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THE IMPLEMENTATION OF A DEVELOPED MICROBUBBLE GENERATOR ON THE AEROBIC WASTEWATER TREATMENT

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ABSTRACT

An experimental study to examine the capabilities of the microbubble generator (MBG) on aerobic wastewater treatment was carried out under laboratory and industrial conditions. The tested MBG types were porous pipe & orifice and an MBG with a spherical body and drilled holes. In the laboratory-testing condition, an MBG was placed at a depth of 40 cm from the water surface. Three different pressure transducers were installed around the body of the MBG in order to analyze the inlet water pressure, the air-suction pressure, and the pressure at the outlet of the MBG. Next, the bubble diameter was measured by capturing the bubble pictures using a digital camera and analyzed using a developed image-processing technique. In order to simulate the application of the microbubble generator in the industrial field, a feasibility test of the MBG in aerobic wastewater treatment was performed. The results show the increase in MBG quantity with a higher ability to increase the oxygen, and that it is necessary to arrange the placement of each MBG in configuration to minimize bubble coalescence. Furthermore, by using a bio-ball as the porous media for microorganism attachment in aerobic wastewater treatment, the feasibility test showed promising results. Carbon on demand (COD) could be reduced to around 354 mg/l. The value of dissolved Oxygen (DO) was larger than 2 mg/L. The Ph level remained at 6, and temperature remained no more than 35ºC, which meet the requirements of aerobic wastewater treatment.

Keywords: Bubble generation efficiency; Freight aerobic wastewater treatment; Image-processing technique; Microbubble generator

1. INTRODUCTION

A microbubble is defined as bubbles with a diameter 50–200 µm. It has unique characteristics, such as high gas dissolution, low rising velocity, and a high interfacial area (Liu et al, 2013). These properties give microbubbles a number of advantages when applied in aerobic wastewater treatment. Aerobic wastewater treatment is defined as wastewater treatment using aerobic microorganisms in order to decompose organic waste matter, where aeration plays an important role with the oxygen supplying the microorganisms. The oxygen supply rate to microorganisms has to be rapid because of the oxygen-feed limitation, which requires a large amount of energy consumption for the oxygen supply. Therefore, highly efficient oxygen supply

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methods are required (Li, 2006). A microbubble generator has the capability of meeting the above requirement.

In general, microbubbles can be generated using several techniques. Researchers have made several efforts to develop a generator that can produce microbubbles with minimal power requirements (Parmar et al., 2013). The simplest technique (from the materials and manufacturing side) is a generator that uses flowing fluid to create microbubbles. The flowing fluid is streamed through a narrow gap, which is made by using a spherical body or orifice inside the microbubble generator. According to the energy conversion law, the fluid velocity will increase and the pressure becomes negative. This negative pressure creates an automatic suction of air outside the microbubble generator and will generate the microbubbles (Sadatomi et al., 2006; Sadatomi et al., 2008). However, the fundamental knowledge inside the microbubble generator has not been clearly defined.

In the present study, three types of MBG were tested in order to observe how the primary factor affects the generation of microbubbles by using a flowing fluid-type of microbubble generator. Furthermore, experiments on MBG implementation in aerobic wastewater treatment were also performed to develop a novel model by using the developed MBG in aerobic wastewater treatment.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were carried out in the fluid mechanics lab, in the Department of Mechanical and Industrial Engineering at Gadjah Mada University. The experimental facility was constructed to analyze the mechanical parameters that affect generating microbubbles, as shown in Figure 1.

