# EFFECT OF MICROBUBBLE GENERATOR OPERATING PARAMETERS ON OXYGEN TRANSFER EFFICIENCY IN WATER

**ANDINET T.K.[1], KIM J.S.[1], LEE J.Y.[2] and KIM I.H.[1,2]**

[1]Department of Construction Environment Engineering, University of Science and Technology, Daejeon, 305-333, Republic of Korea, [2] Korea Institute of Civil Engineering and Building Technology (KICT), Gyeonggi-Do, 411- 712, Republic of Korea.
E-mail: ihkim@kict.re.kr

**ABSTRACT**

Dissolved oxygen (DO) is a fundamental requirement for a healthy aquatic ecosystem and it specifies the capability of waterbody to support a balanced ecosystem. It is probably the single state variable that provides maximum information about water quality conditions in natural waters. In this study, dissolved oxygen formation was investigated at laboratory scale by using micro-bubble generator, in which saturator pressure, water supply and gas flow rates and type of gas were the main operating factors considered. The effect of changing the operating parameters was described in terms of dissolution performance using volumetric mass transfer rate, which is very important element for aerator design and scale-up. Pressure values from 1 to 6 atm were taken for the analysis. The volumetric mass transfer coefficient was limited below 0.01 per min for air; however, the value varied from 0.10 to 0.13 per min for oxygen at 4.5 L/min flow rate, showing increasing pattern with pressure. Corresponding system operating cost-benefit using pure oxygen at 4.5 atm pressure was found to be better than that of air. Thus, for improvement of natural water bottom area environment, use of pure oxygen microbubbles results in higher DO and system transfer efficiency. Even though the use of air to produce microbubbles seems more economical, considering the excessive dissolution of gas with the bubbles, use of pure oxygen is appropriate.

**Keywords**: Microbubble, DO, Operating Parameters, Mass transfer, Operating cost.

## 1. Introduction

In Korea, as natural lakes are limited in number and small in size, a large number of water storage reservoirs are constructed to meet fresh water demand of the society (Cha, *et al*., 2011). However, the reservoirs created large zones of dead water and in consequence suffered from water quality troubles due to eutrophication (Bae, 2013; Liu, *et al*., 2012). To control eutrophication, intervention measure such as aeration of the water body is necessary until changes in catchment management practices result in reduced input of nutrients (Tekile *et al*., 2015). Some aerators have already been installed; nevertheless, most of them supply quite coarse air bubbles which rise rapidly, burst on the water surface and hence inefficient in gas transfer (Heo and Kim, 2004; Oh, *et al*., 2013).

Alternatively, if microbubbles, which have characteristics such as large gas-liquid interfacial area and extremely slow rising velocity, are used, the oxygen transfer to water will be facilitated. And, in controlling eutrophication, hypolimnetic aeration is preferred to destratification due to its ability to selectively oxygenating the hypolimnion of stratified lakes and reservoirs, while maintaining thermal stratification. This can be effectively achieved using microbubbles which show limited vertical mixing. Besides, by choosing appropriate type of gas, oxygen transferred to hypolimnetic water can be optimized.

In this study, pressurized microbubble generator was used to examine the influence of the microbubble generator operating parameters on dissolved oxygen (DO) formation, with a specific focus on the oxygen mass transfer ($K_La$) from bubbles to surrounding water. $K_La$ is most important parameter for design and scale-up of aerators (Ashely, *et al*., 1991). Assuming the same size mechanical devices for initial cost, the system running cost-benefit for the different operating scenarios are analyzed based on the amount of gas transfer per unit time.

## 2. Materials and methods

### 2.1. Experimental apparatus and test conditions

When water is introduced into a pump, the water velocity becomes extremely high compared to that at the exit, thus causing the pressure at downstream of the body become negative. With the aid of the negative pressure, air is automatically sucked through the small orifice drilled on the wall, and the air sucked is broken into a huge number of microbubbles. The bubbles with the water are guided to a saturator (nozzle or separator) where the air is effectively mixed with water and pressure is properly produced before passing to the cylindrical reactor where the bubbles supply the oxygen. The saturator was a cylindrical stainless steel having height of 0.5 m and diameter 0.3 m. Excess gas was exhaled from a release valve on the top of the separator.

