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Analysis of Aeration Rate and Bubble Characterizations with Different Diffusers

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Abstract

This study addressed the increasing of dissolved oxygen (DO), using DO meter, bubble vertical velocity and size between different types of air diffuser, using Tracker software. Based on the findings of this study, it was found that bubble vertical velocity and size are affected by several factors such as flow rate, type of air diffuser, and flow turbulence. Among these factors, it was noticed that the flow rate has the greatest effect on the bubble vertical velocity and size followed by type of air diffuser. Obtained results show that a large sphere diffuser (D_l) provided the greatest increasing rate of DO and finer bubbles which easily dissolved into the water. But a small sphere (D_s) and cylinder (D_c) diffuser provided bigger bubbles with higher bubble vertical velocity which led to less of contact time and lower DO increasing rate.

Keywords: Dissolved Oxygen, Aeration, Bubble Vertical Velocity, Air Diffuser

1. INTRODUCTION

One of the most common methods for treating domestic and industrial wastewaters is activated sludge. Diffused aeration or mechanical aeration are used to provide oxygen to the wastewater in an activated sludge process. The diffuser is used to introduce air bubbles near the bottom of the tank in diffusing aeration. For optimal oxygen transfer to water (Atta et al., 2011).

Aeration of wastewater improves the removal of Biological Oxygen Demand (BOD), which is the amount of oxygen consumed by microorganisms in the oxidation of pollutants in wastewater, Nitrogen removal, and aerobic sludge treatment. And the cost of aeration comes to more than 50% of the total energy consumption of the entire treatment process and that could be reduced substantially by using intermittent aeration (Garcia-Ochoa et al., 2000; Calik et al., 2004; Liu et al., 2006).

The type, size, and shape of the diffuser; the air flow rate; the depth of submersion; tank design; and wastewater characteristics all influence the effectiveness of oxygen transfer. The oxygen concentration inside and outside the air bubbles is the most critical component. The second most significant aspect is surface area as higher surface area enhances oxygen transfer. A longer bubble residency time for air bubbles inside water allows oxygen to dissolve in water. A small bubble size improves oxygen transfer for two reasons. First, if a large bubble divides into smaller bubbles, the surface area of these smaller bubbles increases. Second, a smaller bubble will have less buoyancy force, resulting in a longer residency time and more travel time to reach the water's surface (Sommerfeld, M., 2009).

Levitsky et al. (2005, p. 242) studied the water oxygenation in an experimental aerator with different air–water interaction patterns. A device for water saturation by gas using enhanced air–water interaction was studied experimentally. The flow of gas and water in the device was organized in a way providing efficient gas dispersion into fine bubbles at relatively low gas and liquid supply pressures.

This permits water oxygenation to be improved and the aeration expenses to be reduced as compared with existing aerators. The setup for experimental study of the device and the measurement procedure were described. The data obtained confirm an efficiency of the proposed aerator for water oxygenation.

Alkhalidi & Amano (2011, p. 397) presented the factors affecting air bubble size when air is injected through a perforated membrane into a water pool. Critical factors that govern the size of air bubbles are the air pressure, the flow rate and the hole size of the diffuser membrane. In order to have better understanding of how bubble size can be affected and what the most affecting conditions are, the study was conducted in a computational fluid dynamic investigation that was validated by the experimental results.

This study presents aeration rate from different types of air diffuser and factors affecting bubble formation through water tank, flow rate effect and bubble vertical velocity and bubble size using a high-speed camera and software to validate the experimental study.

2. Materials and Methods

2.1 Experimental Set-up

This study investigates the increasing of dissolved oxygen level, in aeration tank as shown in Figure 1.

The aeration model is the experimental model which is used to show the increasing level of dissolved oxygen. The water tank consists of glass basin and top-open with dimension 30cmx30cmx120cm and water level was set at 100 cm height in 25°C water tank.

There were 4 types of air diffuser, Figure 2, 2-cm-diameter small sphere (D_s), 4-cm-diameter big sphere (D_b), 3-cm-diameter and 5-cm-high cylinder (D_c) and 6-cm-diameter large sphere (D_l) diffuser, with average 0.1 mm porosity, were used in this experiment by placed at bottom of the water tank. The aeration was set at 20 L/min for every diffuser. DO was measured every 20 min in first hour, every 30 min in second hour and every 60 min in third and fourth hour.