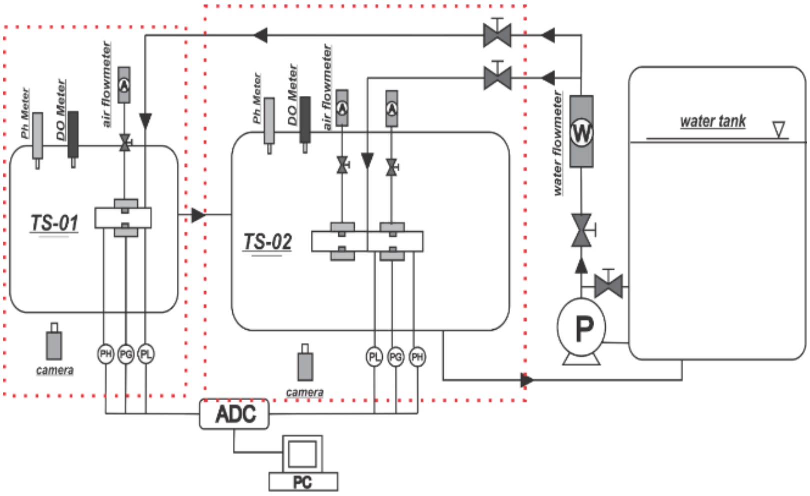


Figure 1 Schematic diagram of experimental apparatus

The water was pumped by the centrifugal pump through PVC pipe (50.8 mm of the inner diameter) and circulated inside the facility. The water mass flow rate was measured using a calibrated water flowmeter. Inside the test section, the water flowed into the microbubble generator, and due to the sudden change of the cross-sectional area downstream, the water pressure became negative and sucked the atmospheric air into the MBG. The mass flow rate of the sucked air was regulated by the air flowmeter. The pressure fluctuation inside the MBG was measured by the pressure transducer sensor (MPX5500/5100) installed along the body of the microbubble generator. The data were sent directly to the computer at a sampling rate of 667 Hz. Next, the water quality parameters, such as the dissolved oxygen (DO) and temperature, were measured by a DO meter (Lutron DO 5510).

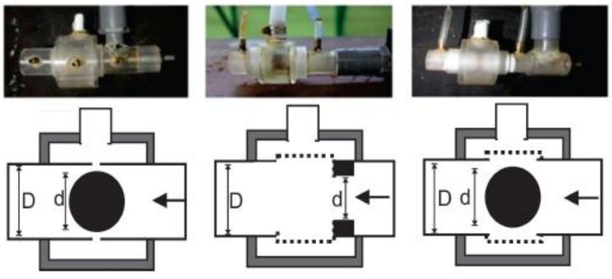
As shown in Figure 1, TS-01 was built to investigate the mechanical parameters that affect the microbubble generator in generating microbubbles. A glass aquarium sized 75 cm × 50 cm × 40 cm was installed in this test section. TS-02 was a glass aquarium sized 100 cm × 100 cm × 40 cm. They were built to simulate and develop the use of a multi-microbubble generator when applied in the industrial field. A microbubble generator orifice with a porous pipe (PO) was used in this observation due to the simplicity of the product manufacturing.

In the present study, three different designs of microbubble generator were examined, as described in Table 1 and Figure 2: (1) a microbubble generator with a spherical body and drilled holes (DB), (2) a microbubble generator with a spherical body and porous pipe (PB), and (3) a microbubble generator with an orifice and porous pipe (PO).

Table 1 The tested microbubble generators

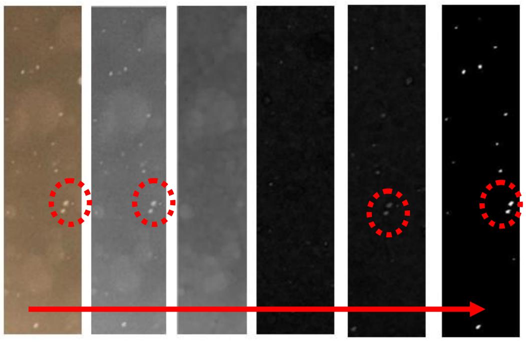
No.	Configuration (Figure 2)	Core	Pipe Diam. (mm)	Hole	Core Diam. (mm)
1.	PO	Orifice	18	Porous pipe	10
2.	PB	Spherical body	18	Porous pipe	14
3.	DB	Spherical body	18	12 drilled holes (d = 0.7 mm)	14

In the present study, bubble size measurements were conducted by processing the captured images of bubbles using image-processing techniques. The important steps in this technique included the image manipulation from the original grayscale image, background image, subtracted image, filtered image, and the binary image, as shown in Figure 3. In order to obtain a high-quality image, the camera was set at a shutter speed of 1/4000 fps.



