

Data Acquisition System of Air Bubbles in Steep Channel Flow

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Data Acquisition System of Air Bubbles in Steep Channel Flow

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Abstract: The paper presents data acquisition system of air bubbles in air-water free flow of natural conditions (self-entrainment) in a steep channel. Two parameters are of interest, namely air concentration and air bubble velocity. The steep channel was made of acrylic flume 20x40x100 centimeters size with bottom slope of 13 degrees. The flow discharge in the channel was 11 liters per second. The data acquisition of air bubbles consists mainly of CCTV camera to capture the air bubbles image and image processor software to define the air concentration and to track the air bubble velocity. Measurement results indicate that air bubbles do not reach channel bed. The air concentration in the mid-depth of the flow is 5%. The air bubbles have not uniformly been present throughout the flow depth. The air entrainment in the flow is thus in the developing region and has not reached fully developed one. The air concentration profile obtained by the measurement can be described by $C = -0.8566z^2 + 8.7075z + 3.1209$ with $R^2 = 0.981$. The expression is valid to predict values of air concentration in the developing region of 13° channel bottom slope. The instrument, however, has not produced satisfactory measurement on air bubble velocity. A series of experiments is now underway to further study the performance of the data acquisition system.

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Keywords: data acquisition system, air bubbles, steep channel.

1 INTRODUCTION

Two-phase flow is part of a multi-phase flow. Flow of different phases is widely encountered in everyday life and in industrial processes. Examples of two-phase flow can be seen in flow from exhaust, flow of cement and sand in pipe, and flow on chute spillway. Phase flow above steep channel is a phase of water and air. Air phase is typically in the form of air bubbles (Tndarto, 1998).

One of important characters in the flow on a chute spillway is incoming air from the atmosphere into the flow and mix with water. This is widely known as self air entrainment. Falvey (1980) defines the self air entrainment as the entry of air from the atmosphere into water bodies. Air entrainment is marked by the present of air bubbles on the flow surface. This is usually seen as white color layer because air bubble reflects light.

Air entrainment as described above can also be referred to as self aeration.

Data acquisition system can be defined as a system that serves to retrieve, process, and present the data. Data acquisition systems typically consists of two sub-systems, namely the hardware sub-system that functions as decision tool to get data from the object to be measured and software sub-system to collect and process data which can then be displayed.

The hardware in the present air bubble measurement apparatus consists mainly of CCTV camera equipped with CCD (Charge-coupled Device) sensor. This device serves to take images of air bubbles. Video camera reads air bubbles in the flow and stores the data as video images ready for image processing.

The software for image data processing provides tools to manipulate video images such that the images give clear picture of the air bubbles in the flow. First step in the image processing is transferring the RGB format of the original images into black-and-white format in 8-bit size images. After some image quality improvements, the air bubbles become identifiable and can be described quantitatively. The information gained from this process is the location and geometry of individual air bubble. The geometry is expressed by the diameter, circumference, and area of individual bubble. Such quantitative information can be used to describe the air bubbles (Ferreira and Rasban, 2010).

Another tool of the software is image tracking. This facility provides tool to interpret bubble images to obtain velocity of the air bubble. This and the geometric information of the air bubble are the main objective of air bubble measurement.

2 METHOD

The measurements of air bubbles were conducted in a rectangular flume whose dimension is 20x40x1100 cm and bottom slope is 13°. A head tank, which was

located 5 m above the floor, and v-notch discharge measuring device were provided to control the flow discharge. The flow discharge was maintained at 1 l/s. A second discharge of 20 l/s was also operated, but the measurement data of this experiment are not discussed in this paper.

The data acquisition device consists of CCTV camera equipped with a CCD sensor. The camera was placed on one side of the flume. Two 500 W halogen lamps were placed on the other side of the flume. A screen made of tracing paper and paper colors light green were provided to uniformly spread the lamps light. Control of the measurement was done by computer. Images of air bubbles captured by the camera were then processed by using image data processing to quantify the geometric features and velocity of the air bubbles. Figure 1 depicts the schematic diagram of the data acquisition instruments.

