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Method of determining the volume of forming gas bubbles

Abstract

The paper presents a method of determining the volume of gas bubble formation. This issue is important because of the choice of parameters in the processes of mass exchange between gas and liquid. The idea of measurement method is based on filming the formation of gas bubbles, and on this basis is made image analysis process. These papers describe the steps relevant the separation of gas bubble image and calculations of its volume. In addition a sample researches have conducted, for whom defined the uncertainty of measurement. Analysis of the results determined the boundary intervals, at which a change in the pattern forming bubbles occurs, which results in that the diameter of the bubbles formed strongly depends on the gas stream emerging from the nozzle.

Keywords: image analysis, gas bubbles, measurement volume.

1. Introduction

Preparation of gas bubbles occurs in the devices and apparatus, in which the mass exchange takes place. The method in which gas bubbles are formed significantly affects on the quality of mass exchange. Due to the complex nature of the phenomena occurring in the process of bubble formation, in practice are used various kinds of theoretical models of gas bubble formation [1]. These models are applicable only to the selected structures bubble formation. In order to verify the theoretical models often are required measurements of forming bubbles. This paper presents a method of determining the equivalent diameter of bubbles forming. As the shape of the bubble depends on many process parameters and is variable in time, it is impossible to determine even a several shapes that could be used as a parameter comparison process.

In practice, the most common measure of generated bubbles is their volume. Based on volume the equivalent diameter is determined [2]. The equivalent diameter is defined as the diameter of a circle with surface corresponding to the flat image of the bubble [3], or it is the diameter of the sphere equivalent to the volume of the bubble [4]. In the following part of the paper the equivalent diameter d_e is calculated from the bubble volume dependence. The volume V of the bubble formed was determined on the basis of his image taken with a video camera, which the diameter was calculated using the formula:

$$d_e = \sqrt[3]{\frac{6V}{\pi}}\ , \tag{1}$$

where: V – volume of bubble, m^3.

The present work presents a description of the measurement method used to determine the volume of gas bubbles forming. The measurement results were compared with known theoretical models of gas bubble formation.

2. Experimental set-up

Experimental studies were carried out on the experimental set-up; the scheme is shown in Fig. 1. The basic element is a glass column 6 with dimensions of 50×150×200 mm. The column was filled with water. In the bottom of the column placed replaceable nozzles 7 of different shape and hole diameter. The nozzle was fasten to provide easy rise up to the top of forming bubbles. Forming bubbles were lit with halogen lamp 5, and the image was recorded by the camera 8. DALSA camera was used with a resolution of 400×500 pixels registering image at 200 frames/second.

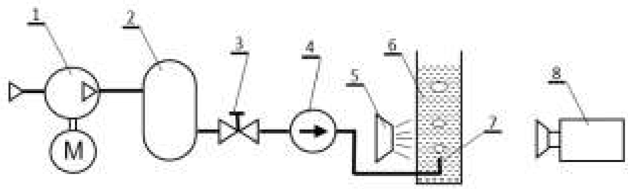


Fig. 1. A schematic drawing of experimental set-up

The gas stream supplied to the nozzle was controlled using a throttle valve 3, and measured by a flow meter 4. The air was pressurized by the diaphragm compressor 1 using the surge tank 2 with a capacity of 5 dm^3.

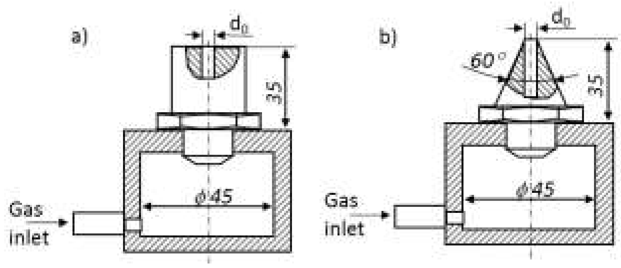


Fig. 2. A schematic drawing of the construction of the nozzle for the production of bubbles a) cylindrical b) conical

Gas bubbles were produced on cylindrical and conical nozzles with holes d_0 with diameters of exit holes: ∅ 1 mm, ∅ 5 mm ∅ 2 mm, ∅ 2.5 mm, ∅ 3 mm, ∅ 4 mm (Fig. 2.). The nozzles were screwed into the pressure-equalizing chamber in the shape of a cylinder having an inner diameter of 45 mm and a height of 40 mm. The holes of the nozzles were 10 lengths greater than 10 d_0, which ensures stabilization of the gas flow. The use of two kinds of nozzles aims at estimate the impact of changes in liquid circulation around the forming bubble. In these two cases, the fluid flows from the bottom of the forming bubble flows at different angles. This changes the dynamic effects associated with the inertia of the liquid.

