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ENHANCEMENT OF AEROBIC WASTEWATER TREATMENT BY THE APPLICATION OF ATTACHED GROWTH MICROORGANISMS AND MICROBUBBLE GENERATOR

Wiratni Budhijanto[1*], Deendarlianto[2], Heppy Kristiyani[1], Dodi Satriawan[1]

[1]*Chemical Engineering Department, Faculty of Engineering, UniversitasGadjahMada, Jl. Grafika 2 Kampus UGM, Yogyakarta 55281, Indonesia*
[2]*Mechanical Engineering Department, Faculty of Engineering, UniversitasGadjahMada, Jl. Grafika 2 Kampus UGM, Yogyakarta 55281, Indonesia*

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ABSTRACT

This paper presents the efficiency improvement in aerobic wastewater treatment technology through the application of a microbubble generator (MBG) for aeration. Aeration using an MBG is accomplished through water circulation and does not need air compressors, making it more energy efficient than conventional aerators. The MBG aerobic system with the variations on liquid flow rate (Q_l) and airflow rate (Q_g) combination was tested using artificial wastewater with a typical composition of organic waste. Experimental data were evaluated by means of a simplified mathematical model to systematically compare different MBG schemes. The study confirmed that the soluble chemical oxygen demand (SCOD) removal efficiency was significantly affected by the Q_g values. Lower Q_g values were preferable because they tended to have higher soluble chemical oxygen demand (SCOD) removal efficiency. However, the microbubbles were less stable at lower Q_g due to the high incidence of bubble collisions. The study concluded that for applications in an actual aerobic waste treatment pond, the positioning of the MBG in the pond had to be carefully designed to minimize the collision tendency.

Keywords: Aerobic digestion; Attached growth; Biofilm; Microbubble generator

1. INTRODUCTION

1.1. The Importance of the Microbubble Generator for Aerobic Waste Treatment

The biggest portion of the energy requirement in a wastewater treatment facility is usually the aerobic treatment because it needs a powerful aeration system to maintain the high Dissolved Oxygen (DO) required by the microorganisms. According to a previous publication (Speece, 1983), conventional aerators, such as gravitational aerators (cascade, packing tower, or tray), spray aerators, diffusers, or mechanical aerators, are usually specified by the amount of air delivery (in m^3 of air/m^3 of treated water). Current studies such as those reported by Terasaka et al. (2011) and Liu et al. (2012) proved that the bubble size significantly affects the efficiency of oxygen mass transfer from the bulk gas to the bulk liquid.

A special device designed to produce microbubbles (with a diameter less than 200 μm) is called "microbubble generator" (MBG). One of the pioneering works in MBGs was published by Sadatomi et al. (2005). In this type of MBG, pressurized water is pumped into a pipe with a spherical body placed at the center. The pressure around this sphere is lowerthanatmospheric

* Corresponding author's email: wiratni@ugm.ac.id, Tel.+62-274-6492170, Fax. +62-274-6492170
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pressure so that at this point, the air is easily sucked into the narrow slit between the sphere and the pipe wall and immediately broken into very small bubbles (the microbubbles). Some modifications to this type of MBG have been tested by optimizing the distance of the ball relative to the water inlet and the flow rate of water and air as well.

The problems of MBG application in an aerobic digestion with activated sludge are the higher adherence of the cells on the bubble surface, which hinders its settling capacity, and the breakage of cells unintentionally sucked into the circulating pump (Liu et al., 2012). These disadvantages reduce the microorganism population available to oxidize the organic matters, although the DO level could be maintained at a higher level.

The proposed solution for the aforementioned problem was to combine a MBG with an attached growth aerobic system, in which the microorganisms were grown on the surface of a chosen media. The current study aimed to study the effect of MBG operational parameter Q_g (the airflow rate) on the SCOD removal efficiency.