(a) (b) (c)

Figure 2 Illustration of the tested microbubble generators



(a) (b) (c) (d) (e) (f)

Figure 3 Sequential process in image processing including: (a) original image; (b) grayscale image; (c) background image; (d) subtracted image; (e) filtered image; (f) binary image

3. RESULTS AND DISCUSSION

3.1. Mechanical Aspect

Figure 4 shows the best air-sucked flow rate to generate microbubbles. Q_G ranges from 0.1 until 0.6 l/min. The water mass flow was kept constant at 33.3 l/min. As shown in the figure, the numbers of the bubbles with diameters of less than 100 μm decrease with the increase of the sucked air mass flow.

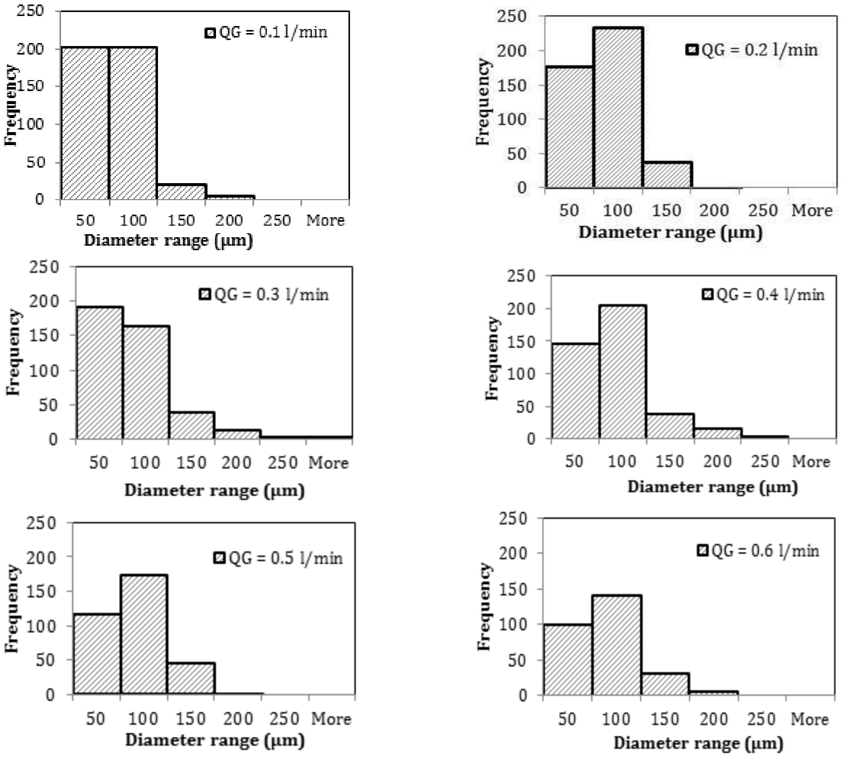
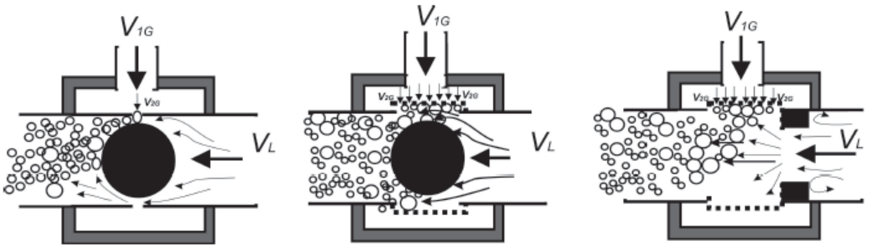


Figure 4 Bubble size distribution in PO-type microbubble generator under various air-sucked flow rate at fixed water mass flow rate of 33.33 l/min



(a) DB (b) PB (c) PO

Figure 5 The microbubble-generating mechanisms for each type of the tested microbubble generator

Figures 5a and b depicts the illustration of the microbubble-generating mechanism in DB and PB observed in the present study. The differences between those two microbubbles are merely at the shape of the air holes, which were the drilled holes (DB) and the porous orifice (PB). Meanwhile, Figure 8c shows microbubbles with the orifice (PO) and uses a porous pipe as the air holes, as also proposed also by Sadatomi (Sadatomi et al., 2008). From the figure, it is clearly understood that the superficial sucked-air velocity will depend on its cross-section area. If the cross-section area increases, the superficial velocity of the sucked air will become lower and it will be easier to generate microbubbles. This is also the reason why the number of generated microbubbles in the porous pipes (PB and PO) are higher, as shown in the comparison of the bubble size distribution in Figure 6.The flow condition was Q_G = 0.2 l/min and Q_L= 33.33 l/min). From this, it is concluded that it is better to make it smaller but scatter it uniformly along the body of the microbubble generator.