At this integrated experimental set-up registered image of the formation of bubbles for different gas streams. To determine the volume of the bubble, which broke away from the nozzle, was used first frame of the image, which was recorded after breaking away the bubble from the end of the nozzle.

3. Reconstruction algorithm

The images recorded by the camera were undergone a process of image analysis based on which is possible to determine the characteristic parameters of the formation of gas bubbles. The image bubbles recorded by the camera are color image of standard RGB color palette. In practice, it is easier to analyze the shape of the bubble, where it has a clear phase boundary. For this purpose, the camera images were undergone a process of binarization. To carry out the process of the image binarization, Vision software was used along with the program LabView 7.1 (Fig. 3). Binarization takes place in several stages. Color Threshold IMAQ module is responsible for the separation from the area of the image pixels representing bubbles. IMAQ Morphology Module is responsible for smoothing out the edges.

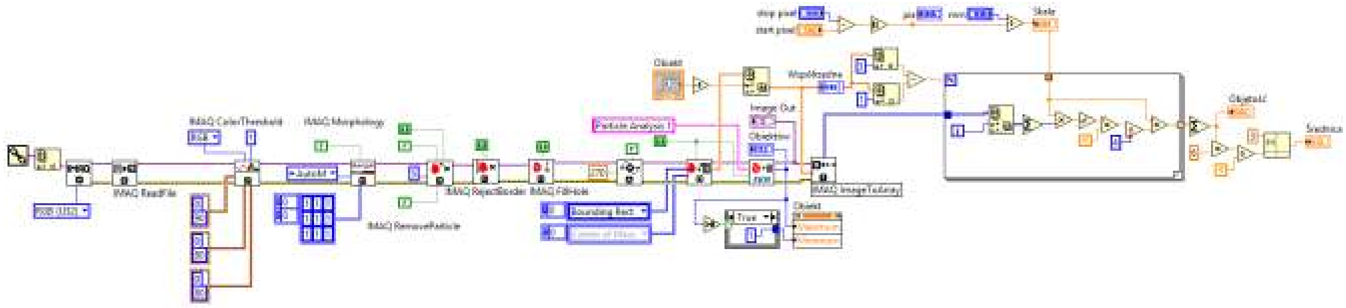


Fig. 3. A schematic diagram of LabView software

Then removed unnecessary elements such as the scale and the pixels belonging to the border and single artifacts (IMAQ modules RemoveParticle and IMAQ RejectBorder). The last phase of the image analysis process is to fill the area inside the bubbles. After this process, takes calculation based on the binary the image generated bubbles parameters such as the centroid and coordinates of the start and end of the image of the bubbles.

An example image is shown in Figure 4. On the left side of the image the millimeter scale is filmed. On its basis, the calibration of the measuring system needed to calculate the volume of gas bubbles has been achieved.

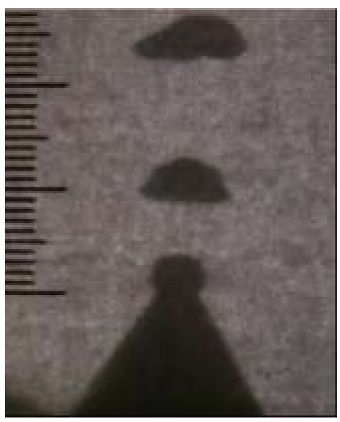


Fig. 4. The image forming bubbles

The picture shown has a gray background, moving gas bubbles are clearly darker than the background. This is caused by the optical phenomena at the border of liquid and vapor phases [5]. In order to the image binarization, it is necessary to conduct intensity process of thresholding primary colors RGB palette. To this has been carried out spectral analysis of the distribution intensity for each color separately. The spectral distributions of the sample image are shown in Fig. 5.

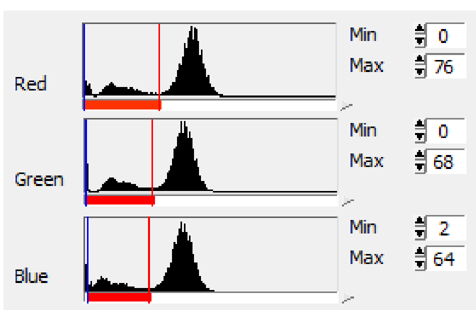


Fig. 5. The intensity distribution of the spectrum of primary colours RGB palette

The color intensity of the biggest relates to the brightest areas, so the background. The separation of image pixels which represent bubbles, takes by cutting from spectrum the areas of greatest intensity. In Fig. 5 for each color determined interval intensity which will be used for further analysis. As a result of separating, the preferred ranges are chosen, and then the inverse transform of the image is performed. It is possible to separate pixels showing gas bubbles (Fig. 6a).