To adjust DO level from 0 mg/L for every diffuser, Sodium Sulfite (Na_2SO_3) was used in this experiment as oxygen scavenger.

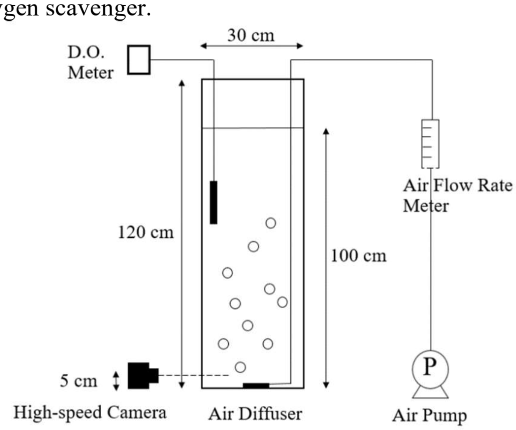


Figure 1 Schematic of Experimental Set-up

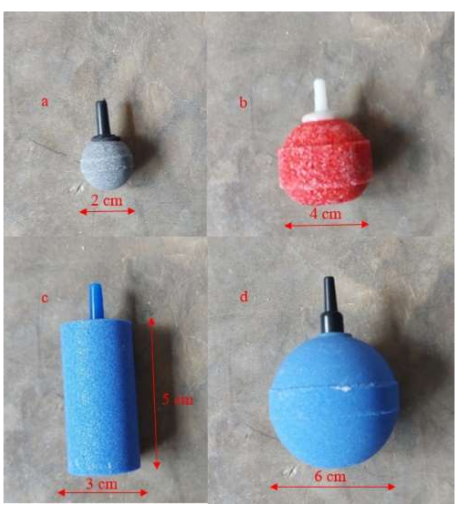


Figure 2 Diffuser types (a) 2-cm-diameter small sphere (D_s) (b) 4-cm-diameter big sphere (D_b), (c) 3-cm-diameter and 5-cm-high cylinder (D_c), (d) 6-cm-diameter large sphere (D_l)

2.2 Image Acquisition

The images of the two-phase flow were collected by a high-speed camera, SONY RX100V, with a resolution of 1980 x 1080 pixel which was set for 3.7 second video recording at 1,000 frames per second (fps) for bubble vertical velocity and size analysis.

2.3 Equivalent Bubble Diameter

Since for the present operational regime the bubble shape was in the ellipsoidal regime, also the major (A) and minor (B) axes as well as the bubble vertical velocity were determined. The equivalent bubble diameter, Figure 3, is determined from the major and minor axis as: $D_A = (AB)^{1/2}$.

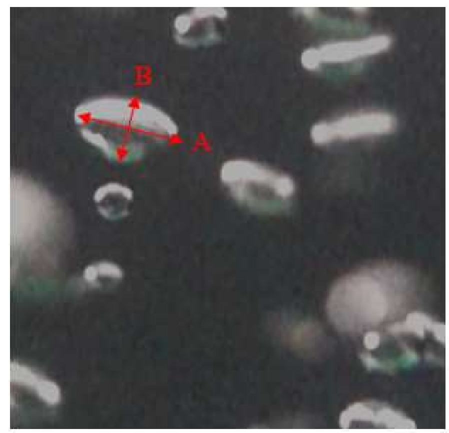


Figure 3 Major (A) and Minor (B) axes of ellipsoidal bubble

2.4 Bubble displacement measurement

Displacement was determined from the still images collected from the digital video camera. Bubble displacement was computed from the still frames obtained from the video image. The still frames were opened in commercial software, "Tracker", which was capable of showing location on an image.

The pixel coordinates (X and Y) of the bubbles center were marked and recorded. X coordinate corresponds to the distance from the left edge and Y coordinate corresponds to the distance from the top edge respectively. The pixel line running through the center of the bubble release point was known. The deviation of the bubble center from the release point was computed by subtracting the X of the bubble center from the X of the bubble release point.

2.5 Tracker Software

Tracker is a video analysis and modeling software developed by Open Source Physics (OSP) with a framework using Java. Tracker is a free application used to analyze videos. Trackers are used to detect an object, the position of the object, the object's velocity or the object's acceleration. The use of this Tracker software media can make it easier to create and represent data in graphical form. Therefore, Tracker is widely used to detect motion material. The purpose of this study was to determine the bubbles' displacement and vertical velocity of using Tracker software.

