Velocity Measurement around a Large Bubble Rising in Stagnant Water in a Round Pipe Using the UVP (2nd Report: The Effect of Bubble Length and Pipe Diameter)

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The averaged liquid velocity fields around a large bubble rising in stagnant liquid in a vertical round pipe were measured using Ultrasonic Velocity Profile monitor (UVP) in order to obtain fundamental information of the gas-liquid two-phase slug flows. Two ultrasonic transducers were set at different directions to get velocity vectors. In this report, the effects of bubble length and the pipe inner diameter on the velocity field are investigated and discussed. In the liquid film near the bubble nose, the liquid downward flow is almost the free-fall with negative of bubble rising velocity as initial velocity even if bubble length and pipe diameter change. The velocity profiles in the liquid phase above and below the large bubble (wake) are also discussed.

Keywords: Ultrasonic Measurements, Large Bubble, Average Velocity Field, Velocity Distribution, Wake

1 INTRODUCTION

Gas-liquid two-phase slug flows in vertical pipes are frequently encountered in industrial pipelines, chemical and nuclear reactors and other fluid machineries. The averaged velocity field around a large bubble rising in a stagnant liquid, which is one of the simplified forms of large bubbles in slug flows in vertical pipes, is first required to know the velocity field around the large bubbles in the slug flow, and to establish a more reasonable model of the flow. The authors have proposed a measuring method using an Ultrasonic Velocity Profile monitor (UVP) to clarify the averaged velocity field around a large bubble, and succeeded to present the velocity field for a vertical pipe of 54mm diameter [1].

As for the existing studies on the measurement of the velocity field around a large bubble rising in a stagnant liquid, we can enumerate the measurement using photochromic dye activation method by Kawaji et al.[2], and those using PIV by Nogueira et al.[3], by van Hout et al.[4], and by Bugg and Saad[5]. Tomiyama et al.[6] also performed the measurements using LDV especially to clarify the flow field in the wakes behind the large bubbles. But, no systematic data including the effect of bubble length and of pipe diameter is available. So we still need a systematic and precise data base on the velocity field, especially on the effect of large bubble length and pipe diameter on the velocity field.

2 EXPERIMENTAL FACILITIES

2.1 Experimental Apparatus and Procedure

A schematic of the experimental apparatus is shown in Figure1.The precise of the apparatus should be referenced the previous report [1].

The test section was consisted of a transparent acrylic round pipe set vertically. To clarify the effect of pipe diameter on the velocity field, we carried out experiments using four different pipes of 26, 32, 42 and 54mm inner diameter. They are denoted by 25A, 32A, 40A and 50A, respectively, in this paper. Two ultrasonic transducers of UVP (frequency: 4MHz) were set at the outside of the test section: one +20 degree and the other –20 degree inclined from the horizontal line.

Velocity field of about 20 large bubbles were measured for one bubble length in each diameter pipe. Four groups of bubble length (L_B = 1.5D, 2D, 3D and 4D) are adopted to investigate the effect of large bubble length on the velocity field.

2.2 Shape of Large Bubble

The shapes of large bubbles were obtained by measuring the film thickness around large bubbles using images from a digital video recorder. As a result, the shapes of the large bubbles in this study are estimated with average relative error of 6.9% by the bubble shape function proposed by Nakahara et al.[8]. Hence the large bubble shape is estimated by this function in this study.

2.3 Equation of Continuity

In order to confirm the uncertainty in measurement, the continuity relation was applied to the measured velocity filed. Figure 2 is an example of the results for the case of D = 50A (54mm) and L_B = 2D. Because the flow system in this study is essentially a static system, the flow rate Q should be zero

