A Study on Bubbly flow using PIV Measurement

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Abstract The partical-image-velocimetry with liquid crystal tracers is used for visualizing and analysis of the bubbly flow in a vertical temperature gradient. This method allows simultaneous measurement of velocity and temperature flow fields at a given instant of time. Quantitative data of velocity were obtained by applying the MQD technique to visualized image. The paper describes the method, and presents the transient velocity patterns of bubbly flow.

1. Introduction

There are many papers on bubbly flow[P I R j]. These works are mainly concentrated on plume itself and isothermal environment. When a bubbly flow is used in the lake or metallurgical furnaces, which is affected by the stratified temperature. Recently, only a few authors analyzed the interaction of the bubble plume with a stratified environment[4-5]. However, The transient flow and the thermal stratification effect of bubbly flow was not accomplished experimentally in these works. Therefore, it appears quite useful to perform supplementary experiments to investigate these details and understand the transient behavior of bubbly flow in a stratified temperature environment. Recently, the advent of particle image velocimetry has been made it possible to obtain high resolution global velocity and vorticity fields, and thermo-sensitive liquid crystals have been successfully used for visualizing temperature field. We apply these new techniques to the bubbly flow in a stratified temperature environment, and show the interaction of the bubble plume with a stratified environment.

The purposes of the present investigation are to visualize simultaneously the complex structures of the flow patterns of bubbly flow in a viscous fluid using the new methods, and analyze the transient mixing flow patterns of bubbly flow.

2. Experimental set up and Procedure

The experimental apparatus of the present study is shown schematically in Fig. 1. It comprises a test cell, two constant temperature baths, two light sources, two water filters, a gas distributor, a flowmeter, a gas tank, a digital thermometer with thermocouple, a digital video camera, and a computer. The test cell is made from two horizontal isothermal 23mm thick copper plates placed at the top and bottom side of the cell and four vertical 10mm thick acrylic resin plates for flow visualization purpose. The inside dimensions of the test cell are $200mm \times 100mm \times 12mm$ ($w \times h \times d$). To investigate bubbly flow in a vertical temperature gradient, the temperature of fluid be stratified by two horizontal copper plates. The upper(hot) and the lower(cold) copper plates are maintained at constant temperature by a water flow which passes through passages over and below copper plates. The temperatures of the waters are controlled by two constant temperature baths (Taitec EL-15F). The temperatures of the surface of copper are measured using k-type thermocouples connected to a digital thermometer(TR2114). The upper copper plate has one 2mm diameter hole at the center for measuring the temperature of the fluid. The lower copper plate has three holes at the center is used for bubble injection. The injector is a 0.2mm diameter and 80mm long brass needle and is connected via acrylic tube to the gas distributor. Silicon oil is used as a working fluid because a combination of silicon oil and the cholesteric liquid crystals gives a very vivid color. The flow field is illuminated with 3mm thin sheet of white light from two metal halide lamps that are located at the both sides of the test cell. A water filter is placed in front of each lamp to prevent excessive radiant heat transfer from the lamp to the working fluid. The reflected light is observed by a 3CCD digital color video camera(SONY). The recorded images are stored on the hard disk of the computer for evaluation. The observation axis of camera was arranged normal to the light sheet plane. The temperature and velocity field were measured by means of liquid crystals suspended as tracer particles in the fluid. The liquid crystal used in this experiment is cholesteric type RM2830(Japan Capsular Products Inc).

The concentration of liquid crystals within the working fluid is about 0.1, weight percent. The color of the light they reflect change from red to blue as the temperature is raised. The colorplay of the liquid crystals is also sensitive to a change in the viewing angle. Thus, the illumination and image capture systems including the test cell were fixed to avoid uncertainties due to variations of the viewing angle during the experiment and calibration procedure. The response time of the color change is of the order of milli-seconds. It is short enough for transient thermal problems in fluids. Detailed information concerning the characteristics of liquid crystals can be found in Dabiri, D. and Gharib,M.[18]. The experimental procedure is as follows. At the beginning of each experiment, the old liquid inside the cell is drained, and the cell is cleaned and rinsed thoroughly using soap and water. The cell is then assembled and filled with silicon oils carefully. The constant temperature baths are turned on to heat the lower copper plate and to cool the upper copper plate. When the natural convection is fully developed in the test cell, the liquid crystal tracers mixed with silicon oils are inserted into the fluid zone in the test cell slowly. After the liquid crystal tracers are well mixed in the whole region of the test cell, the constant temperature baths are readjusted to bring the upper and lower plates of the cell to the desired temperature. After several hours, when the vertical temperature gradient field is established the bubble is injected into the cell, then the temperature and velocity patterns are recorded by 3CCD digital video camera

3. Analysis Method

The algorithm of particle brightness distribution pattern tracking is the most popular. As shown in Fig.2, correct pairs of elements of particle clouds in two consecutive frames on the similarity of image brightness distribution patterns in the two frames by calculating the values of coefficient C_{fg} of cross-correlation defined by Eq.(1)[6]. In Fig.2, W_i stands for the window of interrogation area, W_p stands for the window of a reference pattern. The two figures stand for two consecutive images and P is the point where the velocity is to be calculated. The similarity of image brightness distribution patterns can also be evaluated by the method of minimum quadratic difference D_{fg} defined by Eq.(2)[7].