The data analysis technique is called a Particle Model. The Particle Model is a mathematical model of a point mass. The step positions of the particle are determined by the parameters of the model rather than being marked. Particle Model has a start and end frame that define the frames of the video in which they are drawn.

An object can be said to be moving if every time its position changes with a certain reference. Some of the quantities related to straight motion include distance and space, speed and velocity, and acceleration. Based on the speed, straight motion can be divided into two, namely regular straight motion and straight motion that changes regularly. Displacement is a vector quantity that states the change in the position of the object at the reference point. Whereas distance is a scalar quantity which states the length of the path that an object passes. Speed is the result of a comparison between the distance traveled and the time an event occurs. If velocity is defined as the distance traveled per unit time, velocity is defined as displacement per unit time.

Regular straight motion is the motion of an object in a straight line at a fixed speed. Fixed speed means that the acceleration experienced by an object that is moving in a regular straight is zero. Therefore, the formula that applies to this motion is the formula for speed and speed. Speed can be formulated as follows:

$$v = \frac{s}{t} \text{..................} \quad (1)$$

Where:
v: speed or velocity (m/s)
s: distance (m)
t: time (s)

Acceleration is the change in speed per unit of time. If an object is moving at an increasing speed, it is called positive acceleration, whereas if an object is moving at a decreasing speed, it is called negative acceleration.

$$a = \frac{v}{t} \text{..................} \quad (2)$$

Where:
a: acceleration (m/s2)
v: velocity (m/s)
t: time (s)

Straight motion with regular changes is the motion of an object in a straight line at a constant acceleration. In addition, objects can also experience negative acceleration or it can be called deceleration. Straight motion changes regularly have an almost constant acceleration or deceleration so that the graph showing the acceleration against time is a horizontal line, while the speed changes so that the graph of velocity against time is a straight line with a slope that intersects the vertical axis.

3.RESULTS AND DISCUSSIONs

The result shows from Figure 4 that using 4 types of air diffuser enhanced the oxygen transfer differently. The variation of air diffuser affects the oxygen mass transfer level. Figure 4 shows that at air flow rate 20 L/min, the dissolved oxygen level in the case of using D_s diffuser increased from 0 mg/L to reach the level of 6.01 mg/L, D_b diffuser increased from 0 mg/L to reach the level of 6.44 mg/L, D_c diffuser increased from 0 mg/L to reach the level of 6.11 mg/L and D_l diffuser increased from 0 mg/L to reach the level of 6.76 mg/L.

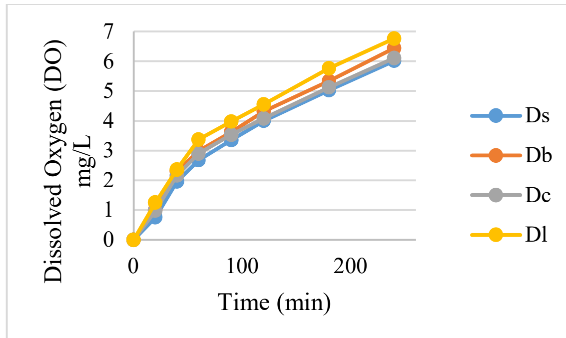


Figure 4 Dissolved oxygen (DO) level at air flow rate 20 L/min

Figure 5 shows that bubbles being captured by the high-speed camera. Figure 6 shows the comparison between bubble size and air diffuser type. Bubble diameter size from D_s was found to be around 2.5 ± 0.5 mm major diameter and 2.0 ± 0.5 mm minor diameter, bubble diameter size from D_b was found to be around 2.0 ± 0.3 mm major diameter and 1.5 ± 0.3 mm minor diameter, bubble diameter size from D_c was found to be around 2.5 ± 0.5 mm major diameter and 2.0 ± 0.5 mm minor diameter and bubble diameter size from D_l was found to be around 1.0 ± 0.2 mm major diameter and 1.0 ± 0.2 mm minor diameter by averaging a random sample of bubbles in a 3.7s video captured at 1,000 fps.