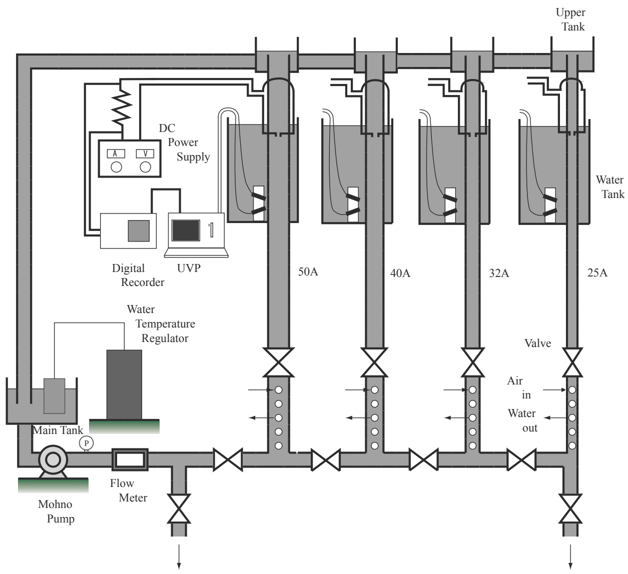

Figure 1: Schematic of Experimental Apparatus

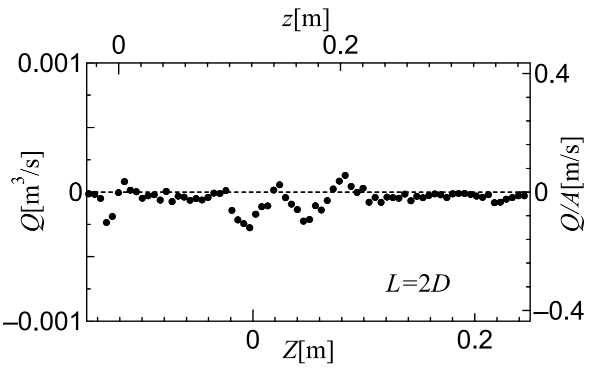

Figure 2: Continuity Relation

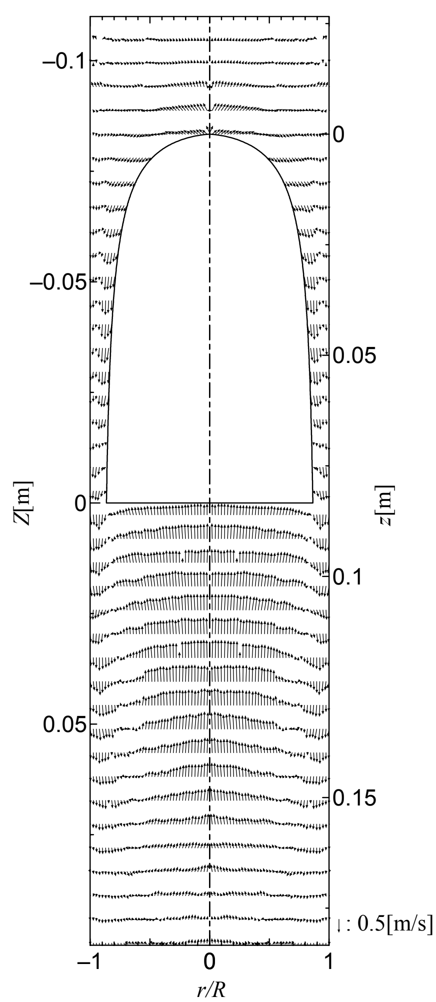

Figure 3: Velocity Field for L_B = 1.5*D*, *D* = 50A

ideally. Although the data depart from zero line in some degree around large bubble tail (*Z* = 0; *Z* denotes the downward distance from the tail of the large bubble and *z* from the nose.), the average absolute value of velocity (*Q/A*) is not so large (= 0.0291m/s) compared with the large bubble rising velocity, u_B (= 0.269m/s). It can be confirmed that the UVP measurement system in this study can measure the velocity field by such accuracy.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Outline of Velocity Field [1]

An example of the obtained result of the velocity field is presented in Figure 3 for a whole slug unit for the case L_B = 1.5*D* and *D* = 50A. It is recognized that the very small velocities are measured in the liquid phase in front of the large bubble. On the other hand, very large velocities are found in the liquid phase in the liquid film around the bubble and behind the large bubble. We can observe a downward accelerating flow in the liquid film, which penetrates into the liquid bulk behind the large bubble near the wall, and attenuates soon. In the center of pipe just below the large bubble, we can see large upward velocities, which form a large ring vortex with the wall-side downward flow.