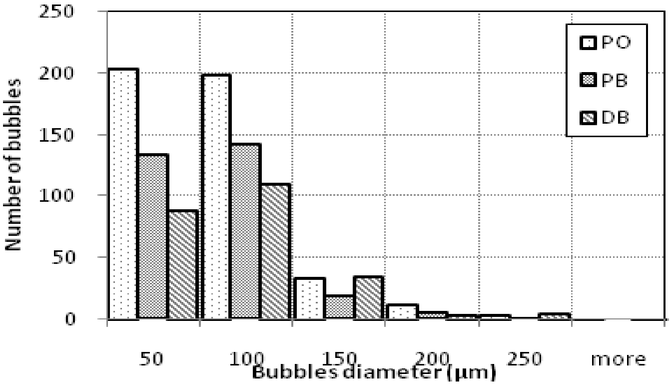


Figure 6 Comparison of the bubble size distribution of the generated microbubbles (Q_G = 0.2 l/min and Q_L= 33.33 l/min)

The hydraulic performance of the microbubble generator was calculated from the pressure distribution inside the microbubble generator. Those data are inlet pressure (PL), vacuum pressure (Vp), and pressure drop (dp). Figure 7 shows the relationship between PL and water flow rate. The data are compared with the A and B devices (Sadatomi et al., 2008), and LP 12.5, LP 14.6, MF 8.4 devices. From the figure, it can be noticed that the PO is superior to the others because the shape of the orifice is not streamlined, which thus causes much more energy loss, as explained by the Bernoulli equation.

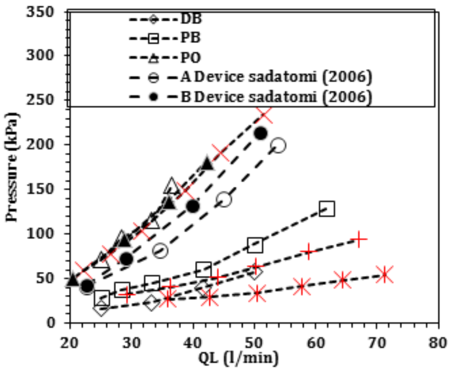


Figure 7 The relationship between inlet pressure (P_L) and the water mass flow rate

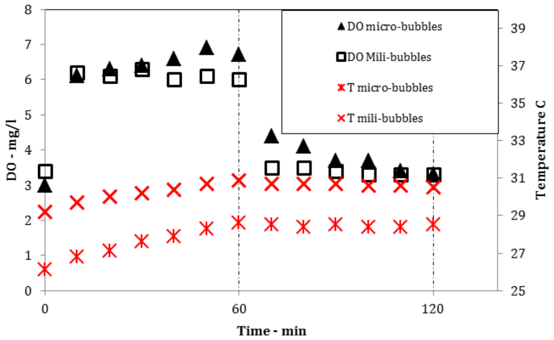


Figure 8 Time variation of the dissolved oxygen

In Figure 7, the A and B devices originally from Sadatomi (Sadatomi et al., 2008) are the microbubble generators with the spherical body with a diameter ratio (d/D) of 0.863. The A device has 12 air holes (diameter = 0.4 mm) and the B device has a lot of holes at 0.125 mm in diameter along a 5-mm-long ring. Close observation of the figure also reveals that the highest number of air holes in the microbubble generator produces a higher inlet pressure (see the DB and the PB).

3.2. Environmental Aspects

Dissolved Oxygen (DO) is one of the parameters that describe the quality of water. The higher the dissolved oxygen, the better the water quality produced. In the present study, a DO meter was used to collect DO data every 10 minutes. Next, the ability of the microbubble generator to dissolve oxygen in the water was examined by varying the air supply for the tested microbubble generators under the same water mass flow rate. At the same time, the water temperature was also measured.

Figure 8 shows that the ability of the microbubble generator to dissolve oxygen in the water.

