Generation of Submicron Bubbles using Venturi Tube Method

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Abstract. In this experiment, submicron bubbles that have diameters less than 1 millimeter were generated by mixing water and gas by hydrodynamic cavitation method. The water was forced to pass through a venturi tube in which the speed of the water will increase in the narrow section, the throat, of the venturi. When the speed of water increased, the pressure would drop at the throat of the venturi causing the outside air to be absorbed via the gas inlet. The gas was then trapped inside the water producing bubbles. The effects of several physical parameters on the characteristics of the bubbles will be discussed thoroughly in this paper. It was found that larger amount of gas pressure during compression will increase the production rate of bubbles and increase the density of bubble within water.

1. Introduction

Bubbles, with varying sizes and type of gases, have important roles in various fields. Their utilization may include – but not limited to – food production, wastewater treatment, drug delivery into cells, and chemical synthesis [1]. Unique properties of the bubble have been observed in scientific researches in the past few years. However, the attempts to study these characteristics are often constrained by several limitations such as the high rising velocity which hinders the surface charge properties of the bubbles [2]. Therefore, this has led to a lot of interest coming from academic individuals to investigate further on the bubbles.

Submicron size bubbles are gas bubbles with sizes are less than 1 millimeter and are commonly made of mixture of vaporized water and dissolved gases. They can be distinguished from ordinary bubbles based on the characteristics which include their sizes and longevity inside water. While larger bubbles with diameters more than 1 mm can only last in a solution for a short period, the smaller ones can stay for a long time in a solution, and some studies have shown that those bubbles remain stable in aqueous solutions up to a few months [2].

The process of formation, growth, and the shrinkage of submicron sized bubbles inside solution is called cavitation. There are four major methods to generate submicron sized bubbles; they are hydrodynamic, optic, acoustic, and particle cavitation [3]. Although each method has its own advantages and disadvantages, the hydrodynamic method using a venturi tube is the most practical way to generate submicron bubbles. Furthermore, the physical parameters of the liquid flow can also be altered to obtain the desired result [4].

A recent research by Xiong and Peng [5] have utilized this method to generate bubbles with nanometer and picometer sizes, however, the characteristic method used is relatively complicated as it needs optical imaging with lasers. Therefore, this research applied a simpler characterizing method, which is effective on determining the generation characteristics of the nozzle used. Considering the rising velocity characteristics [6], the experiment involved a direct bubble imaging using a microscope video camera, and the obtained images are then analyzed using image processing software [7].

2. Generating Device Design

In a proposed venturi model by Terasaka et al. [2, 4], water and gas would be mixed in the tube and the gas bubbles were then shrunk inside the throat of the tube. However, the tube needed two inlets from two pumps therefore a modified model designed by Choi, et al. [8] would be used. The device design used only one inlet for water and the gas would enter the mixture in a hydrodynamic way.
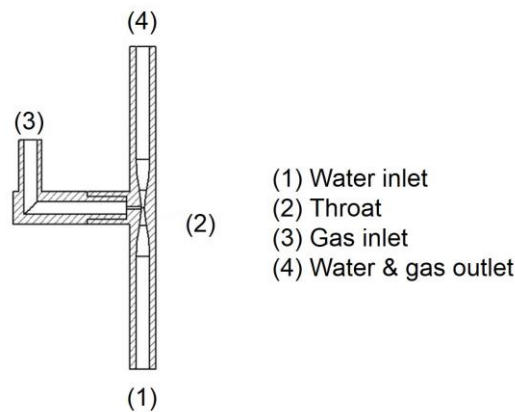
Figure 1. Bubble generating device design

The water was forced to pass through the water inlet of the venturi tube, and its velocity would increase in the narrower part of the tube – the throat. Because of this increase in velocity, the pressure dropped and causing the air from outside of the tube to be absorbed via the gas inlet. The mixture produced by this process was then ejected to a measuring device. This tube has a liquid inlet with diameter of 0.8 cm, throat diameter of 0.2 cm, and gas inlet connected to the throat with 0.06 cm in diameter. This device was designed such that no liquid would enter into the gas inlet when the experiment is conducted. The produced bubbles diameters were also expected to be smaller than the diameter of the gas inlet.