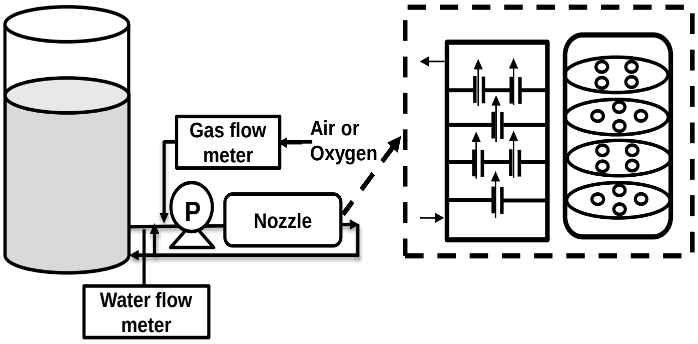


**Figure 1:** Experimental setup for the Microbubble generation.

Figure 1 shows the pressurized microbubble generator. The mixture of liquid and gas is pressurized in the tank, where the gas is dissolved at the saturation concentration. The pressure in the pressurized tank affects the size and number of the microbubbles.The pump had specification of 35 L/min flow rate, 37 m head and 1.5 kWh power consumption. The experiment was conducted in the cylindrical reactor made of transparent acrylic with diameter 0.60 m and height 1.0 m. 200 L volume of circulating water is kept in the tank. Water was supplied from a pump to the microbubble generator via a flow control valve and a flow meter for the liquid flow rate measurement. The gas suction rate into the micro-bubble generator was measured with a flow meter.

The microbubbles were generated in tap water. The gases used to produce the bubbles were oxygen (99.99 % purity, KUM OH Gas Co. Ltd., Korea) and natural air. In the case of air, the generator is left open to the atmospheric air. The water flow rate into the reactor was 20 L/min and gas flow rate of 1.5, 3.0 and 4.5 L/min were considered as operating condition. The gas operating pressures of 2.5, 3.5 and 4.5 atm were used.

### 2.2. Volumetric oxygen mass transfer measurement

At the outset of the experiments, nitrogen gas (99.9 % purity, KUM OH Gas Co. Ltd., Korea) was blown into the water so as to reduce the already dissolved oxygen, DO, content to about 4 mg/l because the tap water showed a high DO value and it requires very long time to reduce to zero (Sadatomi, *et al*., 2012). Then, natural air or pure oxygen was fed into the water through the micro-bubble generator at desired flow rates of gas and the liquid at the bottom of the reactor. The time variation of the oxygen concentration, C, in the reactor water, was measured with a DO meter (Orion Star A223 RDO, Co.) at 30 cm depth from the bottom of the tank. Since temperature affects gas solubility, its measurement (24 ~ 27$^0$C) was taken along with dissolved oxygen and the variation is used as correction factor for oxygen solubility (Lewis, 2006). From the time variation data of C, the volumetric mass transfer coefficient at temperature T, $K_La_T$, was determined by the integrated form of the model for non-steady state test:

$$K_La_T = \frac{\ln[(C_s-C_1)/(C_s-C_2)]}{t_2-t_1} \quad (1)$$

Here, $C_s$ is the DO concentration at equilibrium condition, $t_1$ and $t_2$ are times chosen at which measured oxygen conc., $C_1$ and $C_2$, are 20% ($t_1$) and 80% ($t_2$) respectively of the saturation values for the test water (Ashely, *et al.*, 1991). Plotting Eq. (1) on semilog paper, $K_La$ is estimated provided that $C_s$ is known from DO vs time plot. Based on the amount of oxygen transferred to the water, the costs of pure oxygen and natural air are compared using the following relation:

$$C = \frac{(C_0{*}Q_0)+(P.C{*}C_e{*}T)}{O_S} \quad (2)$$

where; C = operation cost (Won/Kg DO); $C_0$ = oxygen price (Won/L); $Q_0$ = oxygen flow rate (L/min); P.C. = power consumption of pump (kWh); $C_e$ = electricity price (Won/kWh); T = operation time (min) and $O_s$ = amount of DO supply (Kg DO). Won is Korean currency. Mass of oxygen transferred per unit time ($O_s$) is determined by multiplying $K_La$, $C_S$ and volume of water in the tank.

## 3. Results and discussions

Figure 2 shows the DO concentration of air and pure oxygen during the bubble generation. The higher dissolution nature of pure oxygen under different pressure is depicted on the graph.

