2.ISUD
2nd International Symposium on Ultrasonic Doppler Methods
for Fluid Mechanics and Fluid Engineering
September 20-22, 1999
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Liquid Flow Structure around Bubbles
— Effect of Channel Width —

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1. Introduction

To understand the fundamental mechanism of two-phase bubbly flows, a great number of experimental studies have been carried out. There are many measurement techniques for their flow structure. Quick closing valves is one of the most simple methods to measure average void fraction. To measure local void fraction, probe techniques and radiation techniques have been used for a long time. In recent years, a laser Doppler anemometer is widely used to measure void fraction, liquid velocity and its fluctuation. These methods have made a great contribution in clarifying the macroscopic flow structure of two-phase flows. However, there still does not exist a measurement technique which can easily measure the velocity profile around a gas-liquid interface, even though it is necessary to clarify the flow structure around the bubble surface in order to understand the microscopic mechanism of bubbly flows.

The authors have been trying to measure the velocity field in bubbly flows by using the ultrasonic Doppler-shift method. The measurement instrument, the Ultrasonic Velocity Profile Monitor (UVP), was originally developed to measure liquid flows. The system can measure an instantaneous velocity profile along a measuring line by the traveling time of its pulse and Doppler-shift frequency of signals reflected on micro-particles in liquid (Takeda, 1991). When it is applied to bubbly two-phase flow, the ultrasonic pulse is reflected on both micro-particles in liquid phase and gas-liquid interfaces.

The UVP was used to measure air-water bubbly upward flows in rectangular channels. Void fraction was less than 2 %, since it was hard to measure bubbly flows in high void fraction, which can easily induce multiple reflection on bubble surfaces. Measurement was carried out 9 times at each measurement condition, and more than 9000 velocity profiles were recorded. From the measured instantaneous velocity profiles, the position of the bubble surface was decided and the data was rearranged according to the distance from the bubble surface. In this paper, the data analysis method will be explained after describing the experimental equipment. Then, the velocity distribution around bubbles and the effect of channel width on the flow structure will be discussed.

2. Experimental Apparatus

The schematic diagram of the experimental apparatus is shown in Fig.1, which consists of a water circulation system, an air supply system, a test section and a measurement system. Working fluids are air and water. Micro particles (ca. 10μm diameter) of nylon powder were mixed in the water as reflector of ultrasonic pulses. Specific gravity of the powder is 1.02, and it can be said that tracer particles follow the liquid flow well.

Water flowed upward into the test section from the lower entrance of the test section. Water flow rate was controlled by a needle valve and it was measured by an orifice flow meter, both of which were located at the bottom part of the apparatus. Air was injected into the system through five needles (inner diameter: 0.1 mm) at the air-water mixing section, which were also located at the lower end of the test section. The air flow rate was regulated by a float flow meter and an air control valve. During experiments, water temperature was kept between 19 to 21 degree using a pre-cooler and thermo-couples. Also in parallel to the measurement by the UVP, the pressure drop was measured between pressure taps installed on the side wall to get average void fraction. All experiments were carried out under the atmospheric pressure.

Figure 2 shows the test section located between the upper tank and the air-water mixer. Two kinds of vertical test sections were used, both of which were made of Plexiglas with 10 mm wall thickness. The longer side length of the rectangular cross section was constant at 100 mm, and the shorter side length (channel width) was either 10 mm or 20 mm. An ultrasonic transducer was set on the outer surface with a contact angle of 45 degrees toward the liquid main flow direction. Gap between the transducer and the wall was filled with ultrasonic jelly to prevent the reflection of ultrasonic pulses on the wall. Under each experimental condition, measurement was carried out 9 times continuously and more than 9,000 velocity profiles in the channel were obtained along the measuring line.

The experimental conditions are tabulated in Table 1. Also, the UVP configurations used in this study were summarized in Table 2.

Table 1 Experimental conditions

Water superficial velocity (10 mm channel width)	0.12	–	0.18	m/s
Air superficial velocity (10 mm channel width)	0.00235	–	0.00384	m/s
Average void fraction (10 mm channel width)	0.09	–	0.83	%
Bubble diameter (10 mm channel width)	2.7	–	3.1	mm
Water superficial velocity (20 mm channel width)	0.10	–	0.18	m/s
Air superficial velocity (20 mm channel width)	0.00349	–	0.00748	m/s
Average void fraction (20 mm channel width)	0.98	–	2.01	%
Bubble diameter (20 mm channel width)	2.9	–	3.2	mm

Table 2 Specification of the UVP in this study

Basic ultrasonic frequency	4 MHz
Maximum measurable depth	91 – 189 mm
Velocity resolution	5.6 – 2.8 mm/s
Time resolution	16.4 – 32.8 msec
Spatial resolution in water	0.74 mm
Measurement points	128
Number of profiles	1024
Ultrasonic beam diameter	5 mm