This study is important to systematically improve the design of MBGs for wastewater treatment, with respect to both the mechanical design of the MBG and the installation of the MBG in the aerobic pond, when it is combined with attached growth microorganisms. The proposed mathematical model, which was used to objectively compare the outcome of several different operational parameters in this study, would also be useful for scaling-up the laboratory setup to actual scale.

1.2. Theoretical Background on Microbial Attached Growth

Commercial non-porous bioballs were used as the attachment media. The simplified visualization of the biofilm attachment is presented on Figure 1, where R_m stands for the bioball diameter and Z_f represents the biofilm thickness.

The experiment reported in this paper was conducted after the biofilm formation was well established and a quasi-steady state (Rittmann & McCarty, 2001) was achieved. Figure 2 illustrates that the cycle of quasi-steady-state biofilm consists of three main phases, which are the attachment phase, the growth phase, and the stabilization/maintenance phase.

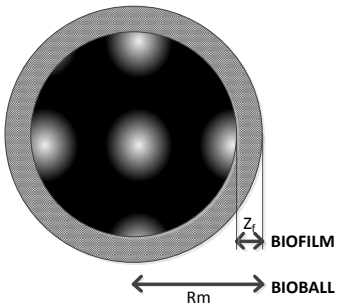


Figure 1 Simplified visualization of biofilm attachment

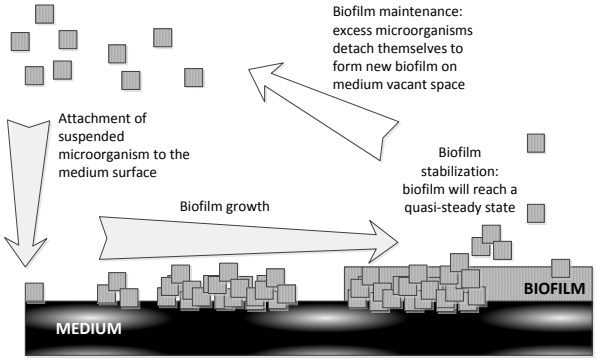


Figure 2 The full cycle of a quasi-steady-state biofilm

The following assumptions were taken to develop a quantification method for the experimental results:

a. Quasi-single substrate expressed as SCOD
b. Quasi-steady-state biofilm with constant and homogeneous thickness
c. No substrate accumulation in the biofilm

1.3. Simplified Mathematical Model for Attached Growth Microorganisms

With respect to SCOD reduction measurement, the mass balance for the substrate in the batch reactor bulk volume (V_R) is expressed in Equations 1 and 2.

$$(rate\,of\ input\ of\ substrate) - (rate\,of\ output\ of\ substrate) = rate\,of\ accumulation\,of\ substrate \tag{1}$$

$$0 - V_R \frac{\mu_g (X_f)_{ss}}{(Y_{XS})_{ss}} - V_R \frac{q_p (X_f)_{ss}}{(Y_{PS})_{ss}} = V_R \frac{dS}{dt} \tag{2}$$

The symbol $(X_f)_{SS}$ represents cell concentration at steady state (mg/L), $(Y_{XS})_{SS}$ is the yield of cell formation per unit substrate consumed (mg cell/mg SCOD), q_p is the coefficient of product formation, and $(Y_{PS})_{SS}$ is the yield of product formed per unit substrate consumed (mg of product/mg SCOD). The specific growth rate (μ_g) is modeled using the Modified Blackman (Shuler & Kargi, 2002) as presented in Equation 3:

$$\mu_g = \frac{\mu_m}{2K_s} S^n \tag{3}$$

In Equation 3, μ_m is the maximum specific growth rate ($hour^{-1}$) and K_s is the saturation constant (mg SCOD/L). Aerobic digestion is characterized by the rapid formation of biomass, soit can be assumed that the effect of the third term is negligible to be compared to the second term. Equation 2 can be simplified as Equation 4:

$$-\frac{dS}{dt} = \frac{\mu_m}{2K_s} \frac{(X_f)_{ss}}{(Y_{XS})_{ss}} S^n \tag{4}$$

