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The design of an ejector type microbubble generator for aeration tanks

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Abstract. The ejector type microbubble generator, which is the method to supply air to water by using cavitation in the nozzle, does not require any air supplier so it is an effective and economical. Also, the distribution of the size of bubbles is diverse. Especially, the size of bubbles is smaller than the bubbles from a conventional air diffuser and bigger than the bubbles from a pressurized dissolution type microbubble generator so it could be applied to the aeration tank for wastewater treatment. However, the performance of the ejector type microbubble generator was affected by hydraulic pressure and MLSS(Mixed Liquor Suspended Solid) concentration so many factors should be considered to apply the generator to aeration tank. Therefore, this study was performed to verify effects of hydraulic pressure and MLSS concentration on oxygen transfer of the ejector type microbubble generator. In the tests, the quantity of sucked air in the nozzle, dissolved oxygen(DO) concentration, oxygen uptake rate(OUR), oxygen transfer coefficient were measured and calculated by using experimental results. In case of the MLSS, the experiments were performed in the condition of MLSS concentration of 0, 2,000, 4,000, 8,000 mg/L. The hydraulic pressure was considered up to 2.0 mH_2O. In the results of experiments, oxygen transfer coefficient was decreased with the increase of MLSS concentration and hydraulic pressure due to the increased viscosity and density of wastewater and decreased air flow rate. Also, by using statistical analysis, when the ejector type microbubble generator was used to supply air to wasterwater, the model equation of DO concentration was suggested to predict DO concentration in wastewater.

Keywords: ejector type microbubble generator; hydraulic pressure; oxygen transfer coefficient (KLa); oxygen uptake rate (OUR); mixed liquor suspended solid (MLSS)

1. Introduction

For biological wastewater treatment, air should be supplied for the respiration of microorganism and the mix of MLSS (mixed liquor suspended solid). Also, the treatment efficiency of wastewater treatment can be estimated by water quality of treated water through using basic parameter such as biological oxygen demand (Baki and Aras. 2018). Conventional air supply equipment, which is generally used to maintain DO concentration at the aeration tank, has weaknesses such as the high energy cost and the low treatment efficiency due to the low level of DO concentration. These disadvantages are caused by short residence time of bubbles and low level of oxygen transfer due to the large size of bubbles (Han *et al*. 2011). Also, the electricity cost to supply air to the aeration tank ranges from 40 to 70 percentage of total operation expenses (Kim *et al*. 2012, Kim *et al*. 2014). Therefore, the methods to increase the efficiency of oxygen transfer should be considered for the reduction of energy and the increase of treatment efficiency. To improve the efficiency of oxygen transfer, a method, which is to minimize the size of air bubble, was suggested to increase the coefficient of mass transfer between gas and liquid by increasing the contact surface and the residence time of bubbles (Lee *et al*. 2012).

For example, air diffuser with porous plate to minimize the size of bubbles was used to overcome the disadvantages of the conventional air supply method (Matter-Müller *et al*. 1981, Chern and Yu. 1995). On the other hand, the ejector type microbubble generator, which is a method to supply air to water by circulating water internally, does not require any air supplier such as compressor because the generator sucks air automatically by using cavitation in the nozzle so this method requires low power cost (Terasaka *et al*. 2011, Maeda *et al*. 2015). Also, the distribution of the size of bubbles is various and the size of bubble is larger than the one from the pressurized dissolution type microbubble generator. Therefore, the problem of sludge rising at the aeration tank due to microbubbles from the pressurized dissolution type microbubble generator could be mitigated. Also, it is able to apply to the aeration tank while DO concentration is maintained and MLSS is mixed for biological treatment (Lim *et al*. 2016).

On the other hand, Stenstrom and Gilbert (1981) demonstrated that factors, which have effect on the oxygen transfer in the aeration tank, were blower, the flow form, configuration of aerator, residence time of solids and nitrification, concentration of MLSS and DO, the characteristics of sewage and temperature and etc. Especially, many researchers had shown factors which have to be considered for oxygen transfer in the water. When the ejector type microbubble generator is applied to the aeration tank, the quantity of sucked air in the nozzle, which is the basis for the air supply to aeration tank, is affected by the operating condition of microbubble generator, structure characteristics of nozzle for pressure drop, hydraulic

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pressure due to water depth and concentration of MLSS (Sadatomi *et al*. 2005, Terasaka *et al*. 2011, Sadatomi *et al*. 2012).