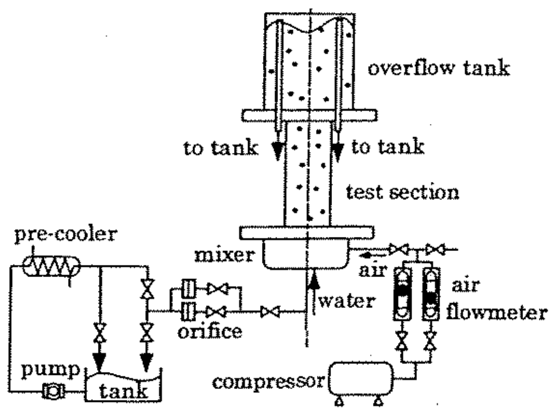


Fig.1 Schematic diagram of the experimental apparatus

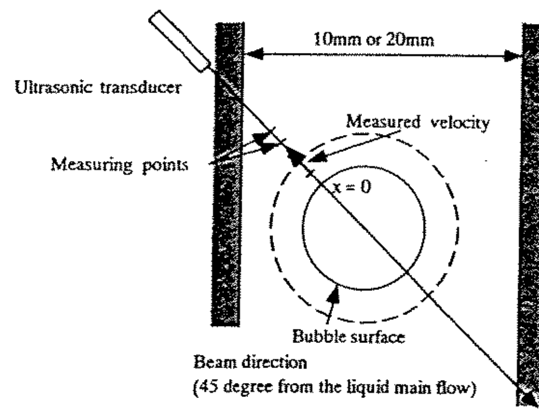


Fig.2 Test section

3. Data Processing method

The UVP system records information about the velocity field as a set of 1,024 instantaneous velocities at 128 positions. In this study, measurement was carried out nine times continuously under each flow rate condition. Therefore, 9,216 (1024 × 9) velocity data were obtained at each measurement position. When the UVP is used to a measurement of bubbly flows, ultrasonic pulses are reflected on bubble's surfaces and micro particles in liquid. Therefore, velocity profiles measured by the UVP include velocities of both liquid phase and bubble's interface. Since it is not possible to know which pulse is reflected on a bubble surface at present, distinction of bubble's interface velocities and liquid velocities was made using the threshold $T(x)$.

$$T(x) = C \times V_S(x) \qquad \text{(Eq.1)}$$

where the value $T(x)$ is defined as the product of a constant C and the time-averaged velocity $V_S(x)$ of the liquid single-phase flow (Fig.3).

According to this manner, 9,216 velocity profiles were divided into two groups, Group (a) and (b). If a bubble exists on the measuring line when a ultrasonic pulse is emitted from the transducer, the velocity profile recorded at that moment is selected as Group (b). If bubbles do not exist on the measuring line, the velocity profile is put into Group (a). By averaging velocities of Group (a), the time-averaged velocity profile of liquid main flow can be obtained. From the set of Group (b), it is possible to get velocity profiles around bubble surface if the relative coordinate is adopted whose origin is set on the bubble's surface.

