsymbol{v}_g - \boldsymbol{v}_l) \times rot \boldsymbol{v}_l \end{aligned}$$

Where C_L, ρ_l, d_b, v_g and v_l are net transverse lift force coefficient, liquid density, bubble equivalent diameter, bubble velocity and liquid velocity, respectively. In order to determine the lift coefficient, bubble equivalent diameter was calculated by the volume of each bubble, and the velocity of the bubble is evaluated by the bubble trajectory.

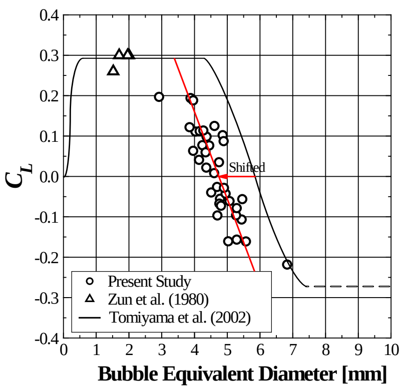

Fig. 4. Lift coefficient in air-water system

Fig. 4. shows net transverse lift force coefficient determined from the experimental data of the present study, Zun et al., (1980) and prediction of air-water system by Tomiyama et al., (2002). The present lift coefficient shifted to the left (smaller bubble diameter) side within the interval of 1.1 mm for the bubble equivalent diameter from the prediction of Tomiyama et al., (2002) and the critical migration diameter, where C_L = 0, is measured as 4.75 mm. Considering Tomiyama et al., (2002) pointed that it might be inappropriate to make a direct comparison between the calculation and experiment in his paper, the tendencies of the results show reasonable agreements with their prediction of the lift coefficient in air-water system.

4. Conclusion and Discussion

In order to measure the lift force of the bubble in stable shear flow, the present L-shape water channel for the low-viscosity system was developed. The net lift force coefficient of various sized single bubble was evaluated for the certain shear angle.

- The average shear angle was 3.98 s^{-1} for 67.5 lpm.
- Lift coefficient was determined for the bubble equivalent diameter of 2.92 mm < d_b < 6.83 mm.
- Approximated first order d_b-C_L slope was 0.2 for the present study and Tomiyama et al., (2002).
- Determined C_L of the present study was shifted to the 1.1 mm left side in bubble equivalent diameter from the Tomiyama et al., (2002).

The tendencies of the experimental results show reasonable agreement with pervious researches, so that the results could provide the data set for 3-D CFD simulation of low viscosity system; however, further discussions about the influences of dimensionless numbers and water contamination ratio for the lift coefficient should be operated in next research.

ACKOWLEDGEMENT

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