For a quasi-steady-state biofilm, the value of maximum specific growth rate (μ_m), cell concentration $(X_f)_{SS}$, yield cell produced per unit of substrate consumption $(Y_{XS})_{SS}$, and saturation constant (K_S) are assumed to be constants and can be lumped into the single constant k_L. Equation 4 then can be simplified as Equation 5.

$$-\frac{dS}{dt} = k_L S^n \tag{5}$$

Equation 5 is used to evaluate the experimental data. The governing variables that define the performance of the MBG as the aeration system for the aerobic digestion reactor are the liquid flow rate of the liquid circulated through the MBG (Q_L) and the airflow rate sucked into the narrow slit of the MBG (Q_g). The effect of varied combination of Q_L and Q_g will be reflected in the values of k_L and n in Equation 5.

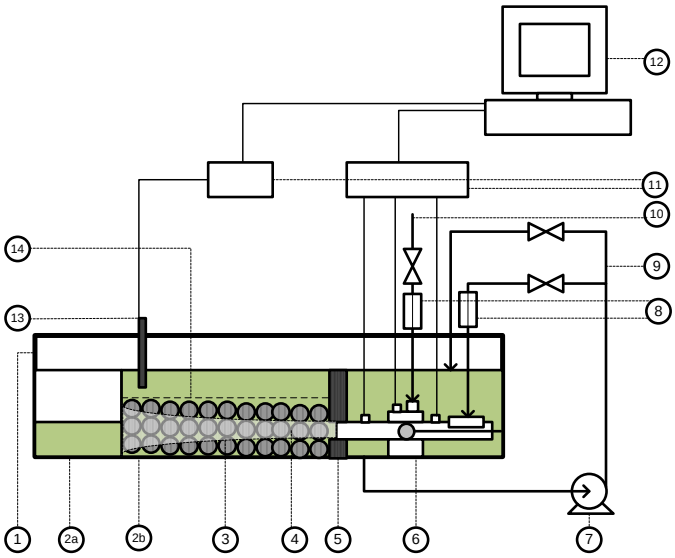
2. METHODOLOGY

2.1. Materials

The initial substrate and feeding used in this study to grow the mesophilic indigenous microbes was artificial waste with the typical organic waste composition made of commercial tapioca starch (1643 mg/L) and cane sugar (93 mg/L), which were both obtained from a local market inYogyakarta, and technical-grade urea (86 mg/L) and technical-grade potassium dihydrogen phosphate (164 mg/L), which were both commercial fertilizer supplied by Tani Maju Trading Company in Yogyakarta. All ingredients were dissolved in tap water. The initial SCOD of this artificial waste during normal runs ranges between 1400–2000 mg/L.

2.2. Experimental Setup

The experimental setup is illustrated in Figure 3. The capacity of the aerobic compartment of the container is 75 cm × 50 cm × 40 cm, with the MBG mounted at the bottom of the container. The MBG was fabricated and installed according to a previous publication (Anggita et al., 2013). The main specifications of the MBG (Figure 4) were six holes for air suction, the spherical body with the diameter of 16 mm, the inlet pipe diameter of 18 mm, and air suction hole diameter of 0.75 mm. The pressurized water is introduced into the MBG perpendicular to the axial flow of the microbubbles to create a spiral flow of the microbubbles. The ball was placed at the point of air suction. The water flow rate (Q_L) was kept constant at 2.5 L/min.



1 Transparent container
2a Overflow compartment
2b Aerobic compartment
3 Bioballs
4 Microbubble aeration area
5 Filter
6 MGB
7 Pump
8 Flow meters
9 Water pipeline
10 Air pipeline
11 A/D converter
12 Personal computer
13 DO meter
14 Screen

Figure 3 Experimental setup

The aerobic compartment holds 280 bioballs (Figure 5),which are kept in place using a screen placed at the top of the packing (Masłoń & Tomaszek, 2015). The liquid was aerated using the MBG with 4 minutes on and 10 minutes off intervals. After 24 hours, the feeding was started (5 L per feeding, one feeding per day). A sample was taken from the overflow to be assayed for its SCOD according to the American Public Health Association (APHA) standard method (Eaton et al., 2005). Eight variations were tested at airflow rate (Q_g) of 0.1 L/min, 0.2 L/min, 0.3 L/min, 0.4 L/min, 0.5 L/min, 0.6 L/min, 0.7 L/min, and 0.8 L/min. For each Q_g variation, a feeding was given every 24 hours and the SCOD was periodically measured between two feedings. Feeding cycles were repeated at least three times for each Q_g value.

