A Comparative Study of Conventional Aerator and Microbubble Generator in Aerobic Reactors for Wastewater Treatment

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Abstract. Aeration in aerobic reactor for wastewater treatment has an important role in determining its performance. In this case, sufficient oxygen supply with good mixing is necessary to guarantee a good pollutant biodegradation. However, biodegradation is not the only parameter to consider when designing an aerator, energy consumption and cost also have important roles. In this study, a conventional air diffuser (CAD) and a low-cost microbubble generator (MBG) were compared in a 400-L reactor for two aerobic wastewater treatment process configurations, i.e. suspended culture and attached culture (with pumice stones).

Dissolved oxygen (DO) concentration throughout the reactor was initially investigated with tap water. Results indicated that the maximum DO which could be obtained for the two types of aerators were almost similar, in the range of 7.7 to 7.9 mg/L. But the lowest values are different, i.e. 5.6 mg/L for CAD and 6.8 mg/L for MBG, showing that homogeneity was better for MBG. This might be due to smaller bubble sizes produced by MBG which were able to stay inside the liquid for a longer time. Afterward, comparison of the two aerators were performed for aerating activated aerobic sludge. Without pumice stones, DO concentration for MBG and CAD was almost similar, but for MBG, lower values were found in the bottom of the tank indicating the higher activated sludge concentration. When using pumice stones, MBG again shows its superiority indicated by a higher DO values reaching 6.4 mg/L, compared to 5.6 mg/L for the CAD. These results revealed the promising potential of MBG as a low-cost aerator to be used in aerobic reactor for wastewater treatment with attached culture.

1. Introduction

Activated sludge processes (ASP) is one important step in wastewater treatment plant (WWTP) in which is done aerobically by providing aeration to the reactors or the ponds. Various aeration system can be applied in the ASP, including diffused air system (i.e. non-porous diffuser or porous diffusers, disks, perforated membranes) and mechanical aeration (vertical and horizontal shaft aerators) [1]. However, it is known that the energy requirement for aeration in WWTP is quite high, covering 30-75% of the total energy consumption [2]. For this reason, numerous studies have been performed in order to find an aeration system with a much lower energy consumption.

Microbubble aerators or generators (MBGs) have recently gained attention to be used for wastewater treatment [3]. Compared to the conventional aerators, MBGs have a number of advantages, such as its compact size, portability, and fast oxygen dissolution rate. Various type of MBGs has been investigated, such as spiral liquid flow, venturi, ejector, and pressurized dissolution type [4]. A 150-L aerobic reactor equipped with bioball-attached culture was studied with an ejector type MBG and the results showed that the organic removal efficiency was influenced by the flowrate of the air [5]. In another study, a 50-
A L tank equipped with a MBG and mesh-filter filtration was designed and studied, and the results revealed its potentiality to be used for wastewater treatment [4].

Aerators’ working efficiency in ASP can be generally correlated with its ability to maintain a steady dissolved oxygen (DO) concentration. This is influenced by the volumetric oxygen mass transfer coefficient (KLa), and a complex interrelation between various factors, such as bubble size, hydrodynamics, properties of the fluids, etc. [2]. For a certain ASP system, a parameter called an alpha-factor α is usually used to describe the oxygen transfer in the biological aerated system. This α-factor is the ratio between KLa of the process solution to KLa of clean water. This parameter is very system specific and thus it is always worth to check this parameter for every new system [2,6].

For MBG, due to its small bubble size, it is indeed expected that higher oxygen mass transfer rate will occur. However, very limited study has been carried out to compare the performance of MBGs and conventional aerators in ASP.

In this study, a comparative study for an ejector type MBG and a conventional aerator was performed systematically. A 500-L tank designed to be used for a decentralized wastewater treatment was used in this research. Two type of reactor configurations were used, i.e. a regular mixed tank and a tank equipped with pumice stones (attached culture). DO concentration of clean tap water and sludge were recorded and logged for a certain time period at several places inside the reactors. DO concentration, the calculated volumetric oxygen mass transfer coefficient, and the overall performance of the reactors were then compared and discussed thoroughly.

2. Methodology

Reactor Set-Up

Four 400-L tanks either filled with tap water or activated sludge were used in this study. Two of the tanks were filled with activated sludge seeded from the central wastewater treatment plant of Jogjakarta, Indonesia (IPAL Sewon, Balai PISA MP). These aerobic reactors run continuously, treating synthetic greywater made from starch, sugar, and some additional nutrients.

![Figure 1](image)

**Figure 1.** Illustration of the reactors set-up, (a) aerator without pumice stones, (b) MBG without pumice stones, (c) aerator with pumice stones, and (d) MBG with pumice stones (attached culture).

With 1: aerator, 2: air bubble, 3: pumice stones, 4: pump, 5: MBG, and 6: air microbubble.