Because the outline of the pitch from left side of the image is always present in the same place it is possible to delete it, since after calibration it is no longer needed for further calculations. In this way obtained binary image of forming process bubbles (Fig. 6b).

Images created in this way often have an artifacts and unnatural jagged edges at the interface. The next step in the process of image analysis is to remove small objects about the size of a few pixels, resulting in the removal of artifacts. By performing process of smooth the edges are achieved natural images of phase boundary. The final procedure is to fill all the enclosed spaces (inside the bubble image) (Fig.6c).

For such a crafted image may be carried out recognition process of bubbling. It consists in the extracting the groups of pixels adjacent to each other. On the basis, coordinates of the rectangles described in the image bubble (Fig.6d) are determined. Thus designated areas will be used to calculate the volume of the bubbles.

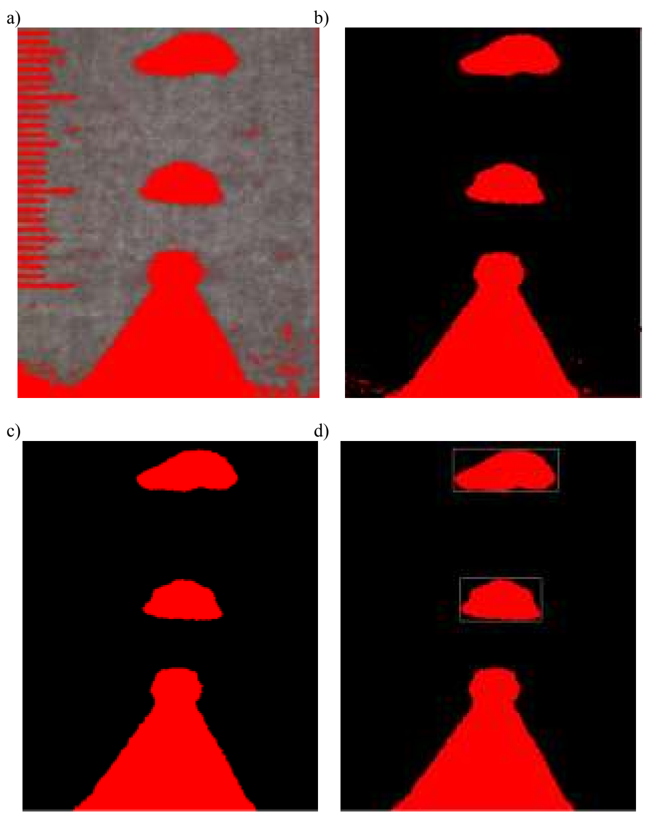


Fig. 6. The next steps of the analysis image process _ a) the image after the Threshold b) image after removing unnecessary elements c) the image after removing the artifacts and smoothing the edges d) identification of bubbles

4. Measurement of the bubbles volume

Reconstruction, and the designation of the volume of the bubble detaches consists of approximation his shape by a series of cylinders (Fig. 7a) [6].

The values of each diameter of base of the cylinder are determined by the binary image of bubble (Fig.7b). The diameters are calculated based on counts the number of pixels in a line image, then based on the value of pixels in millimeters. A succession of diameters are measured with a constant step size of one pixel, and on this basis is determined height of the cylinder h_z.

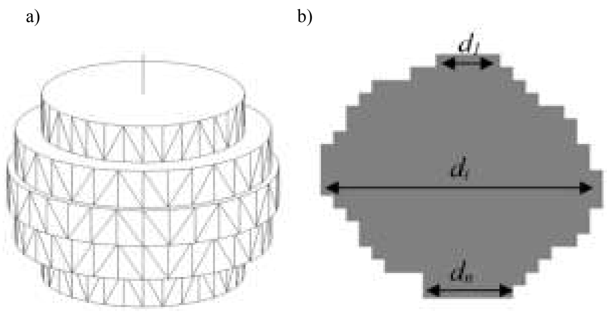


Fig. 7. Calculating the volume of bubbles forming a) determining the partial diameters b) the idea of volume determination

The volume of bubble volume is the sum of cylinders making up the bubble. To approximate the bubble shape by the elliptical cylinder, the formula for the volume takes the following form:

$$V = \sum_{i=1}^{n-1} V_i = \frac{h\pi}{4} \sum_{i=1}^{n-1} d_i^2 , \quad (2)$$

where:

V_i – one slice volume, m^3,
d_i – diameters of the ellipse describing the slice, m,
h – height of the cylinder, m,
n – number of cylinders composing the bubble.