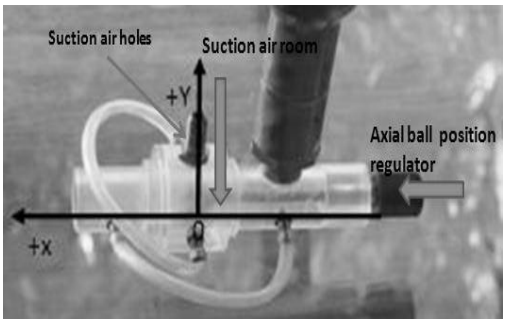


Figure 4 MBG used in this study(Anggita et al., 2013)

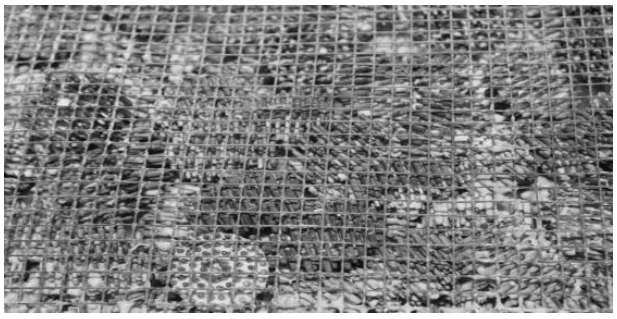


Figure 5 Bioball packing retained under screen with attached biomass

3. RESULTS AND DISCUSSION

Figure 6 presents the original record of data taken from the reactor setup described in the previous section, including the period when the reactor failed due to the wrong composition of feeding. Figure 6 also highlights the difficulty of analyzing bioprocess data if it were only the outlet concentration of the substrate used as sole indicator of the bioreactor performance. It is important to emphasize that Figure 6 was not conclusive at all regarding the comparison among eight values of Q_g. However, the comparison became more obvious when it the values of k_L defined in Equation 5 were compared.