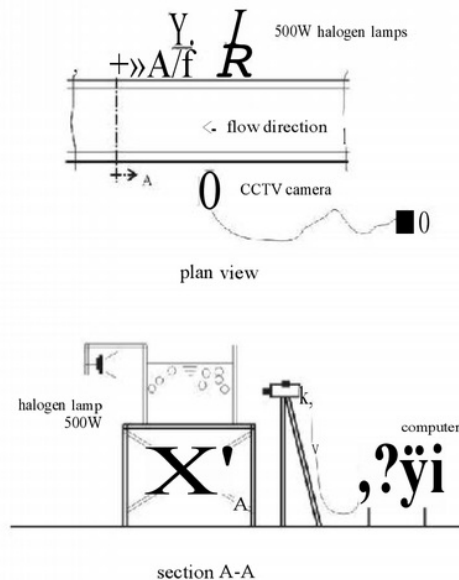


Figure 1. Equipments of the air bubbles data acquisition.

The steps to determine the profile of air bubbles concentration, C , are (1) taking pictures of air bubbles using CCTV camera that is equipped with CCD sensor, (2) saving image of air bubbles using video capture software, ImageJ, (3) converting video images to still images, (4) describing the dimension of air bubbles, (6) defining profile of air bubble concentration, and (7) finding equation describing the air bubbles profile, C as a function of depth, z .

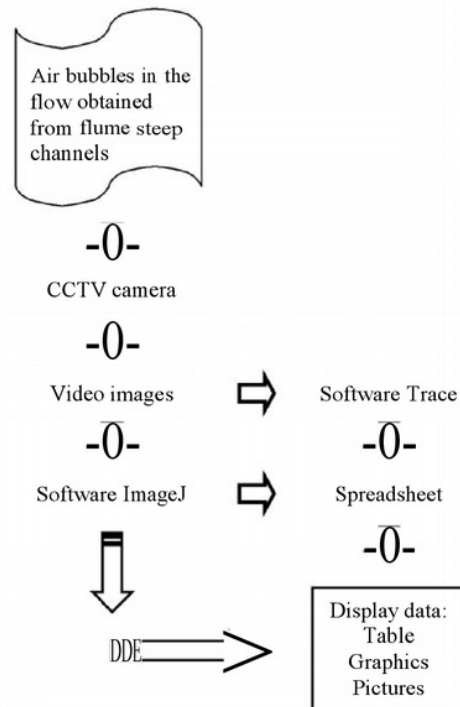


Figure 2. Procedure for the air bubbles measurement and processing.

The steps to determine the direction and velocity of air bubbles are (1) based on the third step in determining the distribution of air bubbles, selection was made on sequence of images that show identifiable air bubbles, (2) on the first frame, mark air bubble using Trace software, (3) on the second frame, mark the new position of the air bubble, (4) measure the distance and angle of straight line connecting the old and new positions of the air bubble, (5) get the velocity of air bubble as the distance over which the air bubble has traveled divided by the time interval between the successive frames.

The above procedures were applied to air bubbles data taken from trial run. The analysis follows the following steps: (1) measure the position of air bubbles from the channel bed, z , using ImageJ software, (2) measure the diameter and circumference of the air bubble using ImageJ software, (3) calculate the area of air bubbles, (4) calculate air bubble concentration at several depths using ImageJ software, (5) define profile of air bubble concentration, $C(z)$, and (6) calculate the angle and velocity of air bubbles using ImageJ and Trace softwares.

3 RESULTS AND DISCUSSION

3.1 Identification of Air Bubbles

The steps in identifying air bubbles are (1) open the TImageJ software, (2) select a still image of air bubbles that has been stored in the file, (3) convert the RGB images to 8-bit black-and-white format, (4) modify image brightness to get clear image of air bubbles. The results of these steps are air bubbles that can be easily identified.

This section and the ones that follow present the identification and measurement of air bubbles on five consecutive image frames.

