Measurements of Bubble Jets by 3D PTV and UVP

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To show three dimensional flow structures is useful and effective when we treat with complicated flows such as bubble jets. A three-dimensional particle tracking velocimetry (3D PTV) is one solution, but has unknown factors. In the present study, we conduct the simultaneous measurements of 3D PTV with an ultrasonic velocity profiler (UVP) using the common tracer particles. The simultaneous measurements have other applicable possibilities, as well as accuracy check of 3D PTV. We tested four conditions Ⅰ-Ⅳ of tracer particles. As a result, UVP is not applicable for small number of the tracer particles. On the other hand, 3D PTV is not applicable for large number of the tracer particles. We have found the optimum condition for both measurements, and confirm the accuracy of measurements. In addition, we apply 3D PTV technique to bubble jets using air bubbles as tracer particles.

Keywords: PTV, UVP, Three Dimension, Bubble, Jet

1 INTRODUCTION

Recently, we have often suffered from water pollutions caused by eutrophication in lakes, ponds, harbors and so on. Engineers have developed a simple method to improve water quality, using bubble jets which are called aeration to make oxygen in water to resolve water pollution. As well, bubble's motion becomes important in many applications, such as chemical bubble columns, chemical reactors, gas absorbers, fermenters, bubble pumps and nuclear power plants. But each bubble motion in such flows is not sufficiently understood yet.

The authors' final aim is to reveal basic features of air-bubble jets into water. Concretely speaking, we try to measure the movements of bubbles one by one, quantitatively and simultaneously, and to show three-dimensional bubble-jet characteristics precisely and statistically.

Yamamoto et al. [1] have studied the concerning fluid motions using a three-dimensional particle tracking velocimetry (referred to as 3D PTV, for example [2]). Bergmann et al. [3] have studied the concerning fluid and bubble's motion in two dimensions.

Here, for above the purpose, we focus not on fluid motion but on bubbles' motion, and we develop the 3D PTV technique using bubbles as tracer particles. This technique has the following advantages. The technique can give us the information of many bubbles' velocity at each time. There exists no sensor which disturbs the flow. And we get three-dimensional information of a whole flow area successively. However, generally, this method has a disadvantage in accuracy.

In the present study, at first, we check the accuracy of 3D PTV. Namely, we carry out simultaneous measurements of 3D PTV with an ultrasonic velocity profiler [4] (referred to as UVP), which is more accurate in general. So, we conduct the simultaneous measurements in a turbulent and spatially-complicated flow, that is, a swirling flow in a cylindrical container. We will find the suitable condition of particle's density and particle's size to conduct simultaneous measurements by both 3D PTV and UVP, and then confirm the agreement. Next, from the certified 3D PTV method, we study the bubble-jet features.

2 EXPERIMENTAL METHOD

2.1 Experimental apparatus

To check the accuracy of 3D PTV, we measure a swirling flow by both 3D PTV and UVP simultaneously. Fig. 1 shows an experimental apparatus. A cylindrical container ① made of transparent acrylic resin is filled with water. We put the cylindrical container on a magnetic stirrer ②. A stirring object ③ on the cylindrical container bottom drives a swirling flow.

A 3D PTV system consists of the following: a YAG laser ④ as a light source, two sets of high-speed video cameras ⑤ with a frame rate of 1/500 [s], camera interfaces ⑥ and a personal computer ⑦ on which we conduct 3D PTV analyses. For accurate 3D PTV measurements, we have to diminish the image distortion due to the cylindrical container's surface curvature. We put a rectangular-prism container which covers the cylindrical container, and we fill the space between the containers with water as well.

An UVP system consists of the following: an ultrasonic transducer ⑧ as an UVP probe, which is placed outside the cylindrical container, and an UVP monitor ⑨ for simultaneous measurements with 3D PTV.

Fig.2 shows the present coordinate system, with the position of an UVP probe. We put the probe between the rectangular-prism and cylindrical containers.

3D PTV needs more than two cameras, and here we use a pair of cameras A and B. As shown in

Fig.1, the camera A is above the cylindrical container, the camera B is on the side. Fig.3 shows a sample stereo photo by the cameras A and B. Here, the fluid is in a swirling motion, and we can confirm that tracer particles are uniformly scattered.

