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Effect of Bubble Size on Aeration Process

J. Navisa, T. Sravya, M. Swetha and M. Venkatesan
Shcool of Mechenical Engineering, SASTRA University, Thanjavur, Tamil Nadu, 613401, India

Corresponding Author: M. Venkatesan, Shcool of Mechenical Engineering, SASTRA University, Tirumalaisamudram, Thanjavur, Tamil Nadu, 613401, India Tel: +919841309048

ABSTRACT
Water contains a certain amount of oxygen dissolved in it and the relative measure of this oxygen is called as Dissolved Oxygen (DO). The dissolved oxygen content in water can be increased by the process of aeration. The efficiency of oxygen transfer depends on many factors including bubble dimension, flow rate and nozzle diameter. Surface and subsurface aerations are two types of aerations. In the former, aeration is done by exposing water in the form of droplets or thin sheets to air and in the latter air in the form of small bubbles is allowed to rise through water. The objective of this study is to study subsurface aeration and the effect of variation in bubble size, superficial velocity, flow rate and nozzle diameter on the dissolved oxygen content in the sample of water taken. This is done by precipitating a small amount of salt in water by dissolving oxygen and measuring the amount of salt in the water before and after aeration. The bubble dimensions are calculated using image processing techniques. The results show that bubbles of smaller size with maximized surface area, take more time to reach the surface, increasing the residence time of each bubble in the water, allowing a better oxygen transfer rate.

Key words: Aeration, bubble column, image processing

INTRODUCTION
Bubble columns are used as multiphase reactors in process industries and are widely used in waste water treatment plants. The construction of these devices is simple and they are easy to operate and hence are used in many process industries. In a bubble column the gaseous phase is dispersed into a stationary liquid phase. A critical parameter in the design and control of a reactor is the bubble size distribution (Zhang *et al*., 2012). It plays an important role in performance of gas liquid contact.

Aeration is a major process in water treatment in which certain constituents are removed or modified by bringing water and air into close contact by introducing air bubbles and allowing them to rise through water. Compressed air is dispersed in the form of bubbles after it is introduced below the surface of water in this process. Camp (1963) has noted that gas transfer is accomplished mainly through bubbles and the size of the bubble determines the transfer rate. Cumby (1987) mentioned that some mixing effect takes place due to the turbulence imparted by the bubbles as they rise. As the bubbles rise transfer of oxygen also takes place through their surface. The author has also mentioned that smaller the gas bubble, the larger interfacial area per unit volume and so bubbles of smaller size (e.g., less than 5 mm diameter) are desirable. These can be produced by sparging air through small holes, less than 3 mm diameter. When a nozzle that is submerged in water is operated, oxygen transfer to water occurs over two main interfaces. As the bubbles ascend through the water column, oxygen is transferred through the bubble water interface. This also occurs across the gas-liquid interface at the water surface. DeMoyer *et al.* (2003) through their experiments conclude that the total oxygen transfer takes place both through the surface and the bubble-water interface. However, oxygen transfer at bubble water interface contributes most of the oxygen. They obtained the results numerically and verified them experimentally. Fayolle *et al.* (2007) through their numerical studies have shown that when the bubble size decreases by 10%, the oxygen transfer coefficient is found to increase by 15%. Conversely, when the bubble diameter increases by 10% the oxygen transfer coefficient decreases by 11%. The above results confirm the necessity to measure the air bubble dimensions. The authors have concluded that adequate tools are required for the estimation and modelling of the bubble size at the diffuser level.

Image processing: Gonzalez and Woods (2007) define the field of digital image processing as the processing of digital images by means of a digital computer. In the recent times this field has seen a lot of advancement with many theories and algorithms coming up for requirements like edge detection, feature enhancement and so on. Its application has also widened with the need for medical imaging, astronomical imaging, etc. In fluid mechanics image processing has become a powerful tool to study flow patterns and characterization of two phase flow. Dinh and Choi (1999) have presented that image processing techniques can be applied in air/water two phase flow. Schafer *et al.* (2002) studied the bubble size distributions using image processing techniques in a bubble column reactor used for industrial purposes. Kim and Park (2007) developed an algorithm to construct a three-dimensional image of bubble from two orthogonal images and measured its size and volume in a two phase flow. Wang and Dong (2009) proposed a method for the calculation of bubble volume using image processing techniques.