The flow condition was Q_L = 61.67 l/min and Q_G = 0.3 l/min for the microbubble condition. In addition, Q_G = 0.8 l/min was examined for the small bubble condition. The PB was used as the tested microbubble generator. From the figure, it can be noticed that in the first 60 minutes the microbubble generator was set as ON. For last 60 minutes, the MBG was in OFF mode. During the ON and OFF modes, the dissolved oxygen was a little higher than the small bubble condition. This happened because microbubbles rise at a lower velocity than small bubbles.

Figure 9 shows the selected results for the effect microbubbles configuration on the dissolved oxygen. Close observation of the figure reveals that the configuration of the four MBGs produced the highest oxygen concentration, but to keep the oxygen concentration in the water when the oxygen supply was stopped, the configuration of three MBGs is better due to the bubble coalescence in the configuration of four MBGs. From the obtained data, it can be concluded that the more the number of the MBG, the better the ability to increase the oxygen; it is necessary to arrange the placement of each MBG in configuration to minimize bubble coalescence, and therefore the fluid can hold the DO for a longer time.

Every microorganism needs time to adapt to a new environment. Therefore, in the present study, every change of Q_G for each experimental run was conducted for three days, with two days as time for adjustment and one day as observation time. Observations were made by the measurements of the Chemical Oxygen Demand (COD), the Dissolved Oxygen (DO), pH, and temperature. COD is the amount of dissolved oxygen required to chemically oxidize organic compounds. COD is usually used to represent the amount of dissolved organic compounds in wastewater. A higher value COD shows that there are higher pollutants in the water. The most affected factor in COD removal efficiency was pH (6.0 to 9.0) and DO concentration (typically 2.0 mg/l, with a minimum of 0.5 mg/l). pH was controlled at the level of the inlet facilities, while the dropout rate was usually highly dependent on the design of the aeration system.

In the present work, the data were taken at a relatively stable pH (6.0–7.5), at the corresponding DO (at least 2.0 mg/l), and at the corresponding temperature (the average temperature of the environment). If observations beyond the values of pH, DO, and temperature were desired, the experiment was repeated. DO, pH, and temperature were taken at regular intervals over 24 hours, while the COD was observed at every four-hour trial period.

Figure10 shows the dynamics of COD removal during the days of observation at various Q_Gs. As shown in the figure, the maximum COD removal was 354 mg/l (at Q_G = 0.5 l/min). However, after Q_G = 0.5 l/min, the amount of COD removal decreases dramatically with the increase of Q_G.

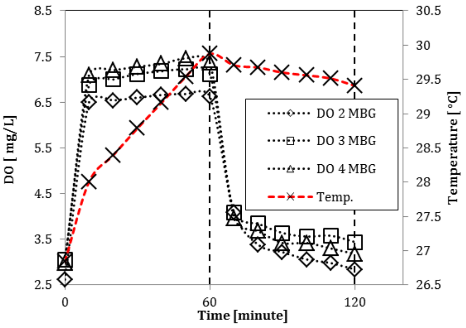


Figure 9 Dissolved oxygen against time in different sizes of bubbles

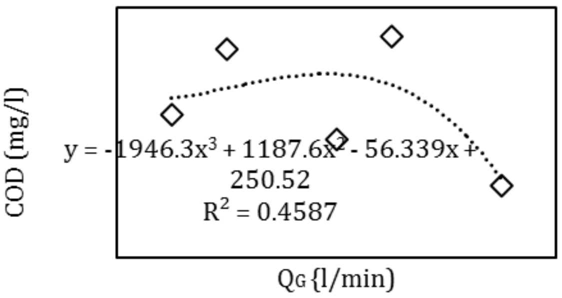


Figure 10 The dynamic average of COD removal against Q_G

4. CONCLUSION

A study concerning the effect of microbubble generation methods, the configuration, and a feasibility test on microbubble application on aerobic wastewater treatment was carried out. From the observed facts it can be concluded that the ratio between air and water velocity inside the microbubble generator and the turbulence force of the flow were the main parameters in the microbubble-generating mechanism. All of the MBGs were able to produce microbubbles in the range of 0–200 µm. The PO successfully generated the best and most stable microbubbles, despite needing much more hydraulic pressure.

The configuration of the tested microbubble generators gives the most effective performance of dissolved oxygen in the liquid. The feasibility test of microbubble application in aerobic wastewater treatment shows a promising result. Although still lower than expectations, it was able to reduce the COD to 354 mg/l on average.

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