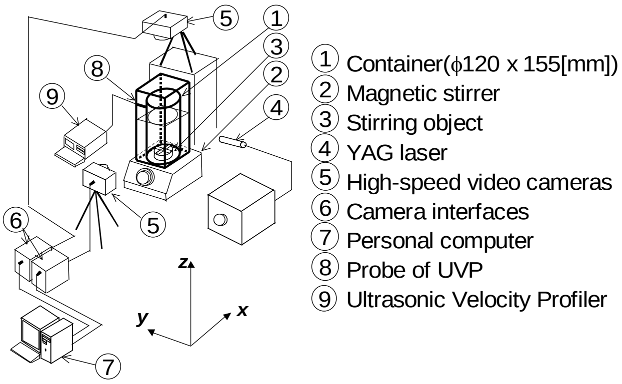


Figure 1: Schematic view of experimental apparatus.

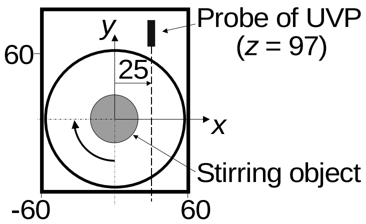
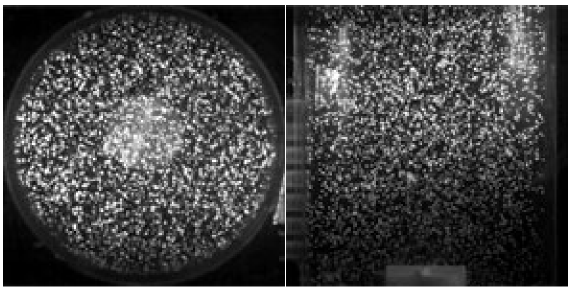


Figure 2: Coordinate system and the position of a UVP probe [mm].



(a) Camera A (b) Camera B

Figure 3: A pair of sample stereo photos for 3D PTV.

Table 1: Tested conditions.

Condition	I	II	III	IV
D_p [mm]	0.6-1.2	0.6-1.2	0.3-0.6	0.3-0.6
V_P [mm^3]	925	1851	444	1851
C_{VP} [%]	0.05	0.11	0.03	0.11
N_P	2500	5000	9300	38800
C_{NP} [mm^{-3}]	0.001	0.003	0.005	0.022
$C_{NP}V_{UVP}$ [mm^{-3}]	0.041	0.083	0.15	0.64

As the tracer particles, we use chemical-bridged polyethylene-resin particles with a mean diameter of 0.18 [mm], which is coated with fluorescent paint. Actual particles' diameter D_P is controlled by the thickness of the paint layer. Tab.1 shows four tested conditions I, II, III and IV, with different D_P and different particles' number N_P. Namely, condition I has the smallest N_P, II the second, and III the third. The condition IV has the largest N_P. The condition I and II have larger D_P, and the condition III and IV have smaller D_P.

2.2 Experimental apparatus for bubble jets

Fig.4 shows an experimental apparatus for bubble-jets measurements. A container ① is a cube of 1 [m] x 1 [m] x 1 [m], and made by acrylic resin. We fill the container with water, whose depth is 0.8 [m]. A compressor ② makes air flow through a flow control valve ③ and pipe ④ into a stainless-steal chamber ⑤. The chamber is placed on the bottom of the cubic container. An air nozzle is on the top of the chamber, through which air bubbles are generated into water. Pressure and temperature in the chamber are measured by a pressure transducer ⑥ and thermocouple ⑦, respectively. These signals through a sensor interface ⑧ are converted in digital data on a PC ⑨. Using two high-speed video cameras with a frame rate of 1/500 [s], two images of bubble flow are taken at the same time. We use a halogen lamp as lighting.

We test two kinds of nozzles. Namely, one is a straight-pipe nozzle with an inner diameter of 0.3 [mm] and a length of 15 [mm], and the other is a convergent nozzle with an inner diameter of 0.1 [mm].

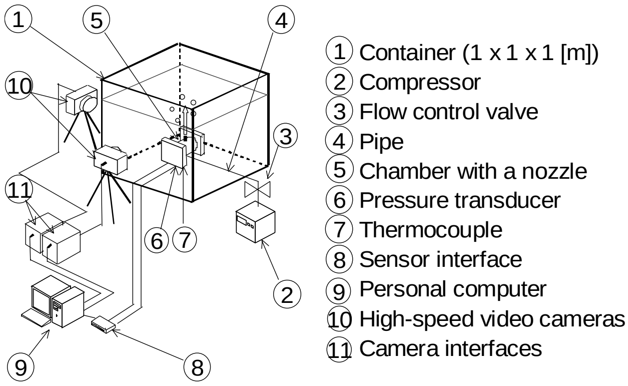


Figure 4: Schematic view of experimental apparatus for bubble jets.

2.3 Outline of 3D PTV analysis

For 3D PTV analysis (see [5]), we regard bubbles as tracer particles. First, using two high-speed video cameras, which are calibrated in advance, we take two simultaneous images of bubbles in a measurement volume. Second, we calculate three-dimensional positions of bubbles from a pair of stereo images. Velocity vectors of bubbles are obtained from 4 successive informations of position. All data processings have been done in a PC.