The processes of aeration have not yet been fully understood. The rate of oxygen transfer from gas to liquid phase is affected by many factors such as method of aeration, type of sparger or nozzles used, turbulence mixing, bubble size and volume, temperature and properties of liquid, type and size of tank etc. Therefore, there is a need for development of new techniques to understand air/water interaction providing high aeration efficiencies. A vast literature is available regarding the mass transfer process of oxygen getting diffused in water. However, literature on the effect of bubble size in aeration process is scarce. In this study an attempt has been made to find out how the process of aeration depends on the bubble-size. This is done by adding a small amount of salt in water and measuring the hardness of the water before and after aeration.

Experimental setup: The experimental setup is shown in the Fig. 1. The set up is a bubble column of rectangular cross section of 30×30 cm and a height of 70 cm. The tank is made of acrylic sheets. Proper sealing of tank is done by using 'Anabond' acrylic glue to prevent leakages. A hole of 5 mm is made at the bottom of the tank to insert the nozzle. The nozzles used are syringe needles made of SS material. Air pumps are used to pump air to the tank at a pressure slightly above atmosphere. The air pumps are of diaphragm type. A Rota meter (11-110 lph) (Eureka make) is used to measure the flow rate of air. The nozzle is connected to the pump through a silica tube and a flow control valve. Air discharged into the tank is controlled by the flow control valve. A graduated scale, placed at the side of the nozzle in the tank is used to measure the true size of the bubble. A flash lamp is used to provide sufficient lighting to capture the image of a bubble. The images and videos are captured using a Canon 1100D camera at 30 fps. The images are captured and processed for three different nozzle diameters.

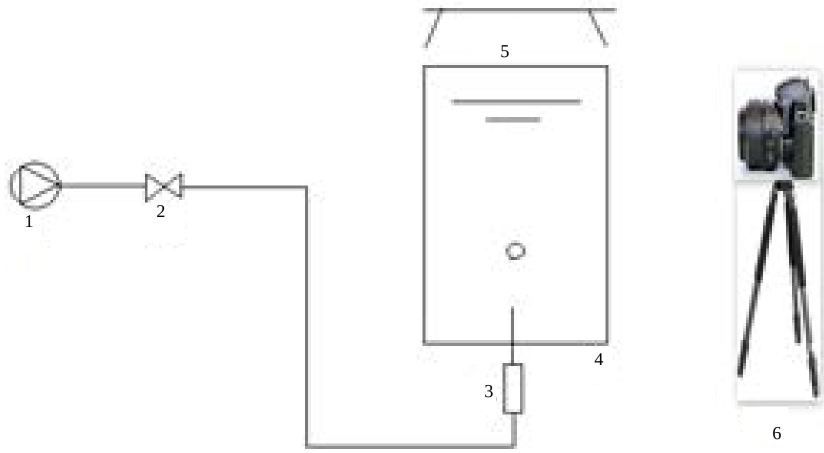

Fig. 1: Experimental set up. 1: Air pump, 2: Control valve, 3: Rota meter, 4: Bubble column (30×30×70 cm), 5: Light source and 6: Camera

Procedure: The tank is filled with a measured quantity of water. The water used is normal tap water. A sample of the water is taken (sample 1). A known quantity of ferrous chloride salt is dissolved in a small quantity of water and added into the tank and the solution is stirred and the sample of this mixed solution of water (sample 2) is taken. The air pump, flow control valve and nozzle are used to create air bubbles through the solution and aerate it. The flow rate is measured with the Rota meter. The water is aerated for 4 h continuously and a sample of aerated water is taken (sample 3). The hardness of these three samples is measured using EDTA test.

Procedure for EDTA test: The sample is pipetted out into a conical flask. A drop of basic buffer (ammonium chloride and ammonium hydroxide) is added. Eriochrome black-T is used as an indicator. The contents of the flask are titrated against the EDTA solution taken in the burette. The endpoint is detected when the colour changes from wine red to steel blue. The titrations are repeated for concordant values. Thus the hardness of the samples is determined.

Image processing technique: The size of the bubbles which play a vital role in the aeration process is measured by image processing. Pixels, the essential building blocks of an image, are derived as a function of the intensity of light falling on the object and the reflectivity of its surface. (In this case, the bubble surface reflects the light from the flash lamp). The resolution of the image decides the number of pixels. While processing an image, an array of pixels is considered. The intensity value of each pixel can then be changed, to transform the image into the required state. Basically images are of the gray scale format and the RGB format. The former involves intensity levels from 0 (white) to 255 (black), the values in between representing various shades of gray. The RGB format on the other hand, has shades of red, green and blue, with its intensity range being a lot wider than that of gray scale. A software named Image J is used to process the captured images. It has a variety of image transforming options which are very efficient in the aspect of finding the dimensions of an object in an image.