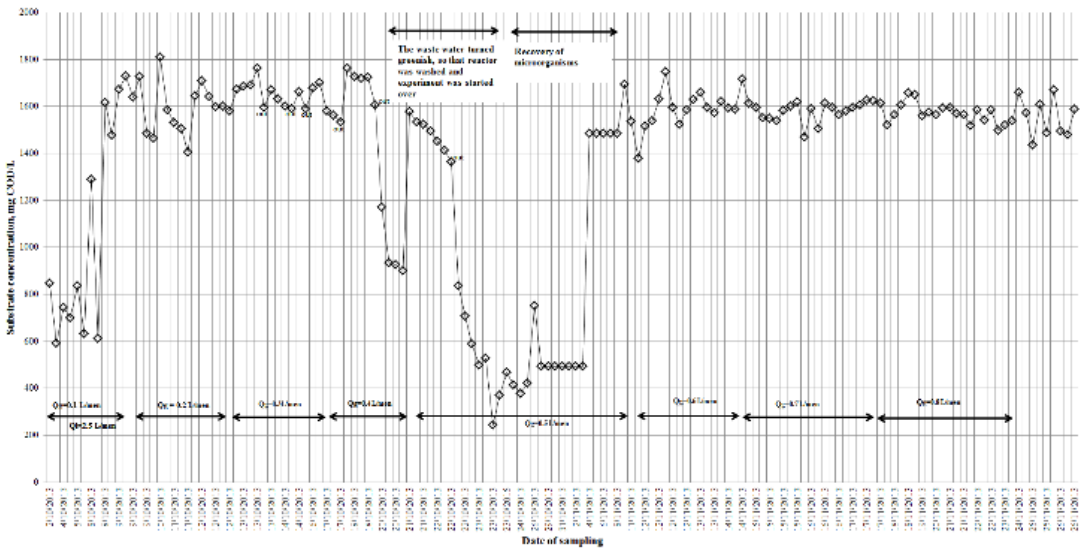


Figure 6 Original record of SCOD data taken in the semi-batch reactor between October 2, 2013 and November 26, 2013 (variation of Q_g at constant Q_L 2.5 L/min)

For every Q_g value, the data could be broken down to show the SCOD decrease from the highest value after a particular feeding to the lowest value prior to the next feeding. Such breakdown was exemplified in Figure 7. These fractions of the data were used to calculate $k_L$using Equation 5. The complete result of the calculated k_L for each breakdown from Figure 7 was presented in Table 1. The model was quite well fitted by the experimental data, as shown in Figure 8.

(a)Q_g = 0.2 L/min (Series 2) (b)Q_g = 0.2 L/min (Series 3)

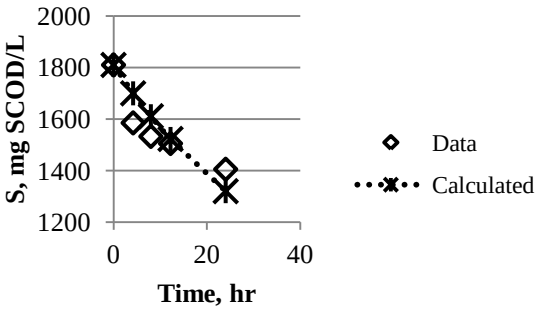
Figure 7 Examples of data breakdown from the original record to observe the substrate degradation between feedings

Table 1 Calculated k_L for each SCOD decrease between two feedings

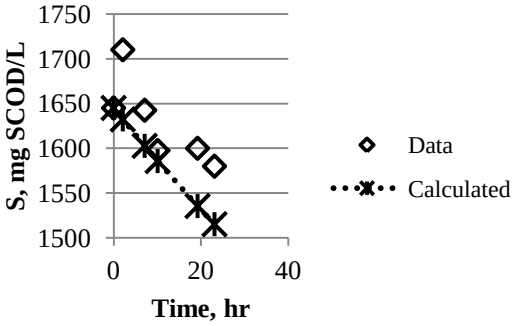
Q_g (L/min)	Series of data	k_L (L/(mg SCOD/hr)*	k_{avg} (L/(mg SCOD/hr)
0.1	1	1.69E-05	1.34965E-05
	2	3.06E-06	
	3	2.62E-05	
	4	1.25E-05	
	5	8.85E-06	
0.2	1	1.85E-05	9.75524E-06
	2	8.54E-06	
	3	2.25E-06	
0.3	1	1.36E-06	1.18361E-06
	2	1.36E-06	
	3	8.31E-07	
0.4	1	2.26E-06	6.51934E-06
	2	3.51E-06	
	3	1.38E-05	
0.5	1	4.33E-06	1.02726E-05
	2	5.75E-06	
	3	2.18E-05	
	4	5.14E-06	
	5	2.35E-05	
	6	1.16E-06	
0.6	1	2.78E-06	1.57885E-06
	2	1.33E-06	
	3	6.27E-07	
0.7	1	1.6E-06	1.08283E-06
	2	9.32E-07	
	3	7.17E-07	
0.8	1	1.6E-06	1.07328E-06
	2	1.03E-06	
	3	1.04E-06	
	4	6.21E-07	

** The best adjustable parameter n (Equation 5) that gave the bestfitting of the experimental data was n=2 for all data series*

To be compared to the model used by Terasaka et al. (2011), the k_L values in Figure 9 were about the same order of magnitude as the maximum specific substrate consumption rate (q_{max}) defined in Terasaka's model. With their comparability to other published results, the k_L values determined in this study are a good parameter to discuss the results of this research.