From now, the precise characteristics in each part are exhibited and discussed with considering the effect of large bubble length L_B and pipe inner diameter *D*.

3.2 Liquid Velocity above Large Bubble

In order to make the flow field clear, we enlarged the velocity vector display in this region as shown in Figure 4 because in the liquid phase in front of the large bubble, only very small velocities are recognized. The liquid near the pipe axis is lifted owing to the rising bubble nose, whereas near the pipe wall, the downward flow is recognized, which will flow into the liquid film around the large bubble. There is another downward flow near the pipe wall from $z \cong 0$. These two downward flows join together in the film to make a complex flow pattern.

The effect of bubble length is essentially negligible for the velocity field in this area; even if the bubble length changed from 1.5*D* to 4*D*, the velocity field is identical. It is quite natural because the bubble rising velocity and bubble nose shape are identical for different bubble lengths, and this area connects the

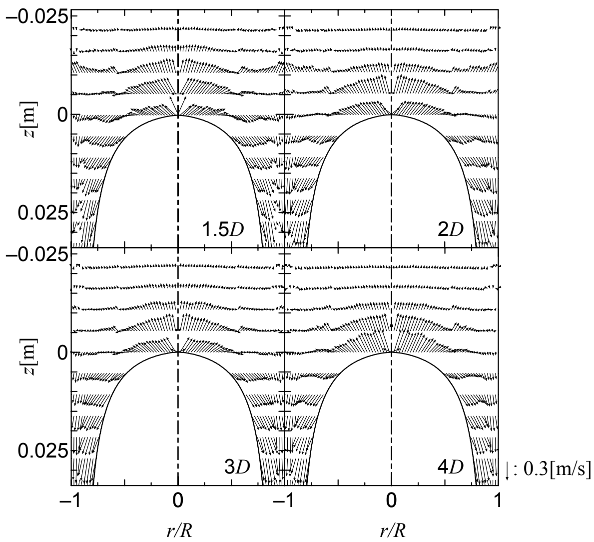

Figure 4: Liquid Velocity in Front of Large Bubble

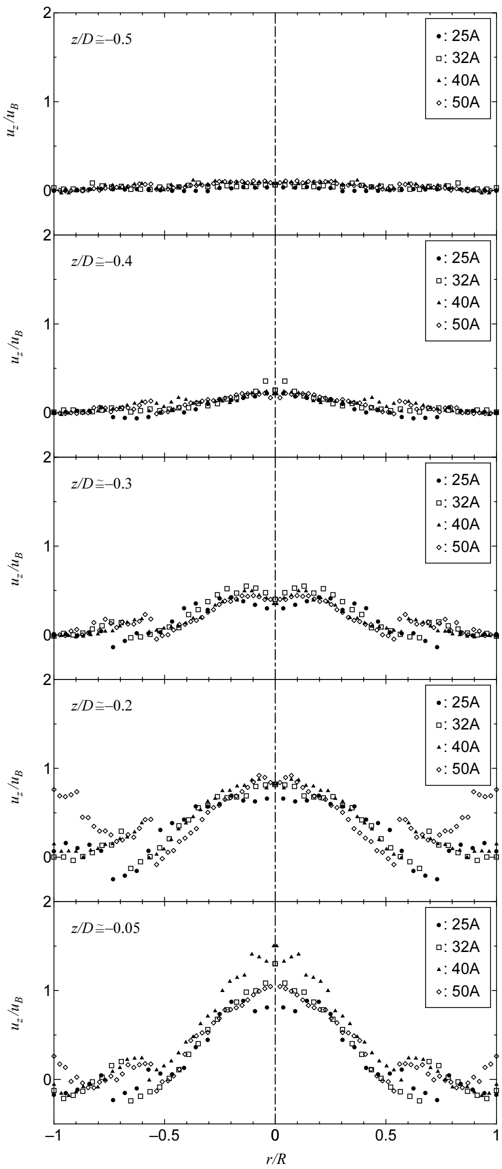

Figure 5: Velocity Profile above Large Bubble (L_B =1.5D)

area where the effect of pipe diameter is obvious as will be described later (wake part) only through the thin liquid film.