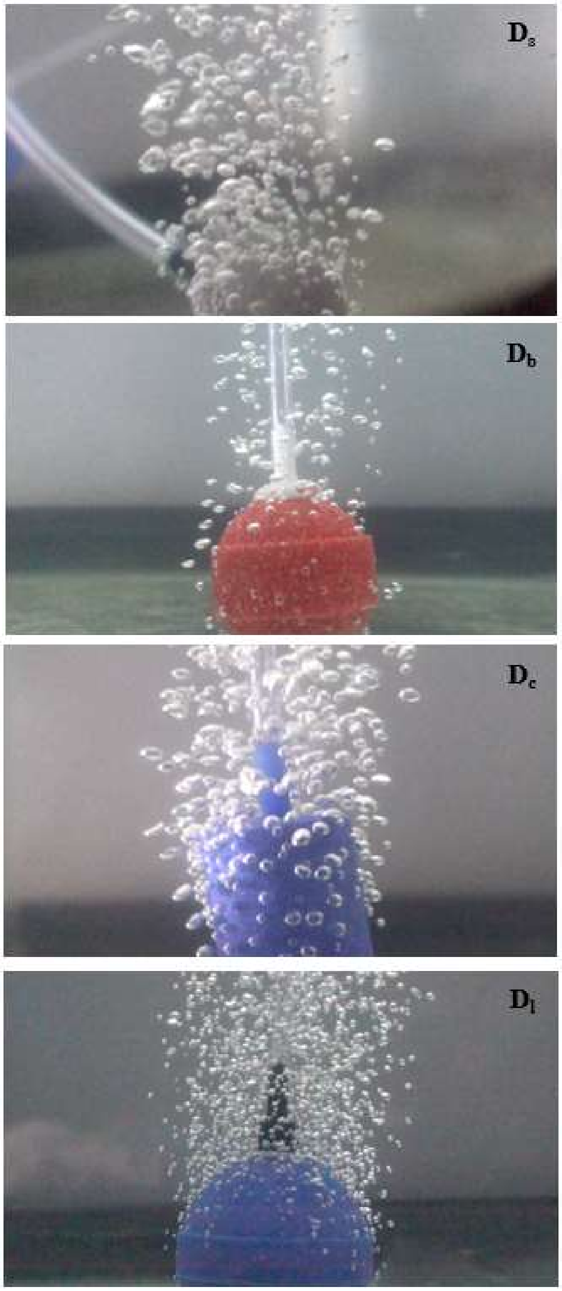


Figure 5 Air diffuser during the experiment

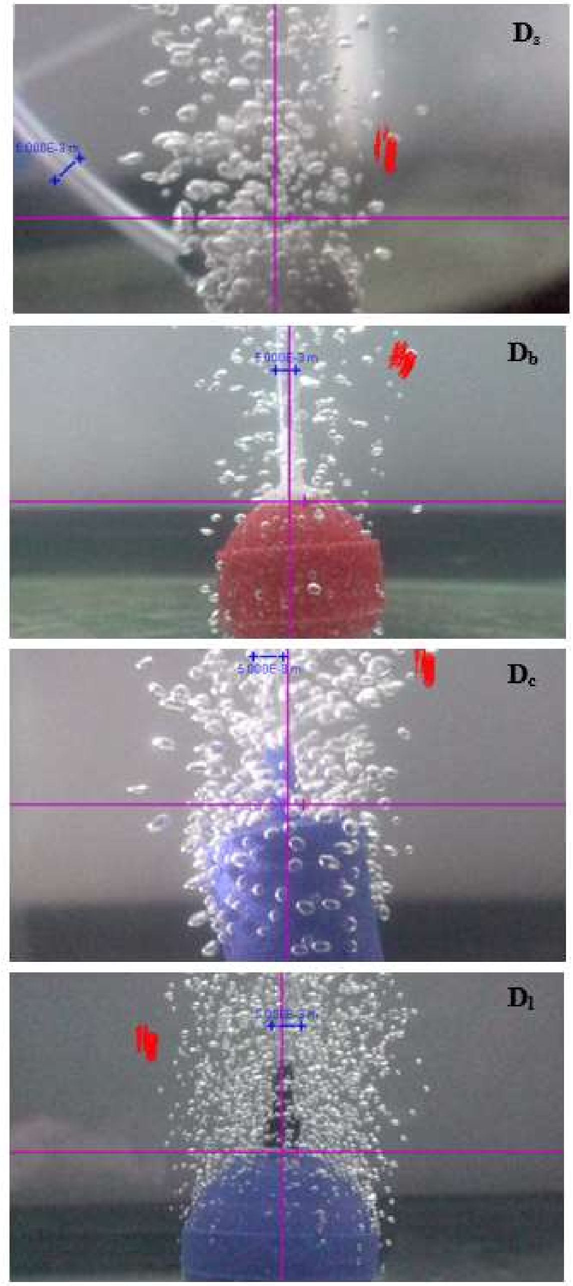


Figure 7 Screenshot of Tracker software

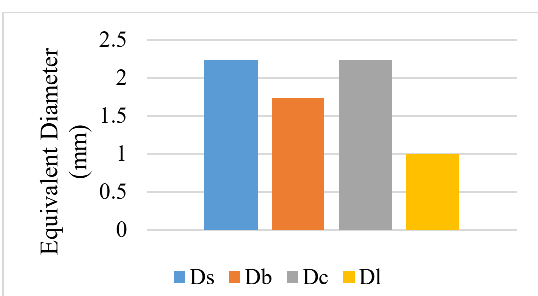
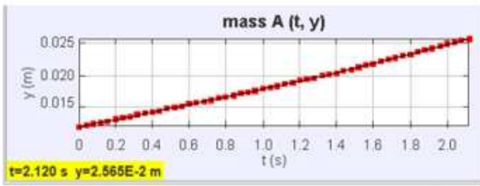


Figure 6 Bubble size from each diffuser

Figure 7 shows the screenshot from Tracker software which used for bubble vertical velocity analysis. Bubbles were selected randomly in a super slow-motion record, 40 times slow-motion.

Figure 8 shows extracted motion data of example bubble from different air diffuser. For bubble vertical velocity measurement, it was seen from Figure 5 and 7, Tracker uses the frame and frame rate to calculate t, and it uses the scale and coordinates of the marks to calculate x and y coordinates for the bubbles. It uses numerical differentiation to calculate y-velocity, vertical velocity.

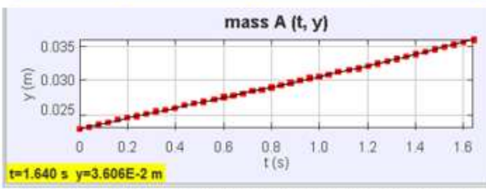
D_s