3. Hydrodynamic Mathematical Model

In this mathematical model the physical parameters that were required to form the bubbles were derived and elaborated:

According to Bernoulli's equations [9]:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = C \tag{1}$$

where C is a constant. Thus,

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \tag{2}$$

There is no height difference between the water inlet and throat, therefore we have

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \tag{3}$$

Dividing both sides by ρ we obtain

$$\frac{P_1}{\rho} + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2 \tag{4}$$

Eq. (4) yields

$$\frac{1}{2}v_1^2 = \frac{1}{2}v_2^2 + \frac{P_2 - P_1}{\rho} \tag{5}$$

The value of v_1 that is needed to cause a pressure drop at the throat of the tube is then obtained as follows

$$v_1^2 = v_2^2 + 2\left(\frac{P_2 - P_1}{\rho}\right) \tag{6}$$

Recalling the continuity of flow $Q_1 = Q_2$

$$A_1 v_1 = A_2 v_2 \tag{7}$$

Eq. (6) then becomes:

$$v_1^2\left(1 - \frac{A_1^2}{A_2^2}\right) = 2\left(\frac{P_2 - P_1}{\rho}\right) \tag{8}$$

This equation then yields:

$$v_1^2 = \frac{2\left(\dfrac{P_2 - P_1}{\rho}\right)}{\left(\dfrac{A_2^2 - A_1^2}{A_2^2}\right)} \tag{9}$$

This equation then yields

$$v_1 = \sqrt{\frac{2A_2^2(P_2 - P_1)}{\rho\left(A_2^2 - A_1^2\right)}} \tag{10}$$

In this experiment a pressure of 5×10^4 Pa was needed, accordingly the water in liquid inlet should be 7 m/s.

4. Experimental Setup

In this experiment, which is schematically described in Figure 2, the water inside a reservoir was compressed with a certain pressure and measured with a pressure gauge. With this compression, the water would move into the venturi tube nozzle that generated the bubble according to the aforementioned mechanism. After they were generated by the nozzle, they were then ejected to a viewing chamber. The compressing pressure was treated as the input and after that the bubble size and amount of bubble generated under different compression pressure would be investigated.

The measurement of bubble size and the identification of the amount of bubbles in a certain time interval were done with a digital microscope that was connected to a PC using an interface application

AMCAP. This device was connected to observe the generation and growth of the bubble inside the viewing chamber. The obtained videos were then partitioned to form images which were then converted to JPEG using DVDSoft Free Studio. These images were then processed using ImageJ application to get the picture of the bubbles.
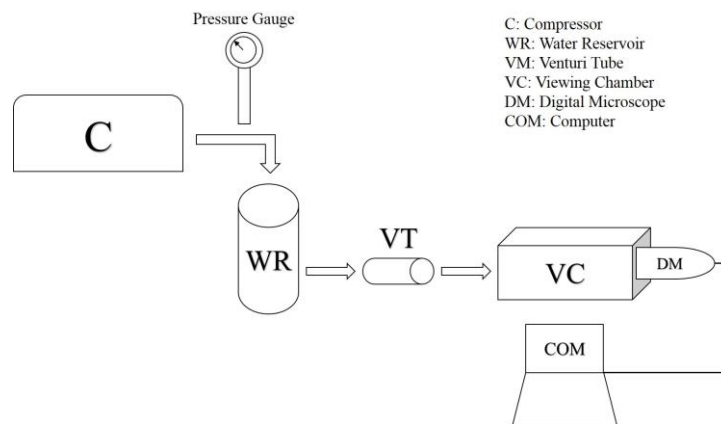