Figure 5 shows the normalized velocity profile or the flow direction velocity component in this region divided by large bubble rising velocity u_B with the pipe diameter as parameter. Agreement of profiles for different pipe diameter is so good even if the positions from the bubble nose, *z/D*, change. Thus, we can conclude that the effect of pipe diameter on the liquid velocity in front of large bubble is explained clearly only by the difference of u_B.

3.3 Liquid Film around Large Bubble

Figure 6 shows the velocity fields in the liquid film for different bubble lengths in 50A pipe. We can observe a downward accelerating flow in the liquid film, which will penetrate the liquid bulk called the wake part behind the large bubble near the wall. Therefore, the velocity of the downward flow when it penetrates the wake depends on the large bubble length; the longer, the faster.

In Figure 7, the maximum downward velocities at each position *z* in the liquid film, u_{zmax}, minus large bubble rising velocity, u_B, are plotted against *z*. If we suppose the liquid downward velocity is the result of the free-fall from $-u_B$ as the initial velocity, the downward velocity data should agree with the curves of free falling in the figure. Near the bubble nose, they agree well, especially *z* is smaller than about 0.05m. The data deviate downward as *z* becomes larger, probably because of the wall friction. Both the bubble length and the pipe diameter do not effect on the feature.

3.4 Wake Part below Large Bubble

The velocity fields in the wake part just below the large bubble are shown in Figure 8 for each large bubble length. As mentioned above, a downward accelerating flow in the liquid film around the large

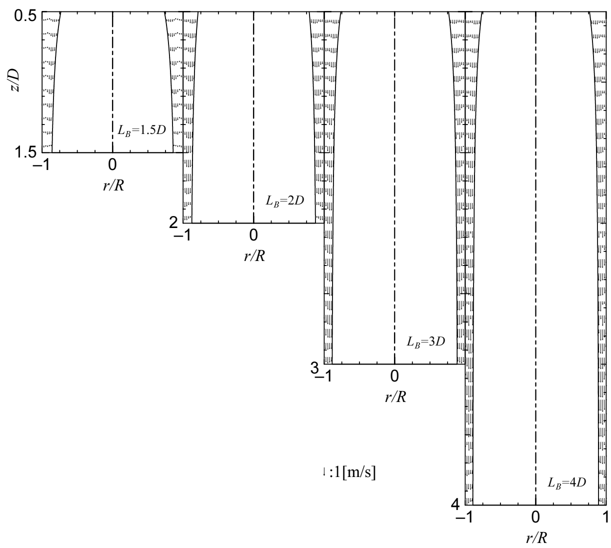

Figure 6: Liquid Velocity Field in Film (D = 50A)

bubble penetrates it, which causes a downward flow near the pipe wall. Around the pipe axis, on the other hand, an upward flow appears following the large bubble. These two flows form a large ring vortex as shown in Figure 8.

In Figure 9, normalized vertical velocity profiles are plotted. The vertical components of the velocity are again divided by large bubble rising velocity. Then, the profiles at the same position from the large bubble tail *Z* normalized by *D* agree very well in four different pipe diameters.

4 SUMMARY

In this report, the effects of bubble length and the pipe inner diameter on the velocity field are investigated and discussed. In the liquid film near the bubble nose, the liquid downward flow is almost the free-fall with negative of bubble rising velocity as initial velocity even if bubble length and pipe diameter change. The velocity profiles in the liquid phase above and below the large bubble (wake) are also discussed. It is concluded the normalization by bubble rising velocity and pipe diameter match the both profiles very well.