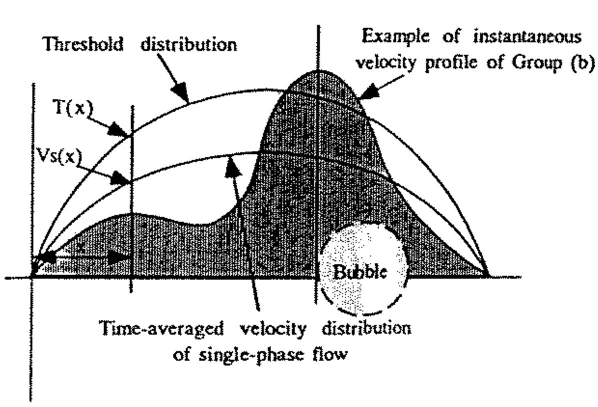


Fig.3 Schematic diagram of the threshold and instantaneous velocity

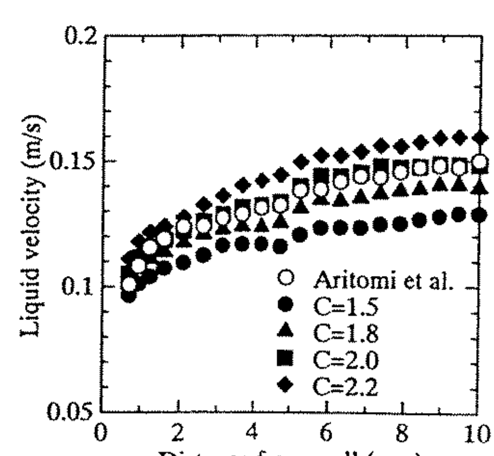


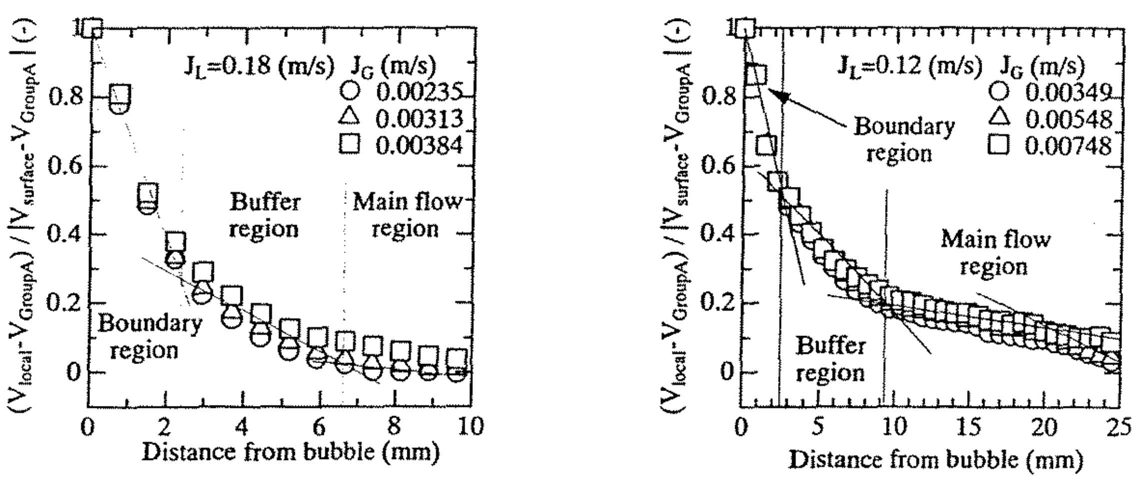
Fig.4 Comparison of liquid velocity distribution in the channel (Group (a))

Figure 4 shows the time-averaged liquid phase velocity profile obtained from Group (a). When the threshold is set larger, a small amount of instantaneous velocity profile is transferred to Group (b) and as a result, the mean velocity of Group (a) increases and an appropriate threshold can not be decided from this result.

In the previous research, our group developed a velocity measurement system for bubbly flows with the UVP (Aritomi et al., 1996, 1997 and Zhou et al., 1998). In Fig.4, time-averaged liquid phase velocity profile obtained using the system is plotted by open circles. The velocity profile has a good correlation with the mean velocity distribution of Group (a) if the constant *C* is set between 1.5 to 2.2 according to the liquid flow rate.

4. Results and Discussion

In Fig.5, normalized relative velocity distributions around bubbles for both 10 and 20 mm channel width are shown. Relative velocity of gas and local liquid velocity is normalized by that at the bubble's surface. Recently, Suzuki et al.(1999) has reported the velocity distribution around bubbles in upward bubbly flow for 10 mm channel width. According to their report, the flow structure around bubbles could be divided into three regions (Fig.5(a)). For 20 mm channel width, the same trend was observed (Fig.5(b)). Relative velocity has large gradient near bubbles and it becomes almost constant in the region more than 9 mm away from a bubble. The region with large velocity gradient was named the 'boundary region'. The area, where the velocity is relatively uniform, was called the 'main flow region', and the area between the 'boundary region' and the 'main flow region' was called the 'buffer region'. As seen in Fig.5, thickness of the boundary layer did not change according to the configuration of the test section. Since the flow is dominated by the relative velocity of gas and local liquid velocity in the boundary region, thickness of the region does not change even if the test section is widened. On the other hand, distance from the bubble surface to the main flow region is broadened when the test section's width is doubled. In the experiments in the channel of 20 mm width, relative velocity tended to decrease in the region more than 20 mm away from a bubble. This tendency would be considered the effect of the wall existence.



(a) 10 mm channel width

(b) 20 mm channel width

Fig.5 Relative velocity distribution around bubbles

References

Takeda, Y.,: Nuclear Engineering and Design, Vol. 126, 277 (1991).

Aritomi, M. et al.,: Journal of Nuclear Science and Technology, Vol. 33, 915 (1996).

Aritomi, M. et al.,: Journal of Nuclear Science and Technology, Vol. 34, 783 (1997).

Zhou, S. et al.,: Journal of Nuclear Science and Technology, Vol. 35, 335 (1998).

Suzuki, Y. et al.: Proceedings of the 7th International Conference on Nuclear Engineering (ICONE-7), Tokyo, ICONE-7163 (1999.4).