The bubble is isolated from the image and the holes are filled by performing binary operations as shown in Fig. 2a and b. After that, the edge detection option is used to refine and sharpen the edges of the air bubbles. For this purpose many algorithms are available, e.g., Sobel algorithm, Canny's algorithm, Rothwell algorithm, Marr-Hildreth edge detector, etc. Image J uses the Canny-Deriche filtering for edge detection as it one of the most reliable edge detection algorithms available. This algorithm uses the convolution of an image along with a symmetric 2D Gaussian and differentiates it in the direction normal to the edge i.e., the gradient direction. This forms a simple and effective directional operator. The edge is clearly identified by the intensity of gray value variations as shown in Fig. 3a for a bubble shown in Fig. 3b. Finally, using the 'Analyze particle' option the area of the bubble is estimated.

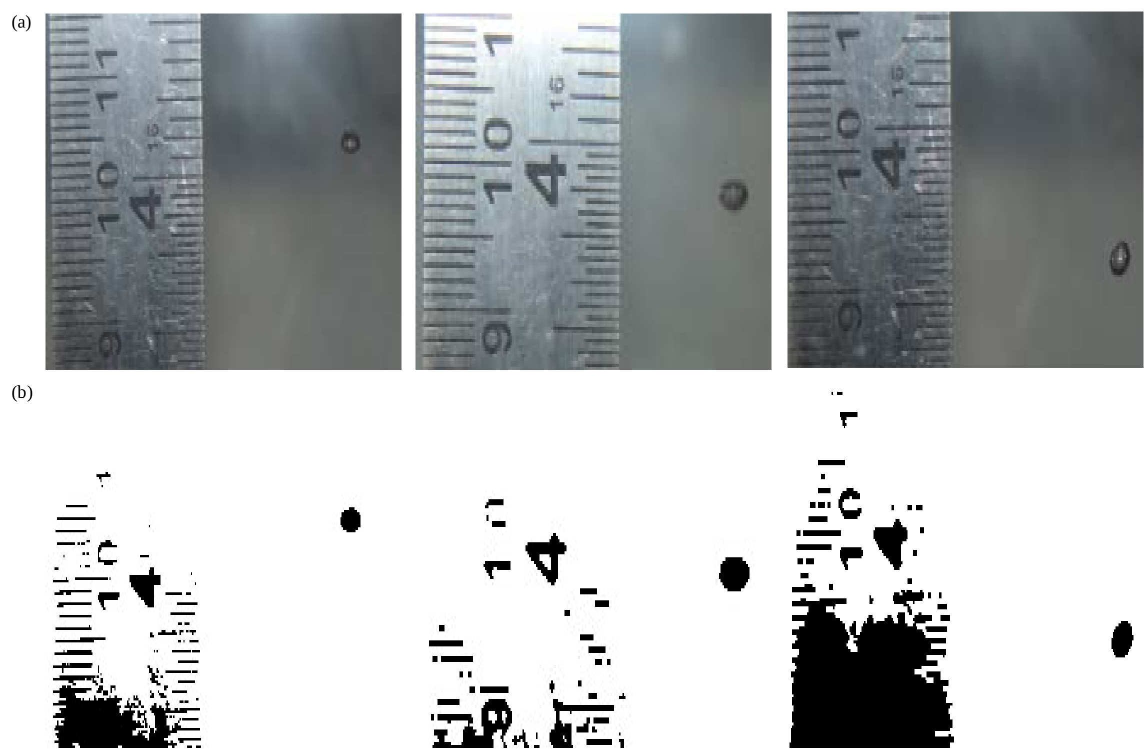

Fig. 2(a-b): Images for nozzle diameter 1.27 mm (a) Original images and (b) Binary images