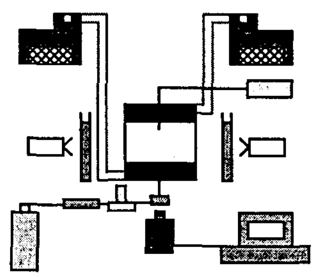

Fig.1 A schematic diagram of experimental apparatus.

$$C_{fg} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} f_{ij} g_{ij}}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} f_{ij} \cdot \sum_{i=1}^{N}\sum_{j=1}^{M} g_{ij}}} \quad (1)$$

$$D_{fg} = \frac{1}{NM}\sum\sum\left(f_{ij} - g_{ij}\right)^2 \quad (2)$$

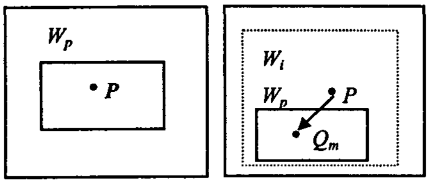

Fig.2 Principle of cross-correlation method based on brightness distribution patterns.

In the present study, 'minimum quadraric dfference' (MQD) technique is used. In these equations, f_{ij}, g_{ij} are digital gray vlues of the pixels in the overlapped interrogation windows of size $M \times N$ pixels which consist of element of particle clouds in the two consecutive frames. The matrices $F(i,j)$,$G(i,j)$ describe certain distributions of limited numbers of digital particle images. The two patterns F and G are the result of two separate records of particle image fields with a time interval Δt between the two records. The areas covered by $F(i,j)$ and $G(i,j)$ are only small fractions of the whole particle image field. When the minimum value of D_{fg} in Eq.(2) is found for a pair of the two interrogation windows, the pair is considered to be identified

4. Results and discussion

The velocity distribution is evaluated by means of PIV because of high image density of tracer particles(liquid crystals). The half of the original image is used for calculating velocity field. The velocity vectors at eight different instants are shown in Fig.3. Fig.3(a) shows the velocity vectors at 0.5 seconds from injecting bubbles. From this figure, we know that the bubble convection induced by rising gas bubbles arises the strong rising flow near the bubbles and recirculating flow at the ambient fluid. At the top bubble, the fluid raised along with bubbles is divided into three directions. One is turning to the downward direction and makes one cell flow near the bubble plumes, the other is side direction for intrusion toward the ambient fluid, others is upward direction. There are weak flows near the vertical left wall. These are erroneous velocity vectors that were caused by natural convection due to heat transfer through the wall. Although the water filter is used, it was very difficult to remove the effects of heat transfer from the light source during the experiments. In Fig.3(b), the secondary cell is shown near the top centerline, which is due to small recirculating flow formed near the free surface of the fluid. As the time is passed, the secondary cell is disappeared. The flow is reached to steady state with forming one large cell and the center of cell is near the middle of the centerline.

5. Conclusions

Partical Image Velocimetry technique is applied which allows to capture quantitative velocity data of full field bubbly flow in a stratified temperature environment. It would be extremely difficult to make such measurements by other technique. From the present results, it is demonstrated that the measurement system is very useful for analyzing unsteady thermal flow phenomena and it is expected that the quantitative data obtained by image processing can be directly used to verify the computational results.

References

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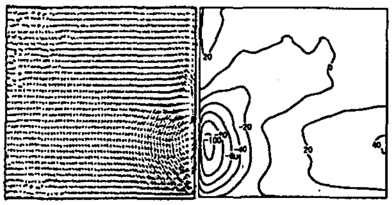
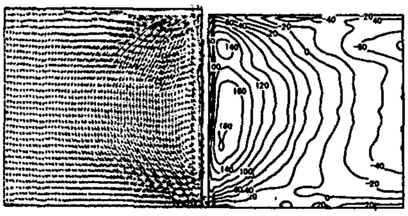
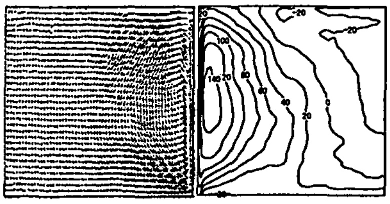


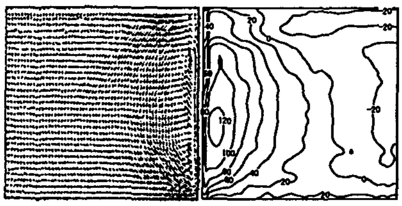
a) t=0.5 sec.



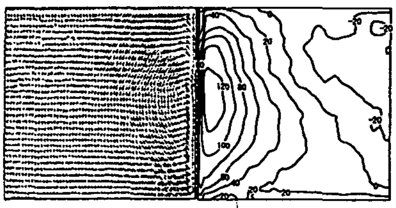
b) t=5.0 sec.



c) t=10 sec.



d) t=15 sec.



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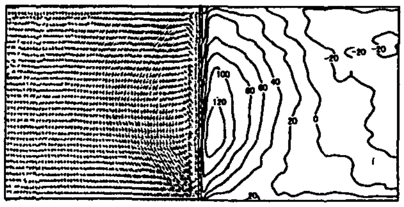

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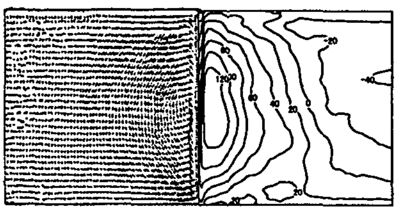
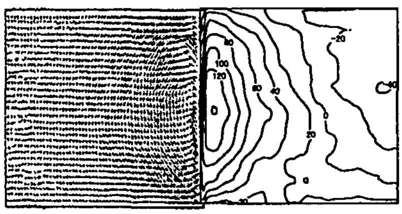


c) t=60 sec.



d) t=180 sec

Fig.3 The velocity vectors and streamlines at different instants