(a)Q_g = 0.2 L/min (Series 2)



(b)Q_g = 0.2 L/min (Series 3)

Figure 8 Examples of data fitting on the model proposed in Equation 5

Figure 9 implies that the higher the value of Q_g, the more consistent the k_L values measured in a particular Q_g value. Nevertheless, at higher Q_g values, the values of k_L were consistently lower than those of smaller Q_g values. These facts were closely related to the effect of Q_g values on the bubble diameter, as exemplified in Figure 10 (Anggita et al., 2013). Microbubbles (at the lower end of the diameter) did not only provide much larger surface area for oxygen transfer, but also created micro-mixing in the liquid so that the organic materials were more equally distributed to the entire biofilm to enhance more efficient conversion (AL-Mashhadani et al., 2015; Nicolella et al., 2000).

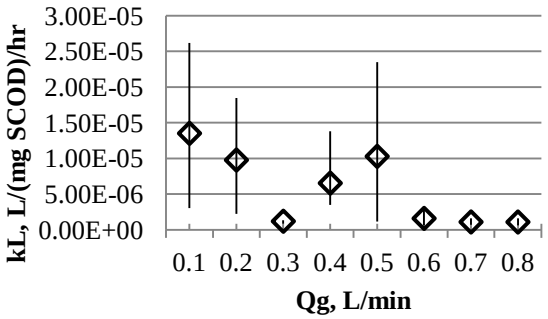


Figure 9 Values of k_L (the quantitative measure of the COD degradation rate as defined in Equation 5) at various Q_g values of the MBG

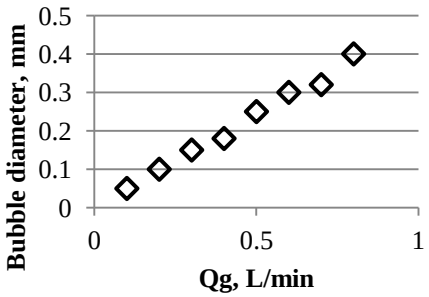


Figure 10 Effect of Q_g on bubble size at Q_L = 2.5 L/min (Anggita et al., 2013)

The bigger bubbles had shorter residence time in the liquid phase, so the k_L value tended to be much lower. Figure 9 indicated that at Q_g> 0.5 L/min, the k_L values would be too low to be compared to those at lower Q_g values. On the other hand, at lower Q_g, although the average k_L values were higher, the variations of k_L values among replicates implied the instability of the bubbles. The small size of the reactor enhanced the tendency of collisions among bubbles, which might combine several microbubbles into one large bubble. When more collisions happen, the benefits of having a micro-size bubble might be less visible and this was represented by lower k_L. The strong dependence of mass transfer coefficient to the bubble size was also reported in a previous publication (Kawahara et al., 2009; Chern & Yang, 2003). Hence, the larger the size of the reactor relative to the MBG size and the position of the MBGs relative to each other (if more than one MBG was used) were very important design parameters in preventing bubble collisions.

4. CONCLUSION

The study showed that MBG application as the aerator in aerobic waste treatment enhanced the efficiency of organic matter decomposition. The airflow rate (Q_g) taken by the MBG significantly affected the SCOD removal efficiency. For the range of Q_g values tested in this research, the lower Q_g (0.1–0.2L/min) showed a tendency to have higher SCOD removal efficiency, which was represented by the value of substrate degradation coefficient (k_L). However, wide fluctuations of k_L values were observed in the lower range. This might be caused by uncontrollable collisions among microbubbles that combine them to form coarse bubbles that had lower k_L values. The fact indicated that the MBG can potentially reduce the energy need for aeration, but the MBG configuration and its position relative to other physical installation in the aerobic pond needs to be carefully designed to avoid excessive microbubble collisions.

5. ACKNOWLEDGEMENT

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