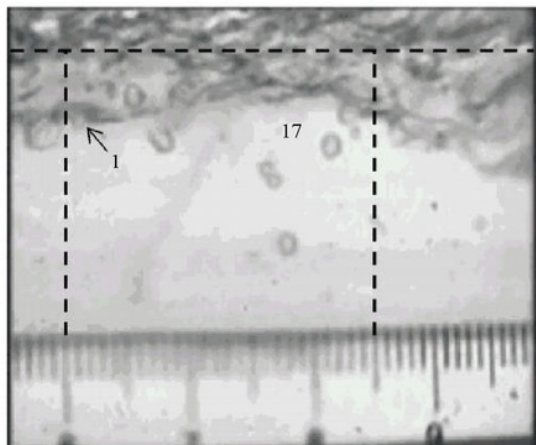


Figure 3. Identification of air bubbles on frame #1.

Identification of air bubbles is limited by the area marked with dashed lines (see Figure 3). The line at the top of the black color is the surface flow. Thick black line at the bottom is the base flow. From the identification, it was obtained that there are 21 air bubbles present inside the marked area. Number 1 and 17 written on Figure 3 show respectively the first air and seventeenth air bubbles. The identification reveals that the air bubble diameter varies. Most of the air bubbles do not form a full round.

Figure 3 above is an example of how to identify air bubbles in one image frame. Identification of air bubbles in the other frames was done in the same way.

3.2 Measurement of Air Bubble Geometry

The first step in measuring the air bubble geometry is to convert pixel size to real distance unit (millimeter, for instance). The procedures are: (1) open the ImageJ software, (2) select a still image of air bubble that has been stored in the file, (3) convert the RGB images to 8-bit black-and-white format, (4) change the scale in pixels to scale of real unit (mm), and (5) measure the

position of the air bubble with respect to the channel bottom. Figure 4 depicts these steps.

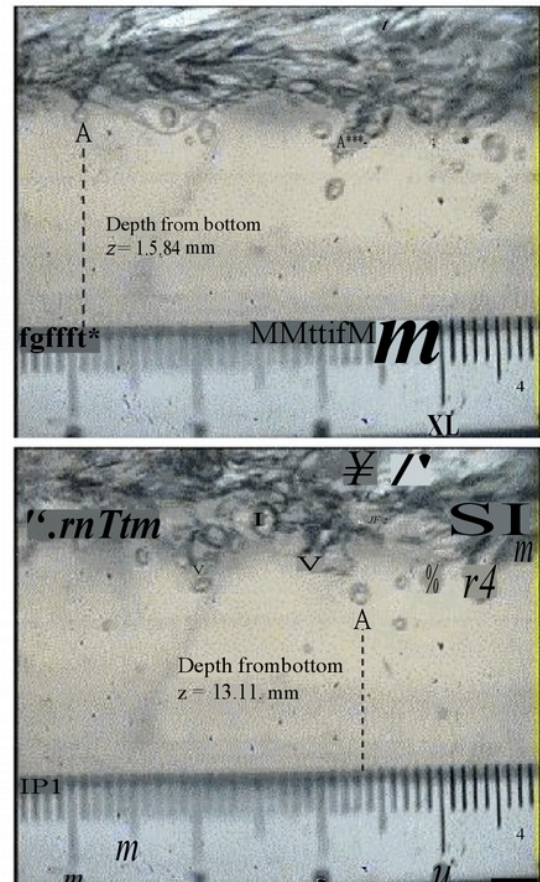


Figure 4. Measurement of air bubble position and geometry on frame #1 (top figure) and frame #3 (bottom figure).

The procedure of measuring the geometry of air bubbles are (1) select the air bubble on the image, (2) measure the vertical distance of the air bubble from the channel bottom, and (3) measure the geometry of air bubble. Table 1 shows two examples of air bubble geometry identified on Figure 4.