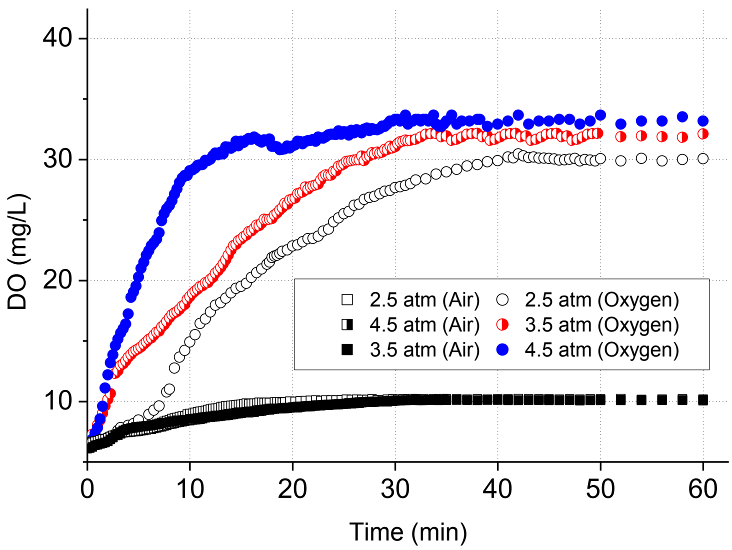


**Figure 2:** Dissolved oxygen variation with time by liquid pressure at 1.5 L/min gas flow.

It is worth mentioning that oxygen microbubbles had in excess of 3 times DO supply than air microbubbles. The DO concentration of the tap water, which initially was about 4 mg/L, rapidly increased to high values of above 30 mg.$L^{-1}$, characterizing oxygen supersaturated water. The concentration is observed to remain constant after climbing to the maximum value during the generation. However, following stopping the bubble generation, the DO concentration decreased slowly until it reached the saturation equilibrium. It was also shown that when higher pressure is applied to the mixture of gas and water, higher gas dissolves into the water. As it is shown in table 1, the dissolution is also found to increase better when the gas flow rate is increased.

The oxygen transfer coefficients are deduced from experimental DO concentration in the plot versus time. The obtained coefficients are presented in table 1. The gas type, its flow rate and pressure are the dominating parameters in oxygen transfer phenomena. From the values, it can be seen that the mass transfer of pure oxygen is significantly higher than that of air, specifically, the value at 4.5 atm and 4.5 L/min gas flow rate is 28 times higher. For the same parameters, for $C_s$ value of 39.22, the best fit line, as shown in figure 3, is given by C = 0.1286*t at $R^2$ = 97.44%; hence giving $K_La$ estimate of 0.1286.

**Table 1:** Volumetric oxygen transfer coefficient for each operating condition.

| Volumetric oxygen transfer coefficient, $K_La$ ($min^{-1}$) | | | | |
|---|---|---|---|---|
| Gas velocity (L/min) | | Liquid velocity, m/s (pressure, atm) | | |
| | | 0.85 (2.5) | 1.02 (3.5) | 1.19 (4.5) |
| Air | 1.5 | 0.005 | 0.005 | 0.004 |
| | 3.0 | 0.005 | 0.005 | 0.005 |
| | 4.5 | 0.006 | 0.005 | 0.004 |
| Oxygen | 1.5 | 0.030 | 0.043 | 0.062 |
| | 3.0 | 0.035 | 0.076 | 0.082 |
| | 4.5 | 0.067 | 0.107 | 0.112 |