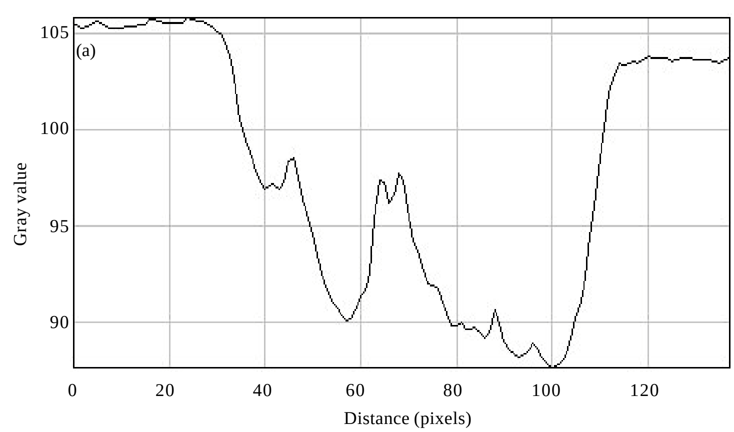

Fig. 3(a-b): Continue

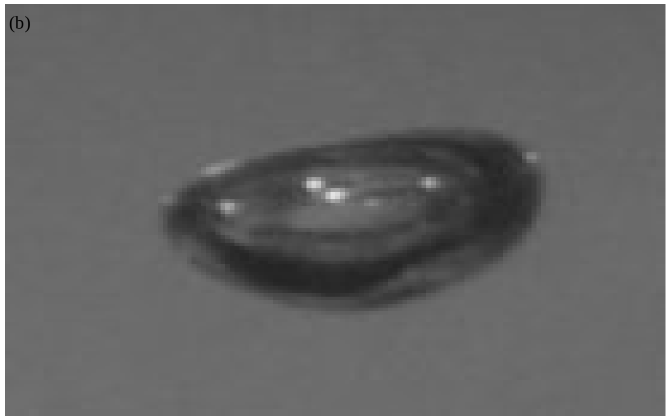

Fig. 3(a-b): (a) Gray scale variation and (b) Original image

Table 1: Hardness values of water for nozzle diameter 1.27 mm

Sample	Volume of sample (mL)	Volume of EDTA (mL)	Hardness (ppm)
Water	2.5	1.1	433.49
Water with salt	3.0	1.9	623.97
Water after aeration	5.0	2.6	512.31

Table 2: Hardness values of water for nozzle diameter 0.9 mm

Sample	Volume of sample (mL)	Volume of EDTA (mL)	Hardness (ppm)
Water	2.5	1.1	433.49
Water with salt	3.0	1.8	591.13
Water after aeration	5.0	2.4	472.90

Table 3: Hardness values of water for nozzle diameter 0.7 mm

Sample	Volume of sample (mL)	Volume of EDTA (mL)	Hardness (ppm)
Water	2.5	1.1	433.49
Water with salt	3.0	1.5	492.60
Water after aeration	6.0	2.6	426.92

RESULTS AND DISCUSSION

Experiments are done using three nozzles of diameters, 1.27, 0.90 and 0.70 mm, each. The sizes of the nozzles were measured using a travelling microscope. The size of the bubbles produced by each of the nozzles is presented below. The bubble size varies as the following:

- 1.27 mm nozzle 2.67 mm bubble
- 0.90 mm nozzle 1.83 mm bubble
- 0.70 mm nozzle 1.45 mm bubble

These values are measured for a fixed superficial gas velocity of 8 m sec^{-1} for all the three nozzles. With the above data, it can be observed that the bubble size is found to decrease as the nozzle size decreases for a fixed superficial gas velocity. Tsuchiya *et al.* (1993) obtained a bubble of size 4 mm for a nozzle of inner diameter 2 mm experimentally which are comparable with the present results where the bubble size is 2.67 mm for a 1.27 mm nozzle. Table 1-3 shows the results obtained for hardness of water with nozzles of diameter 1.27, 0.9 and 0.7 mm, respectively. The samples were collected in three different syringes. The results show that the hardness value of the water has decreased the most for the case in which the smallest nozzle is used. The smaller bubbles released through the nozzel stay longer in water than the larger bubbles and thereby there is an increase in diffusion rate of oxygen from the air bubbles to water. This helps the salt to precipitate and the hardness of water is reduced. The experimental values prove that smaller size bubbles help in better aeration.

CONCLUSION

The subsurface aeration process is experimentally studied. The effect of variation in bubble size and nozzle diameter on the dissolved oxygen content in the sample of water and on the hardness of water are measured. This is done by precipitating a small amount of salt in water and measuring the amount of salt in the water before and after aeration. The bubble dimensions are calculated using image processing techniques. The results show that bubbles of smaller size from smaller nozzle for a fixed superficial gas velocity with maximized surface area, take more time to reach the surface, increasing the residence time of each bubble in the water, allowing a better oxygen transfer rate.

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