Figure 2. Experiment schematics

5. Results and Discussion

The initial observation result (unscaled) of the first bubble generated from the experiment is shown in Figure 3. Afterwards, the images of bubbles formed next to the nozzle on the figure would be used as a reference to count the number of bubbles generated. The initial data of bubble generation rate under unregulated pressure is shown in Figure 4.
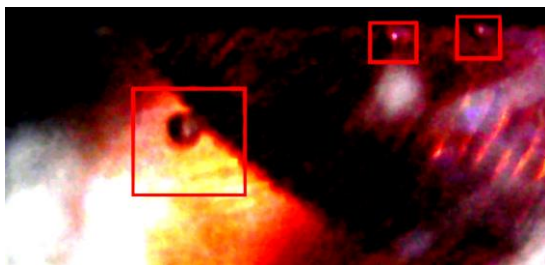
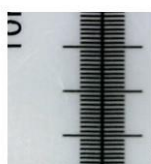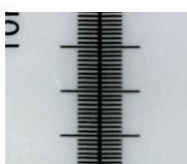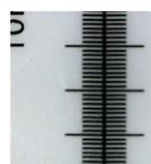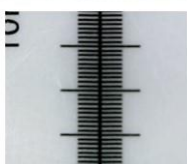**Figure 3**. Unscaled observation result
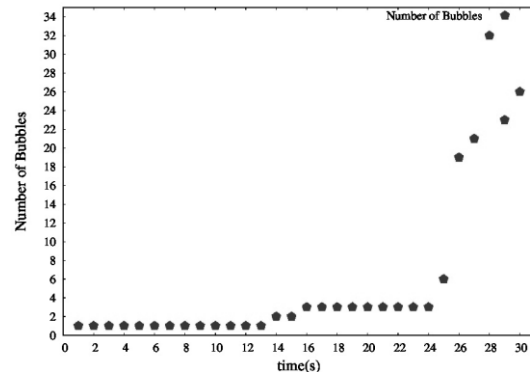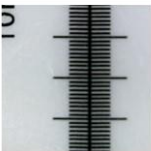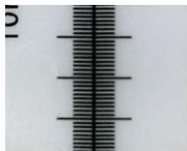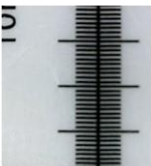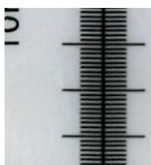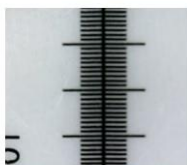
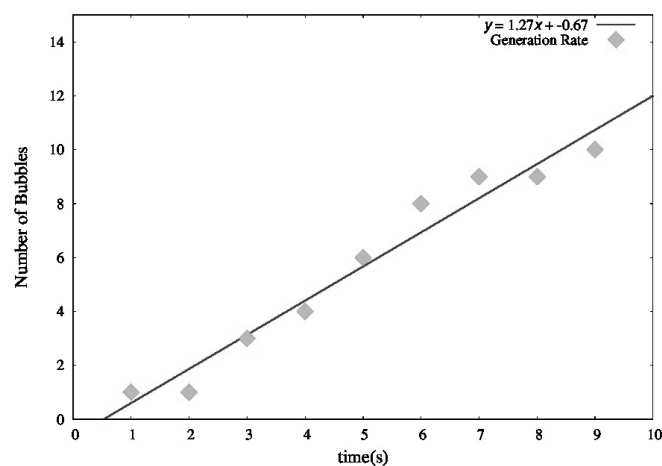**Figure 4**. Number of bubbles generated

It can be seen from the graph in Figure 4 that there was a fluctuation in the number of bubbles at the end of the observation. This was caused by the unregulated compression that is being done to the system, therefore the smaller bubbles condensed faster. Condensation itself is the merging process of the smaller bubbles to forming bigger ones. In addition to making bubbles sizes bigger, the process also potentially clogs the generating nozzle. If clogging happened, the rate of bubbles generation would also fall. The image of bubble formation under regulated compression is shown in Table 1. There were two pressure variations used in this experiment, 8 and 22 psi, over an area of (0.56×0.29) mm^2.

The bubble generation ratio over 9 seconds in the same area is shown in the graph in Figure 5. With a pressure of 8 psi, there are roughly 1.27 bubbles produced per second under a constant pressure, although there are some data that did not fit into the curve, which might be caused by the little amount of data obtained. From Table 1 and Figure 5, it is also found that different compression pressures had influences on bubble size and the amount of bubble generated. According to the table, it was also

noticeable that under the compression of 22 psi the bubbles' diameter was smaller than its less pressurized counterpart. Additionally, a higher compression yields a larger generation rate as shown in Table 1.

Table 1. Bubble generation rate under different regulated pressures (each scale is 0.01 mm)

Time(s)	8 psi	22 psi
0		
1		
2		
3		
4		
5		

Figure 5. Number of bubbles produced at a pressure of 8 psi

6. Conclusion

A device that generates bubbles with diameters within range of micro scale has been made. While the bubbles generated did not reach nanometer scale, these bubbles' diameters have reached hundreds of micrometers. It is evident that the compression influenced the amount of bubbles generated. It is also evident that a constant compression is needed to generate a constant number of bubbles.

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