An example of an image of bubbles is shown in Figure 8. Precision of shape mapping and determine volume largely depends on the image resolution of the bubbles. The boundary errors are:

$$D(d_i) = \Delta k + \Delta d \\ D(h) = \Delta k \quad (3)$$

where:

Δk – calibration error, m,
Δd – size of one pixel of the image, m,

The sensitivity coefficients for the formula (2) are expressed as follows:

$$G^2(d_i) = \left(\frac{h\ \pi}{2}\right)^2 \sum_{i=1}^{N-1} d_i^2 \\ G^2(h) = \left(\frac{\pi}{4}\right)^2 \sum_{i=1}^{N-1} d_i^2 , \quad (4)$$

As it is clear from presented relationships, the uncertainty of measurement will depend on the size of the bubble. Thus flow, in which there is considerable differences in the diameters of bubbles formed, uncertainty is expected to a certain range. The formula for the standard uncertainty takes the form:

$$U^2 = G^2(h)\ \frac{D^2(h)}{3} + G^2(d_i)\ \frac{D^2(d_i)}{3} , \quad (5)$$

Fig. 8. Three-dimensional reconstruction of the shape forming bubbles

5. Experimental results

Research was conducted the formation of gas bubbles to the cylindrical and conical nozzles. In studies the selected nozzle diameter were 1.5 mm and 4 mm. Figure 9 shows the dependence of the equivalent diameter of the gas bubbles formed depending on the gas stream coming out of the nozzle.

Registered characteristics show that for small gas flows forming bubbles have similar diameters. Increasing stream will only increase the intensity of the formation of bubbles. Beyond a certain critical value of the gas stream is an increase in the diameter of the bubbles forming. On this basis, there are defined the limits of the Reynolds number. These numbers of parameters relate to a bench and are defined as follows:

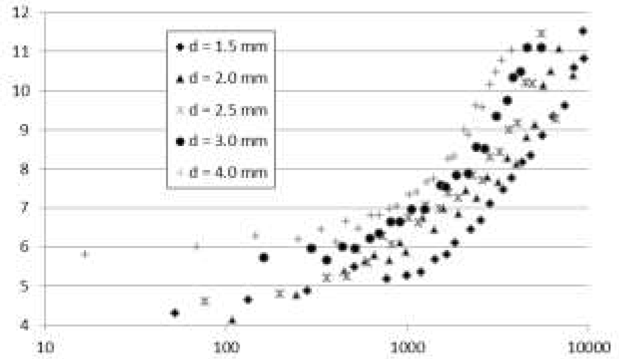
$$Re = \frac{v d \rho_c}{\eta_c} , \quad (6)$$

where:

d – nozzle diameter, m,
ρ_c – liquid density, kg/m^3,
η_c – liquid viscosity, Pa·s,
v – average speed of gas flowing from the nozzle, m/s.

As caused by mentioned characteristics of the cylindrical nozzle (Fig.9) immutability of bubbles forming diameter occurs when Reynolds numbers are less than 300. Range of Reynolds numbers 300 – 1500 in the field is responsible for the formation of a pseudo-structure and a transient state. But for Reynolds number of 1500, a chain structure is formed. For which strong correlation is observed between the diameter of the gas bubbles formed and the gas stream that comes out of nozzle. The influence of the shape of the nozzle onto areas in which the various structures are formed is small. For example, for the conical nozzle spherical structures are created for Reynolds numbers less than 200, while the chain structure is formed at Reynolds numbers of 1500. Compared with a cylindrical nozzle ranges are very similar to each other. Furthermore, there is a great similarity of the diameters of gas bubbles formed.

a)



b)

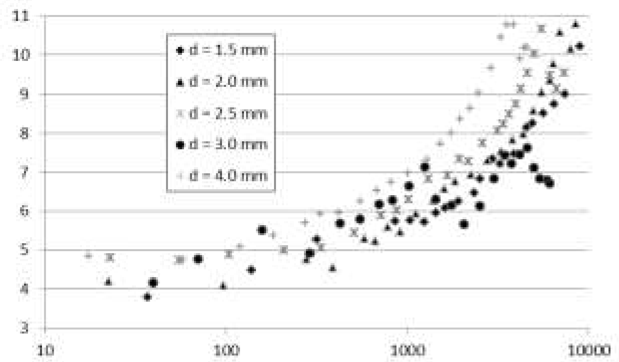


Fig. 9. Measurement results for a) the cylindrical nozzle b) the conical nozzle

6. Conclusions

The paper presents the measurement method used to determine the equivalent diameter and volume of bubbles forming. The presented method allows to specify these parameters based on the image of bubble formation registered by camera.

Initial studies of the formation of gas bubbles confirmed the usefulness of the presented method. The results will be used to develop and verify the theoretical models of the formation of gas bubbles. Determination of the limit values of Reynolds numbers at which is a change the structure of the formation of bubbles, greatly simplifies the design of equipment and machines, which takes place the formation of gas bubbles. The presented method can be applied to the study of other processes, for example the study of the process of liquid drops formation.

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