Therefore, this study was performed to apply the ejector type microbubble generator, which is a method to supply effectively air to the aeration tank and reduce power cost, to the aeration tank. Especially, this study focused on the effect of MLSS and hydraulic pressure due to water depth on oxygen transfer, when the ejector type microbubble generator that use the venture nozzle is applied to the reactor. Furthermore, through using multiple linear regression analysis, the regression equation of DO concentration according to experimental conditions were deducted.

2. Experimental Methods

2.1. Materials

To use MLSS and treated water for the adjustment of MLSS concentration, the experiments were performed in the Songdo sewage treatment facility. Songdo sewage treatment facility are using A2O+MBR process and the capacity of the facility is 42,500 ton/day. To compare the oxygen transfer efficiency according to the concentration of MLSS and hydraulic pressure, the concentration of MLSS was controlled as 0, 2,000, 4,000, 8,000 mg/L. When the concentration of MLSS is 0 mg/L, tap water was used for the experiment. Also, the hydraulic pressure was controlled as 0.5, 1.0, 1.5, 2.0 mH_2O.

2.2 Experimental equipment

As shown in Fig. 1, the cylinder with the base diameter of 0.5 m and the height of 2.3 m was used. Also, valve for wastewater circulation in the mentioned above was installed at the bottom of reactor. The operating pressure of microbubble generator, which controls the quantity of wasterwater circulation by pump, was regulated by inverter of control box in the generator. To calculate oxygen transfer coefficient by measuring DO concentration, DO meter (ProODO®, YSI, USA) was placed at 0.1 m below for the surface according to hydraulic pressure. In the case of nozzle, the results of the former research was reflected in the specification of the nozzle used in this experiment(Lim *et al*. 2015). Fig. 2 shows configuration of the nozzle used in this experiment. The throat diameter and length of throat were 6 mm and 40 mm. In addition, the diameter of air inlet was 2 mm. Also, the quantity of air flow rate in the nozzle was measured by gas flow meter. To compare the characteristics of oxygen transfer of the ejector type microbubble generator and the conventional air diffuser of disk type (KS-QC100, Keyrsin, Korea), the conventional air diffuser was used and the diameter of the diffuser was 105 mm.

2.3 Experimental methods

2.3.1 The quantity of air flow rate

To verify the effect of hydraulic pressure and MLSS concentration on the quantity of air flow rate, the quantity of air flow rate according to the experimental conditions was measured every 30 seconds by gas flow meter. Also, the experimental conditions was shown in Table 1.

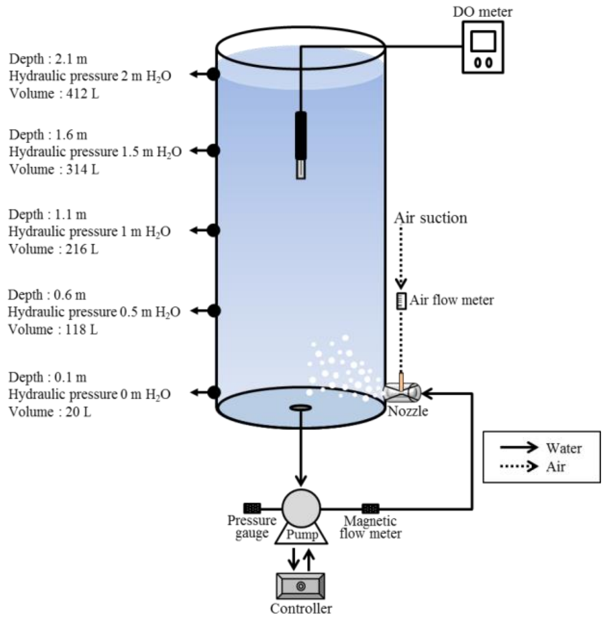

Fig. 1 Schematic diagram of experimental apparatus

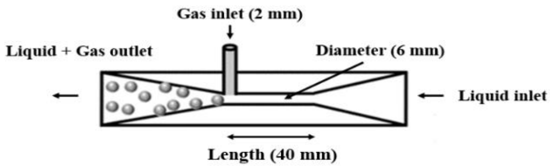

Fig. 2 Schematic diagram of ejector type venturi nozzle

Table 1 Experimental conditions

Characteristics		Specification
The ejector type microbubble generator	Gauge pressure (bar)	5
	Water flow rate (L/min)	48.0-48.3
Hydraulic pressure (mH_2O)		0.5, 1.0, 1.5, 2.0
MLSS concentration (mg/L)		0, 2,000, 4,000, 8,000