Columns mass A

t(s)	x (m)	y (m)	v_y (m/s)
1.680	-2.329E-2	2.240E-2	7.468E-3
1.720	-2.338E-2	2.270E-2	7.261E-3
1.760	-2.347E-2	2.298E-2	7.198E-3
1.800	-2.356E-2	2.327E-2	7.425E-3
1.840	-2.366E-2	2.357E-2	7.540E-3
1.880	-2.375E-2	2.388E-2	7.542E-3
1.920	-2.384E-2	2.418E-2	7.398E-3
1.960	-2.395E-2	2.447E-2	7.477E-3
2.000	-2.403E-2	2.478E-2	7.499E-3
2.040	-2.414E-2	2.507E-2	7.351E-3
2.080	-2.423E-2	2.536E-2	7.251E-3
2.120	-2.432E-2	2.565E-2	

D_b

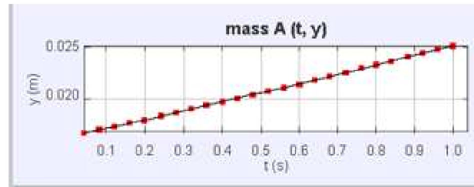


Columns mass A

t(s)	x (m)	y (m)	v_y (m/s)
0.000	2.380E-2	2.306E-2	
0.040	2.388E-2	2.339E-2	8.184E-3
0.080	2.401E-2	2.371E-2	7.775E-3
0.120	2.410E-2	2.402E-2	7.379E-3
0.160	2.424E-2	2.430E-2	7.668E-3
0.200	2.437E-2	2.463E-2	7.840E-3
0.240	2.452E-2	2.493E-2	7.444E-3
0.280	2.467E-2	2.523E-2	7.375E-3
0.320	2.489E-2	2.552E-2	7.338E-3
0.360	2.510E-2	2.581E-2	7.323E-3
0.400	2.531E-2	2.611E-2	7.836E-3
0.440	2.546E-2	2.644E-2	7.964E-3