3 RESULTS AND DISCUSSION

3.1 Simultaneous measurements of 3D PTV with UVP

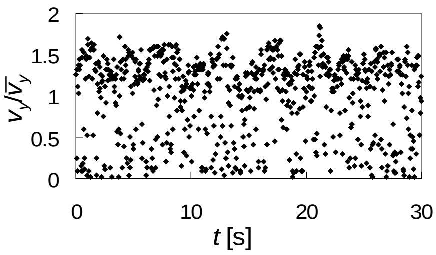
Figure 5 shows time history of flow velocity by UVP for each condition at y=0 [mm]. On the condition Ⅰ, we can see scattered data between $v_y/\overline{v_y}$ of 0 to 1. Then, the standard deviation σ becomes large. As is seen later, small v_y is considered to be the error due to the lack of tracer particles in UVP-measurement volume. As the total number of tracer particles N_P increases, the value of v_y concentrates its mean value $\overline{v_y}$ (see the condition Ⅱ,Ⅲand Ⅳ). One exception is v_y = 0. However, even the condition Ⅱ, the number of data with v_y = 0 is very small, therefore, time-mean value $\overline{v_y}$ has negligible effect. So, for appropriate UVP measurements, we need N_P per unit volume C_{NP} greater than that on the condition Ⅰ. And we confirm that the conditions Ⅱ, Ⅲ and Ⅳ are in good accuracy.

About the size of tracer particles, we compare the conditions Ⅱ,Ⅲ. Here, the particles on the conditionⅡis two-times bigger than the condition Ⅲ. So, we can see no effective size effect of the tracer particles. And the tested particle diameter D_P is in a suitable range for UVP measurements.

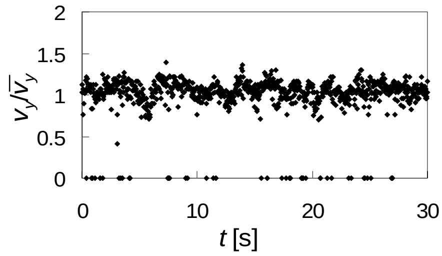
Fig.6 shows comparisons between 3D PTV and UVP about spatial profiles of time-mean velocity $\overline{v_y}$. On the condition Ⅰ $\overline{v_y}$ by UVP is lower than that by 3D PTV. As is shown in Fig.5 (a), UVP data includes many errors with lower values of $\overline{v_y}$. Then UVP data in Fig.6 (a) is considered to be lower than the actual data.

In Fig.6 (b), namely, on the conditionⅡ, 3D PTV is in good agreement with UVP. So, the condition Ⅱ is considered to be suitable for the simultaneous measurements by both 3D PTV and UVP.

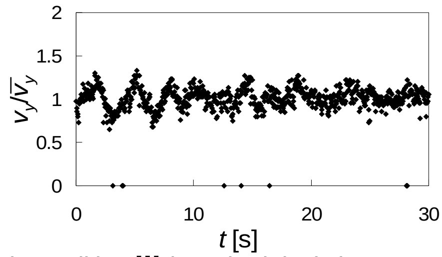
In Fig.6 (c) and (d), namely, on the condition Ⅲ and Ⅳ, 3D PTV results are lower than UVP. In general, 3D PTV is not suitable for a large number of tracer particles. And the conditions Ⅲ and Ⅳ are considered to be those with excessive tracer-particle numbers.



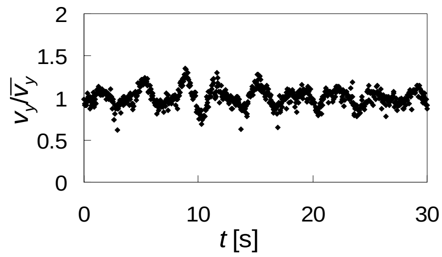
(a) Condition Ⅰ (standard deviation σ=0.49)



(b) Condition Ⅱ (standard deviation σ=0.25)

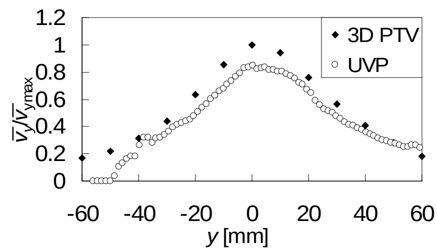


(c) Condition Ⅲ (standard deviation σ=0.15)