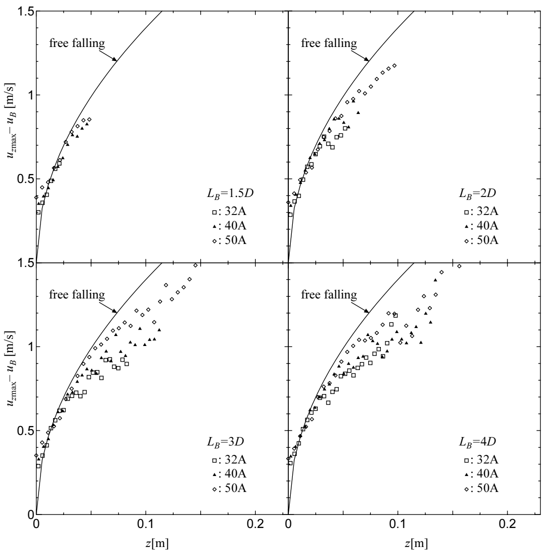

Figure 7: Liquid Downward Velocity in the Film

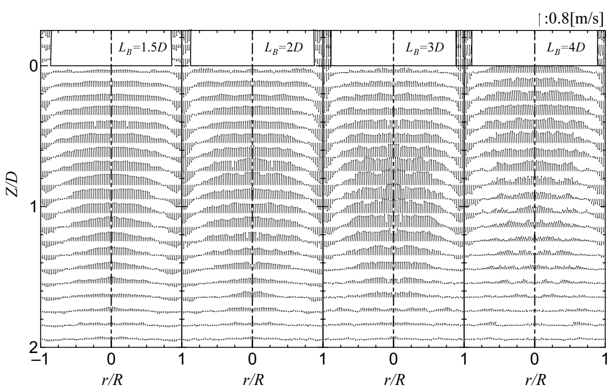

Figure 8: Velocity Fields in Wake (*D* = 50A)

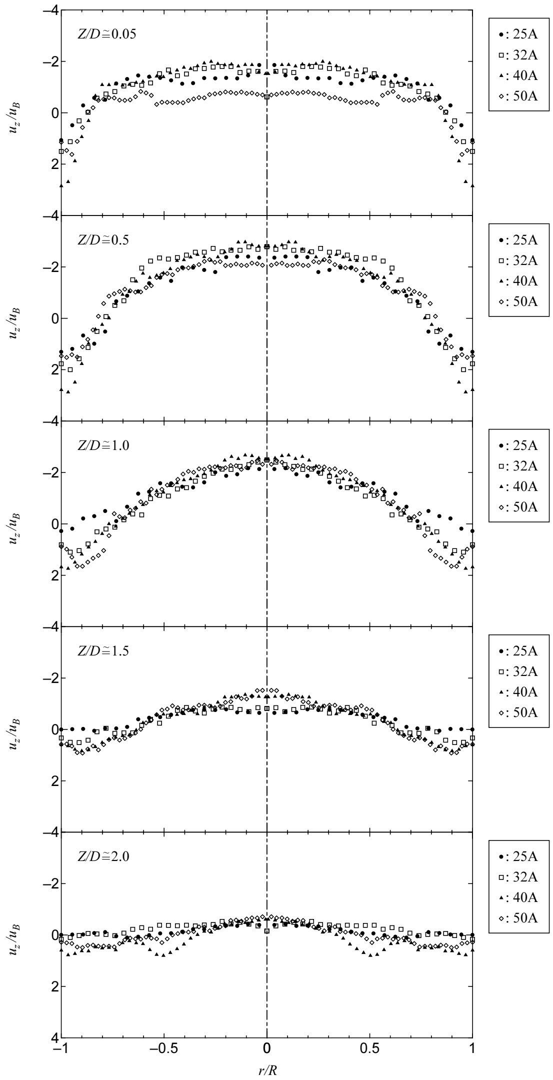

Figure 9: Velocity Profiles in Wake (L_B =1.5*D*)

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