2.1. Experimental Method

The list of experiments performed in this study is shown in Table 1 and the system illustration is shown in Figure 1. For each experiment, the air flowrate of the aerators and MBGs were kept constant at 3.3 L/min. DO increment of the system was measured and recorded with DO meters (Lutron DO-5512SD) at nine points, differing in its height and location relative to the center of the tanks. Additionally, for configuration with MBG and pumice stones (Figure 1d), logging with a smaller time increment (every
30 seconds) were also done to access the DO increase in the beginning of experiment for calculating the volumetric oxygen transfer rate, $K_{La}$.

Activated sludge samples from the tank was regularly taken and analyzed for its mixed liquor suspended solids content (MLSS) and turbidity (turbidity meter, SGZ-200BS).

**Table 1.** List of experimental set-ups performed in this study

| Reactor Configuration | Type of Aerator | Aerator | MBG |
|-----------------------|-----------------|---------|-----|
| Without pumice stones | (a) Water, Sludge | (b) Water, Sludge |
| With pumice stones    | (c) Water, Sludge | (d) Water, Sludge |

2.2. Data Analysis

Based on the DO concentration recorded, the oxygen transfer rate (OTR, mg/L/h) for each experiment can be described as in Equation (1) [2,7]. The relation between time and DO concentration as a function of time, can be calculated using Equation (2-3).

$$O \text{TR} = \frac{dC}{dt} = K_{La} \cdot (C^* - C) \quad (1)$$

$$\frac{C^* - C}{C^* - C_0} = e^{-K_{La} \cdot (t - t_0)} \quad (2)$$

$$\ln \frac{C^* - C}{C^* - C_0} = -K_{La} \cdot (t - t_0) \quad (3)$$

with $K_{La}$ is the volumetric mass transfer coefficient (1/h), $C^*$ is the DO saturation level (mg/L), $C_0$ is the initial DO concentration at time $t_0$ (mg/L) and $C$ is the DO concentration at time $t$ (mg/L). In clean water, $K_{La}$ can be estimated from the slope of Equation (3) and referred as $K_{La,CW}$.

For activated sludge or wastewater during ASP, the value of $K_{La,WW}$ can be estimated using Equation (4) where $r_M$ is the rate of oxygen used by the microorganisms and is assumed to be $2 g/d$ per gram of mixed-liquor volatile suspended solids (MLVSS), $C^*$ is the DO saturation level (mg/L), $C_0$ is the maximum DO (mg/L) that could be reached on a reactor with oxygen consumption, in reactor in operation with wastewater [8]. For all experiments, $C^*$ is assumed to be 9.7 mg/L.

$$\frac{dc}{dt} = K_{La,WW}(C^* - C) - r_M \quad (4)$$

At steady state, $C = C_0$.

$$K_{La,WW} = \frac{r_M}{C^* - C_0} \quad (5)$$

Further, a parameter called an $\alpha$-factor can be calculated based on Equation (6).

$$\alpha = \frac{K_{La,WW}}{K_{La,CW}} \quad (6)$$

3. Results and Discussion

The results of this study are divided into two main part, i.e. experiments in tap water and in activated sludge.

3.1. Aerator Performance in Tap Water

Figure 2 shows the DO increments for experiments with tap water, using aerator and MBG, for configuration with and without pumice stones. Several observations can be made from this data. First, when comparing the aeration types, it can be seen that in general MBG results in a more homogenous DO concentration distribution (top, middle, and bottom). In aerators, especially when using no pumice...
stones, DO values are much higher in some part of the tank (top and middle). This phenomenon can be explained by the existence of big bubbles which raised very quickly to the top part of the liquid. On the other hand, DO values are much lower in the bottom part of the tank, indicating the probability of a dead zone.

Second, when comparing the reactor configurations, it is clear that when using pumice stones, the maximum DO concentration in both tanks with aerator and MBG dropped, compared to the ones without pumice stones. It is expected, because the existence of pumice stones added barriers for oxygen transfer thus causing dead zones in those bottom parts.

![Figure 2](image-url)

**Figure 2.** DO concentration in water as a function of location inside the tank (top, middle, bottom and left, middle, and right) for experiments: (a) aerator and no pumice stones, (b) MBG and no pumice stones, (c) aerator and with pumice stones, and (d) MBG and with pumice stones. The lowest value indicates the starting point before the aeration was started and the highest point indicates the values after 10 min of aeration.

In addition to the DO concentrations shown in Figure 2, the increase of DO concentration in the beginning of the aeration was also recorded. From these data, using Equation (3), plots of \( \ln \frac{C}{C_0} \) versus time could be made and \( K_L a \) is further approached by the slope of the plot. Figure 3 shows one example of how the fitting was done. The \( K_L a \) values obtained from this study are summarized in Table 2.

| Reactor Configuration | Value of Calculated \( K_L a \) (1/h) |
|-----------------------|-------------------------------------|
|                       | With Aerator                       | With MBG                             |
| Without pumice stones | Middle 19.80                        | Middle 89.64                         |
|                       | Bottom 20.88                        | Bottom 64.08                         |
| With pumice stones    | Middle 32.40                        | Middle 46.80                         |
|                       | Bottom 27.36                        | Bottom 18.72                         |

From Table 2, it can be seen that in general MBG results in a much higher \( K_L a \) values for both reactors configuration (with and without pumice stones), indicating better oxygen mass transfer. When comparing reactor configurations with pumice stones, \( K_L a \) decreases for MBG but slightly increases for conventional aerator. For MBG, the existence of pumice stones added barriers for oxygen transfer thus causing lower \( K_L a \). Additionally, when comparing the different location (middle vs bottom), the
$K_{La}$ values at the bottom part of the reactors, in general, are lower compared to the middle compartment. But for conventional aerators, it seems that pumice stones tended to break the big bubbles into smaller bubbles, thus resulting in a slightly higher $K_{La}$.