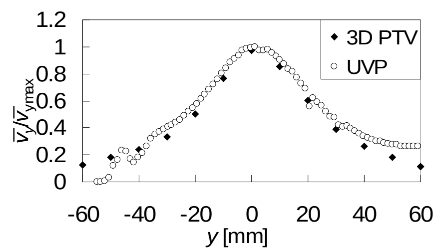


(d) Condition Ⅳ (standard deviation σ=0.11)

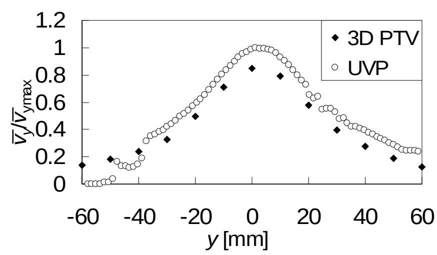
Figure 5: Time history of flow velocity by UVP (y=0 [mm]).



(a) Condition Ⅰ



(b) Condition Ⅱ



(c) Condition Ⅲ

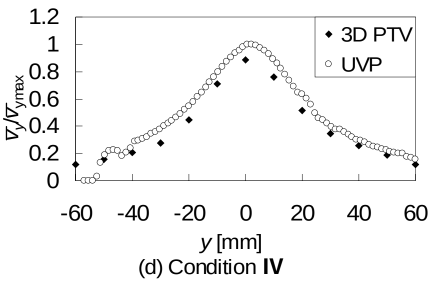


Figure 6: Profile of time-mean velocity $\overline{v_y}$.

3.2 Results of 3D PTV measurements of bubble jets

Now, we apply the 3D PTV to bubble jets, where air bubbles are used as the tracer particles. The parameter is the pressure ratio p_∞/p_0, where p_∞ is the surrounding static pressure at the nozzle exit and p_0 is the chamber static pressure. Fig.7 is a sample of velocity vectors of air bubbles, which is obtained by a sequence of stereo photos.

Fig.8 shows the relation between the pressure ratio p_∞/p_0 and the ensemble average of time mean bubbles V_b. Fig.8 (a) is for the near-centre area (at r = 0-5 [mm]) and Fig.8 (b) is far-centre area (at r = 35-40 [mm]). In the near-centre area, there exists the minimum value at $p_\infty/p_0 \cong 0.6$, which is near the choke boundary. On the other hand, in the far-centre area, as p_∞/p_0 decreases, the value almost monotonously decreases. But, near the chock-boundary pressure, the value changes rapidly. So, these seem to be a qualitative difference between the choked bubble jets and the non-choked ones. The above features are common on both two different nozzles.

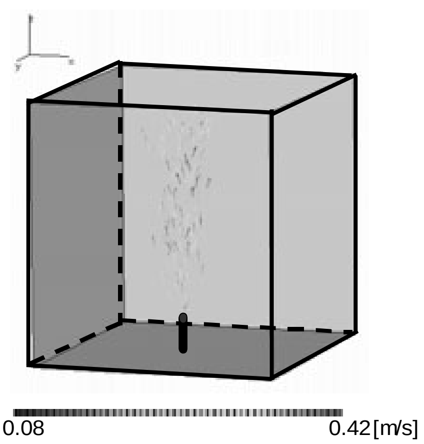


Figure 7: A sample of velocity vectors of bubbles (straight-pipe nozzle; p_∞/p_0=0.791).

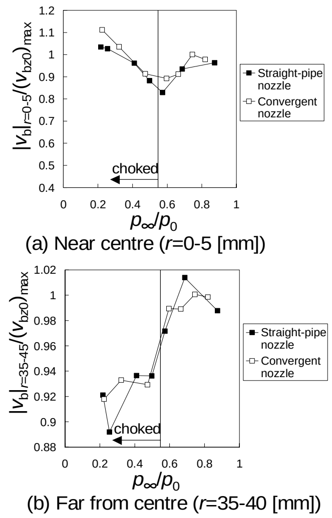


Figure 8: Pressure-ratio effect on mean bubble's velocity (z=220-260[mm]).

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5 CONCLUSIONS

The authors conducted simultaneous measurements by 3D PTV and UVP, and obtain the following conclusions.

1. UVP is not applicable for smaller C_{NP}, and 3D PTV is not applicable for larger CNP. The condition Ⅱ, Ⅲ and Ⅳ is suitable for UVP, and the condition Ⅰ and Ⅱ are suitable for 3D PTV.
2. A suitable condition for the simultaneous measurements is the condition Ⅱ, where D_P = 0.6-1.2 [mm] and C_{NP}=0.003 [mm^{-3}].
3. We have developed time-successive 3D PTV on air-bubble jets into water from a bottom nozzle using the bubbles as tracer particles.

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