2.3.2 Characteristics of oxygen transfer

Tap water was used for the experiment of 0 mg/L of MLSS concentration. To remove DO in tap water, nitrogen gas was used and the DO concentration in the water was limited to 4 mg/L to perform the experiment (Sadatomi *et al*. 2012). The Experiments for 2,000, 4,000 and 8,000 mg/L of the MLSS concentration were conducted 60 minutes after filling wastewater into the reactor to reduce DO concentration because it was not able to use nitrogen gas or chemical due to the impacts of microorganism. To analyze the characteristics of oxygen transfer, DO concentration and the water temperature were measured every 30 seconds until the saturation level of DO concentration by microbubbles. The concentration of saturated oxygen for the wastewater was calculated by using Eq. (1) (Han *et al*. 2011).

$$(C_{SW})_{760} = \frac{(475 - 0.00265 \times S)}{(33.5 + T)} \quad (1)$$

In this equation, $(C_{SW})_{760}$ means the saturated DO concentration of wastewater at atmospheric pressure, S means the concentration of dissolved solid (mg/L) and T is the temperature (℃). The dissolved solids concentration was measured by digital multi-meter (HQ 40d, Hach, USA).

The oxygen transfer coefficient was calculated from Eq. (2).

$$\frac{dc}{dt} = K_L a \times (C_s - C) \quad (2)$$

Here, K_La is the oxygen transfer coefficient (sec^{-1}), C and C_s are the concentration of dissolved oxygen (mg/L) at a time t and at saturation respectively. Also, to assess an activity of microorganism, the oxygen uptake rate (OUR) was used. Oxygen uptake rate can be calculated from Eq. (3). Here, DO_1 means initial DO concentration, DO_2 is the reduced DO concentration due to oxygen uptake by microorganism (Barwal and Chaudhary. 2015).

$$OUR(mgO_2/L/hr) = \frac{(DO_1 - DO_2)}{(t_2 - t_1)} \quad (3)$$

3. Results

3.1 The quantity of air flow rate

The quantity of air flow rate according to concentration of MLSS and hydraulic pressure was shown in Fig. 3. Fig. 3 demonstrated that hydraulic pressure causes the decrease of the quantity of air flow rate. Also, it was able to show that MLSS have effect on the decrease of the quantity of air flow rate slightly. This is because hydraulic pressure affects inlet of nozzle so pressure drop was affected and it seems to cause the decrease of the quantity of air flow rate. Also, in the case of the effect of MLSS, the increase of the viscosity and density of wastewater due to increased MLSS concentration might slightly affect pressure drop so it also seems to be decreased of the quantity of air flow rate (Jamshidi and Mostoufi. 2017).

3.2 Characteristics of oxygen transfer

3.2.1 Oxygen uptake rate

The results of the oxygen uptake rate measurements for each MLSS concentration were shown in Fig. 4. For the MLSS concentration 2,000 mg/L, 4,000 mg/L, 8,000 mg/L, the average oxygen uptake rates were 7.98 mg O_2/L/hr, 12.27 mg O_2/L/hr and 20.66 mg O_2/L/hr, which demonstrated that OUR was proportional to MLSS concentration. To apply the oxygen uptake to the aeration tank, specific oxygen uptake rate (SOUR), which means OUR per the unit of microorganism should be considered. Therefore, when it is considered, SOUR were shown as

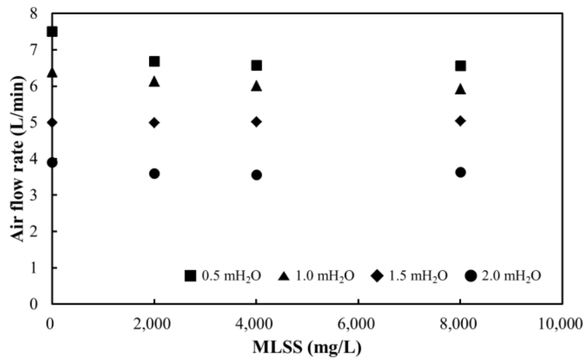

Fig. 3 Effects of MLSS concentration on the quantity of air flow rate according to hydraulic pressure

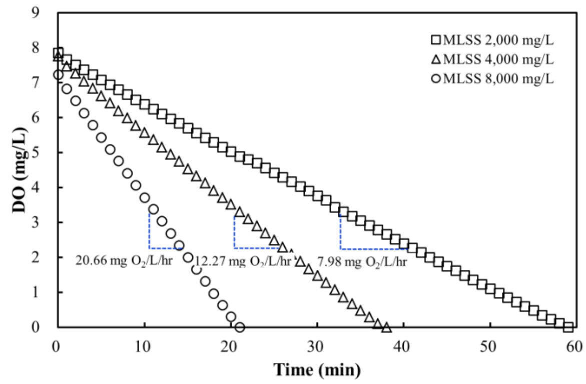

Fig. 4 Oxygen uptake rate according to MLSS concentration

3.99 mg O_2/g MLSS/hr, 3.07 mg O_2/g MLSS/hr, 2.58 mg O_2/g MLSS/hr, respectively.