![Graph](a) Aerator

![Graph](b) MBG

**Figure 3.** Example of data plot of $\ln \left( \frac{C_t - C}{C_t - C_0} \right)$ versus time for water in the reactor configuration with pumice stones (middle position). The slope of each equation indicates the $K_{La}$ values (1/s) and is converted into (1/h) as written in Table 2.

### 3.2. Aerators Performance in Activated Sludge

![Graph](a) Sludge / Aerator

![Graph](b) Sludge / MBG

![Graph](c) Sludge / Aerator

![Graph](d) Sludge / MBG

**Figure 4.** DO concentration in activated sludge as a function of location inside the tank (top, middle, bottom and left, middle, and right) for experiments: (a) aerator and no pumice stones, (b) MBG and no pumice stones, (c) aerator and with pumice stones, and (d) MBG and with pumice stones. The lowest value indicates the starting point before the aeration was started and the highest point indicates the values after 10 min of aeration.

Figure 4 shows the DO values after 10 min of aeration as a function of location inside the reactor when in operation with wastewater/activated sludge. First, when comparing the aeration type, it can be seen that in general MBG results in a higher DO concentration. In regard to the homogeneity, in aerators, especially when using pumice stones, DO values are much lower in some part of the tank (middle and bottom).
DO concentration in reactors with MBG also shows much lower concentration in the bottom part, but it seems occurs in both configurations regardless the use of pumice stones. The reason behind this is most probably due to the strong pulling force by the microbubble and circulated liquid on MBG which tend to bring the activated sludge to the bottom. This phenomenon further results in a much lower DO concentration due to the high oxygen consumption by the activated sludge.

When comparing the pumice stones configuration, it is clear that when using pumice stones, the maximum DO concentration in both tanks with aerator and MBG dropped, compared to the ones without pumice stones. This performance also agrees to the one in water.

Despite the fact that reactors with MBG and pumice stones (attached culture) showed lower and less homogeneous DO concentration, the application of this configuration is beneficial from the point of view of outlet water quality. Because the suspended solids and activated sludge are pushed to be at the bottom with the pumice stones, wash-out could be avoided, and outlet water are much cleaner.

Figure 5 shows DO concentration profile as a function of aeration time, in MBG-reactor using pumice stones, for both water and wastewater/activated sludge. It is clear that when wastewater/activated sludge is in operation in the reactor, the DO concentration is much lower compared to the one in water. This is due to the oxygen consumption by the activated sludge, as stated in Equation (4).

Table 3 summarizes the values $K_{La}$ and $\alpha$ for reactor configuration with pumice stones using MBG. The transfer oxygen rate is influenced by a lot of factors, such as tank volume and dimension, type of aeration, bubble size, and properties of the fluid. From this study, $\alpha$-factor of 0.065 and 0.125 are obtained, for the two different locations of the reactors (Table 3). It is worth to mention that in our case due to the attached culture in the pumice stones, MLSS distribution occurs and thus oxygen transfer rate is also varied depending on the location.
It is known that $\alpha$-factor is influenced by MLSS of the wastewater/activated sludge [6]. Based on the equation of Krampe and Krauth (2003) where $a = e^{-0.08788 \cdot MLSS}$, in our case, MLSS of 6.5 g/L will give an $\alpha$-factor of 0.5648. The typical range of $\alpha$-factor value for diffused air aeration is 0.4-0.8 [8]. However, the calculated $\alpha$-factor values that were obtained in this study, 0.065 and 0.125, are much lower to the typical expected values. One of the probable reasons for the aforementioned phenomenon is the attached culture on the pumice stones causing MLSS gradient on the tank. However, more experiments and validation on the taken assumptions or calculations are needed to be able to get more accurate values.

4. Conclusion
The use of conventional aerators and MBGs in aerobic reactors for wastewater treatment are investigated in this study, using two types reactor configuration, i.e. without pumice stones and with pumice stones for attached culture reactor. DO concentration profiles and homogeneity were initially studied in clean water, and results showed that MBGs gives a higher DO with a better homogeneity. Oxygen mass transfer are also higher with MBG compared to the conventional aerators. DO concentration are lower when testing in activated sludge due to the oxygen consumption. In MBG with pumice stones, the DO concentration in the bottom of the tank is much lower probably due to high oxygen consumption by the activated sludge which has strong attachment to the pumice stones. These results indicate the potentiality of reactor with MBG and attached culture/pumice stones to be used for activated sludge process, wastewater treatment.

5. References
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