Figure 8(1) Bubble displacement, y-axis and time graph

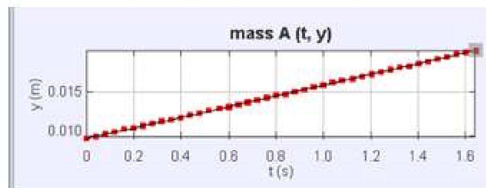
D_c



Columns mass A

t(s)	x (m)	y (m)	v_y (m/s)
0.040	2.379E-2	1.681E-2	
0.080	2.383E-2	1.713E-2	7.621E-3
0.120	2.389E-2	1.742E-2	7.366E-3
0.160	2.394E-2	1.772E-2	7.610E-3
0.200	2.399E-2	1.803E-2	8.199E-3
0.240	2.404E-2	1.838E-2	8.705E-3
0.280	2.409E-2	1.873E-2	8.796E-3
0.320	2.410E-2	1.908E-2	8.832E-3
0.360	2.410E-2	1.943E-2	8.778E-3
0.400	2.410E-2	1.978E-2	8.639E-3
0.440	2.410E-2	2.012E-2	8.576E-3
0.480	2.410E-2	2.047E-2	8.301E-3

D_l



Columns mass A

t(s)	x (m)	y (m)	v_y (m/s)
1.200	-2.241E-2	1.694E-2	6.101E-3
1.240	-2.242E-2	1.719E-2	6.059E-3
1.280	-2.242E-2	1.742E-2	5.979E-3
1.320	-2.242E-2	1.766E-2	5.953E-3
1.360	-2.242E-2	1.790E-2	6.030E-3
1.400	-2.242E-2	1.815E-2	6.308E-3
1.440	-2.242E-2	1.840E-2	6.210E-3
1.480	-2.242E-2	1.864E-2	6.112E-3
1.520	-2.242E-2	1.889E-2	5.919E-3
1.560	-2.241E-2	1.912E-2	6.035E-3
1.600	-2.241E-2	1.938E-2	6.128E-3
1.640	-2.241E-2	1.961E-2	

Figure 8(2) Bubble displacement, y-axis and time graph

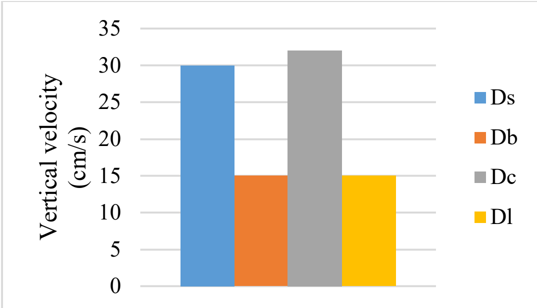


Figure 9 Bubble vertical velocity from each diffuser

The computational results presented in Figure 9 show the bubble vertical velocity from autotracker function. Bubble vertical velocity from D_s was calculated 30 cm/s, Bubble vertical velocity from D_b was calculated 15 cm/s, Bubble vertical velocity from D_c was calculated 32 cm/s and Bubble vertical velocity from D_l was calculated 10 cm/s. Figure 8 shows the screenshot of Tracker software which used for bubble vertical velocity analysis.

The results from the experiment presented that at aeration rate 20 L/min after 4 hours D_l provided the best DO at 6.76 mg/L with the finest bubble and slowest vertical velocity which let the bubbles have more total surface area and contact time in water tank. A similar trend was observed by Amma et al. (2015) who showed factors affecting fine bubble creation and bubble size for activated sludge.

On the other hand, D_c shape let bubble more easily merge each other which bigger bubbles were formed. The bigger ones have less surface area which increase vertical velocity. Therefore, bubbles provided from Dc have less contact time and DO in water tank.

4. Conclusion

The experiment was carried out to investigate the effect of different air diffuser on dissolved oxygen (DO) level, bubble vertical velocity and size. The following are the results:

1. The optimum air diffuser is the large sphere diffuser (D_l), finest porosity, achieving the highest DO level.
2. The bubble equivalent diameter relate significantly with vertical velocity.
3. The DO level depends on bubble vertical velocity and size. The smaller bubbles relate to slower vertical velocity. More contact time is greater DO level obtain.
4. The smaller diffuser increases bubble merging opportunity with lower DO level.

5. Acknowledgment

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7. BIOGRAPHIES

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