3.2.2 Oxygen transfer coefficient

Fig. 5 shows the calculation results of oxygen transfer coefficient in hydraulic pressure of 0.5 mH_2O, when the effects of microorganism were considered. In the experiment for tap water, the oxygen transfer coefficient was 0.0113 sec^{-1}. In the experiments of various MLSS concentration, the oxygen transfer coefficient were 0.0016 sec^{-1} at the MLSS concentration of 2,000 mg/L, 0.0011 sec^{-1} at the MLSS concentration of 4,000 mg/L, 0.0004 sec^{-1} at the MLSS concentration of 8,000 mg/L respectively. Also, in the various experimental conditions, oxygen transfer coefficient tended to be decreased according to the increase of MLSS concentration. However, oxygen transfer coefficient was increased with the quantity of air flow rate. To compare the characteristic of oxygen transfer coefficient between the ejector type microbubble generator and conventional air diffuser, the same quantity of air flow rate of the ejector type microbubble generator in diverse experimental conditions was applied to the conventional air diffuser. As a result, the oxygen transfer coefficient of the conventional air diffuser was 0.0043 sec^{-1} in the experiment for tap water. Also, in the MLSS concentration of 2,000 mg/L, 4,000 mg/L, 8,000 mg/L, the oxygen transfer coefficients were 0.0006 sec^{-1}, 0.0003 sec^{-1}, 0.0001 sec^{-1}, respectively. Therefore, it was able to know that the ejector type microbubble generator was more effective than the

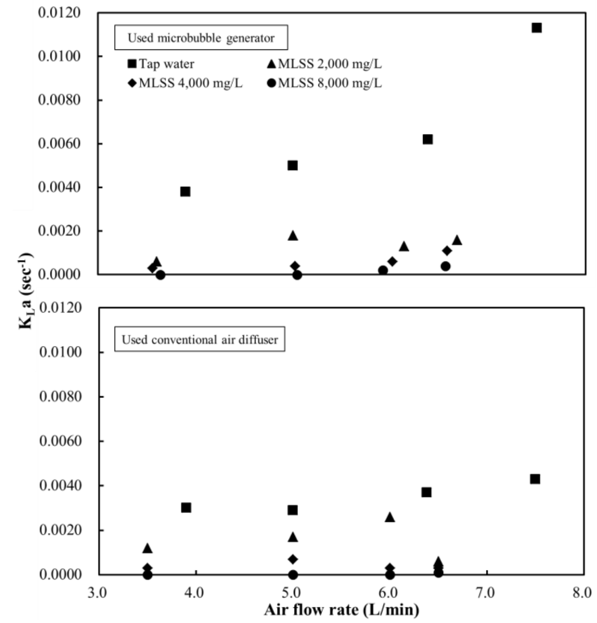

Fig. 5 Effects of the quantity of air flow rate on K_La according to MLSS concentration

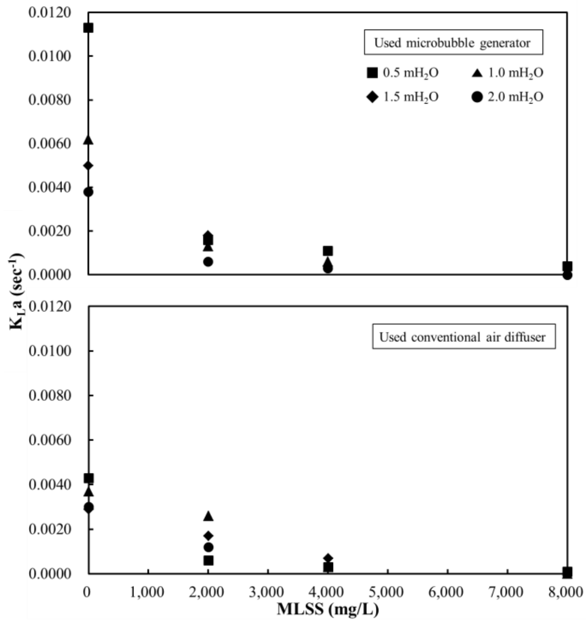

Fig. 6 Effects of MLSS concentration on K_La according to hydraulic pressure

conventional air diffuser to supply air to water and this results seemed to be caused by difference of residence time and oxygen transfer between conventional bubbles and microbubbles.