Table 1. Geometry of air bubbles

| No. | Area | Peri-meter | Major dia. | Minor dia. | Round | Depth |
|-----|-------|------------|------------|------------|-------|-------|
| 1. | 1.805 | 4.71 | 1.52 | 1.52 | 1.00 | 15.84 |
| 2. | 3.088 | 6.21 | 2.08 | 1.89 | 0.91 | 13.13 |

As presented on Figure 4 and Table 1, the position of the air bubbles #1 shown by the dashed line is 15.84 mm from the channel bottom, major and minor diameters are both 1.52 mm, area is 1.805 mm², perimeter is 4.71 mm. The bubble shape is round

having round factor of unity. The geometry of the air bubble #2 are: position 13.13 mm, major diameter 2.08 mm, minor diameter 1.89 mm, area 3.088 mm², perimeter 6.21 mm. The bubble shape is not round having round factor of 0.91.

Figure 4 shows two examples of how to measure the geometry and position of the base flow of air bubbles. Measurement of position and geometry of air bubbles from the base flow in the other image frames are carried out with the same manner.

3.3 Measurement of Air Bubble Concentration

Air bubbles concentration is defined as the ratio of air bubble area and the sectional area of the measurement station. The measurement station is located at 8.6 m downstream of the flume inlet section. The flow depth was divided into five equidistance layers. Figure 5 depict the measurement of air bubbles on image frame #4 and #5.

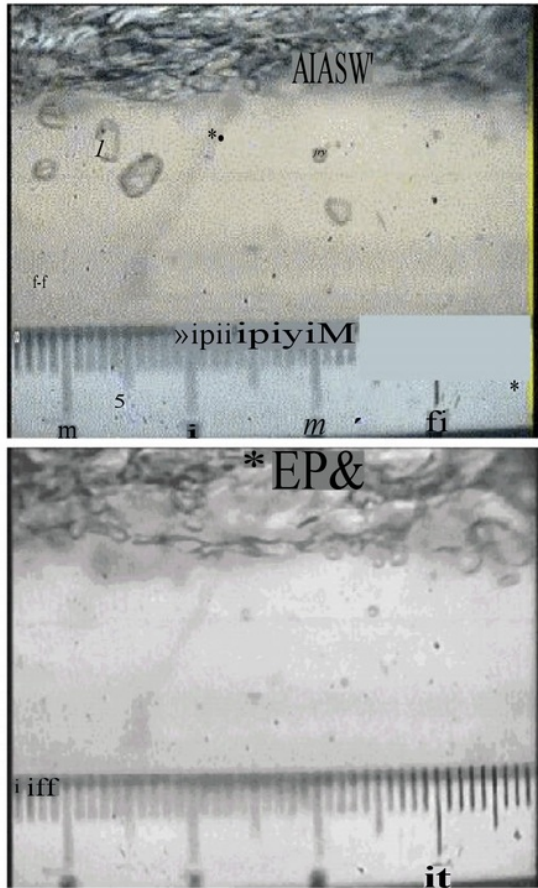


Figure 5. Measurement of air bubble concentration on frame #4 (top figure) and frame #5 (bottom figure).

Table 2 summarizes air bubble concentrations obtained from measurement at the five frames. Figure 6 is the plot of the average concentration at those frames.

Table 2. Concentration of air bubbles on five successive frames at a position of 8.6 m downstream of the flume inlet

| Range of depth (mm) | Air bubble concentration (%) | | | | |
|---------------------|------------------------------|----------|----------|----------|----------|
| | frame #1 | frame #2 | frame #3 | frame #4 | frame #5 |
| 0-4.1 | 0 | 0 | 0 | 0 | 0 |
| 4.2-8.3 | 0.63 | 0 | 0.11 | 0 | 0.19 |
| 8.4-12.5 | 0.56 | 1.00 | 0.11 | 2.89 | 0.97 |
| 12.6-16.7 | 2.35 | 1.86 | 1.79 | 1.21 | 1.58 |
| 16.8-20.9 | 1.55 | 2.31 | 3.14 | 2.89 | 2.32 |

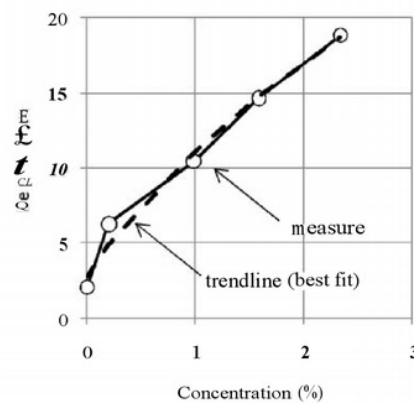


Figure 6. Concentration of air bubbles on five successive frames at a position of 8.6 m downstream of the flume inlet.