Fig. 6 presents effects of MLSS concentration on K_La according to hydraulic pressure. When hydraulic pressure and MLSS concentration were increased, the quantity of air flow rate in the venturi nozzle tended to be decreased so oxygen transfer coefficient had a tendency to be decreased. Especially, in the MLSS concentration of 8,000 mg/L, it was able to know that oxygen transfer efficiency was very low because the capacity of nozzle, which means the quantity of air flow rate, seems to be limited and oxygen uptake rate was high in the MLSS concentration of 8,000 mg/L and that optimal hydraulic pressure according to the capacity of nozzle should be considered by performing this experiments. On the other hand, in the case of the oxygen transfer coefficient of the conventional air diffuser, it was able to show that the oxygen transfer coefficient in the high level of hydraulic pressure was higher than in the low level of hydraulic pressure. It seems to be affected by the short residence time of large bubbles. Although the quantity of supplied air to the conventional air diffuser in the low level of hydraulic pressure was higher than in the high level of hydraulic pressure, it was hard to have sufficient residence time to dissolve air so these results seemed to be represented.

3.3 Model equation

To clear up the functional relationship with each variables, experimental results were statistically analyzed. The linear interaction expression was obtained by using the analysis. Except for fixed operating conditions such as operating pressure of ejector type microbubble generator and diameter of a nozzle throat, the regression equation about DO concentration was derived from the multiple linear regression analysis by using experimental results. And, used statistical analysis program was minitab® 17.

3.3.1 MLSS concentration

The significance verification results of every independent variables and concentration of DO shown that the concentration of MLSS and hydraulic pressure had significantly effect on DO concentration. The model equation of DO concentration about MLSS concentration and hydraulic pressure can be shown as Eq. (4).

$$\mathrm{DO} = 8.2030 - 0.000379 \times \mathrm{M} - 0.000259 \times (\mathrm{H} \times \mathrm{M}) \quad (4)$$

In this equation, M and H represent the concentration of MLSS (mg/L) and the water depth (m), respectively. A correlation coefficient of calculated value from Eq. (4) and the experimental value was 0.9919.

3.3.2 Oxygen uptake rate

The model equation of DO concentration about the oxygen uptake rate can be shown as Eq. (5).

$$\mathrm{DO} = 8.555 - 0.1611 \times \mathrm{OUR} - 0.0910 \times (\mathrm{OUR} \times \mathrm{H}) \quad (5)$$

A correlation coefficient of calculated value from Eq. (5) and the experimental value was 0.9589. When the oxygen uptake rate was applied to the independent variable, the significance probability of independent variables was low and the relation between independent variables was high. Therefore, it was better to use the oxygen uptake rate with other independent variables than the oxygen uptake rate independently.

4. Conclusions

When an ejector type microbubble generator was applied to the various experimental conditions, the characteristics of oxygen transfer were reviewed. In addition, by performing the comparison tests of the ejector type microbubble generator and the conventional air diffuser, the following conclusions could be obtained.

- When hydraulic pressure and MLSS were increased, the oxygen transfer coefficient had a tendency to be decreased because of the decrease of the quantity and the increase of viscosity and density of wastewater. Also, it was able to verify that the quantity of sucked air flow rate in the nozzle was more affected by hydraulic pressure than the concentration of MLSS.
- In the comparison tests of the ejector type microbubble generator and conventional air diffuser, the performance of the ejector type microbubble generator was higher than the one of conventional air diffuser. Especially, in the low level of hydraulic pressure, which means low water depth, the oxygen transfer of the conventional air diffuser was low due to the short residence time of large bubbles.
- The capacity of the venturi nozzle used in the experiments was limited to supply air into water. Especially, in the hydraulic pressure of 2.0 m and MLSS concentration of 8,000 mg/L, oxygen transfer coefficient was very low due to low quantity of air flow rate and high level of oxygen uptake rate so it was able to know that the capacity of the nozzle, MLSS concentration and hydraulic pressure should be considered to supply sufficient air into wastewater.
- From statistical analysis based on the results of the experiments, the model equation of the prediction of DO concentration in wastewater could be obtained. A prediction formula of the concentration of DO was suggested as $DO = 8.2030-0.000379 \times M-0.000259 \times (H \times M)$.

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