The measured concentration profile reveals that the air bubbles have not reach the channel bottom. As expected, the maximum concentration is found at the water surface. The vertical distribution of the air bubble concentration is in line with of Chanson (1997). In addition, Falvey (1980) states that the condition of the distribution of air bubbles as depicted by Figure 6 above is still in the developing regions. The fully developed air entrainment has not been attained. Best fit to the data gives the expression of air bubbles concentration profile as $C = -0.8566\hat{C} + 8.7075\hat{z} + 3.1209$ with $R^2 = 0.981$. This equation is valid to predict the value of the air bubble concentrations in the measurement section of developing air entrainment.

3.4 Measurement of Air Bubble Velocity

The air bubble velocity is measured by tracking method. Not all image frames allow velocity to be defined. Velocity is defined by air bubbles tracking on two consecutive frames. The frequency of the image capturing is 24 frames per second (fps), which seems to be much less than the air bubble velocity.

Figure 7 shows two consecutive frames where air bubble position can be defined. Table 3 presents the velocity definition from this figure. It was found the velocity is 0.954 m/s to the $8^{\circ}26'2''$ direction. The velocity of air bubbles is lower than that of the flow being 4.457 m/s).

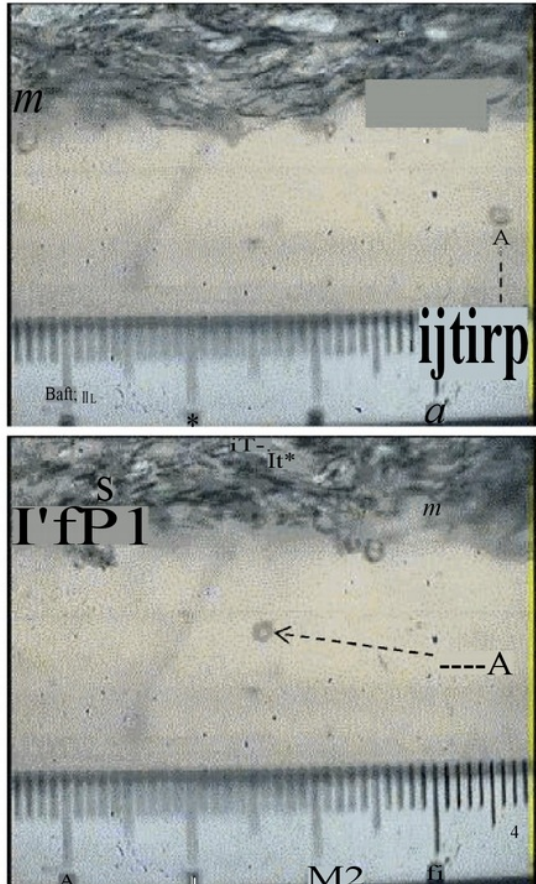


Figure 7. Measurement of air bubble velocity: initial position (top figure) and 1/24 seconds afterward (bottom figure).

Table 3. Velocity of air bubbles at 8.60 m downstream of the flume inlet

| Position | Depth (mm) | Area (mm ²) | Velocity (m/s) | Angle |
|----------|------------|-------------------------|----------------|-------------------|
| 0 | 14.322 | 2.557 | 0.954 | $8^{\circ}26'2''$ |
| 1/24 s | 39.75 | | | |

4 CONCLUSION

The experiment has led to the following conclusions.

Air entrainment in the measurement station is in the developing region. The fully developed air entrainment has not attained. The vertical distribution of the air concentration at this section can be expressed by $C = -0.8566z^2 + 8.7075z + 3.1209$. This equation is valid to predict the air bubbles concentration in the developing region in the channel bottom slope of 13° .

The developed data acquisition is reliable for measuring air bubbles in self air entrainment. Some improvements are, nevertheless, required notably in the frequency of the image capturing.

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