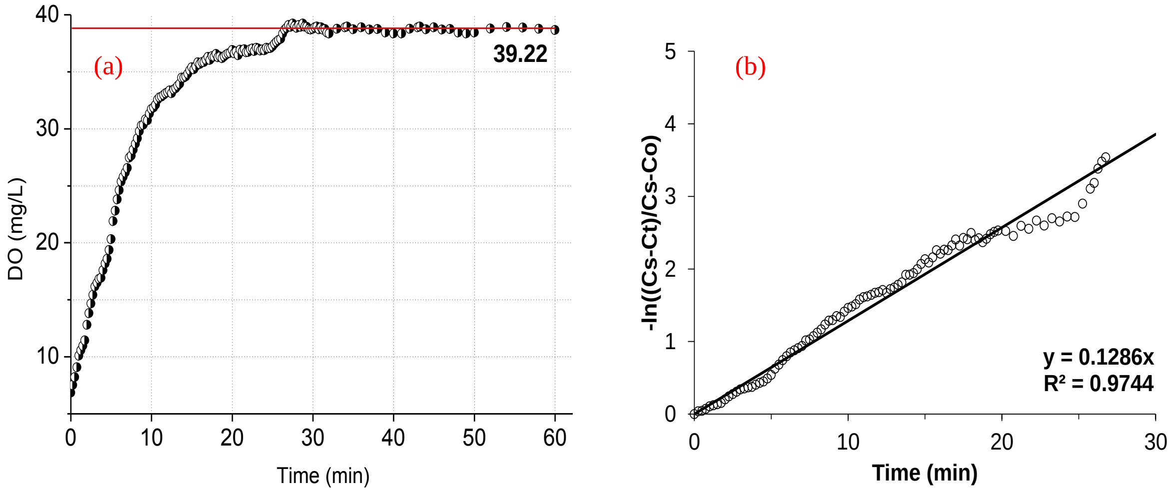


**Figure 3:** (a) DO variation with time at gas flow rate 4.5 L/min and liquid velocity 1.19 m/s and (b) a result of application for volumetric oxygen transfer model.

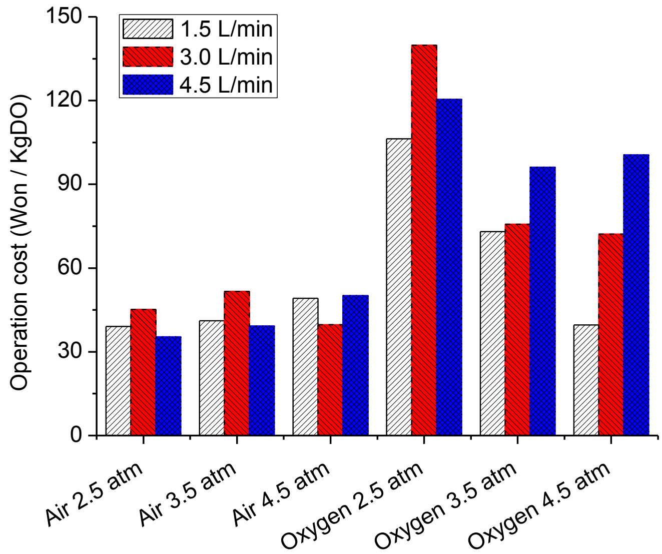


**Figure 4:** Cost comparison of air and pure oxygen under different flow and pressure.

Figure 4 presents running cost-benefit comparison of air and pure oxygen under the considered operating conditions for only 20 min aeration. At gas flow rate of 1.5 L/min and 4.5 atm liquid pressurization, use of pure oxygen is reasonable. Besides, due to massive oxygen transfer (storage beyond certain level), practical oxygen aeration can be operated intermittently and hence saving running cost and contributing to service life of the facility.

## 4. Conclusions

By using a micro-bubble generator, oxygen transfer efficiency was investigated. To know the effects of the operating parameters on the DO, gas type, pressure and gas flow rates were considered for the test. The output is presented in terms of the volumetric mass transfer coefficient, $K_La$. The laboratory experiment indicated that $K_La$ substantially increased with air flow rate and pressure. Thus, for effective generation of the highly soluble microbubbles, reasonable conditions of gas pressure and flow rate should be examined. Moreover, a practical oxygen microbubble system can be best operated using pure oxygen by which the cost-benefit is optimized due to the superb solubility of the oxygen microbubbles. In this experiment the operating cost of oxygen at 4.5 atm pressure and 1.5 L/min flow is found to be lower than that of air.

## REFERENCES


1. Ashley I.K., Hall J.K. and Mavinic S.D. (1991) Factors influencing oxygen transfer in fine pore diffused aeration, wat.res., 25 (12), 1479-1486.
2. Bae H. K. (2013) The Effect of river flow retardation on algal growth, Natural Resources and Conservation, 1(2), 30-34.
3. Cha Y. J., Shim M. P. and Kim S. K. (2012) The Four Major Rivers Restoration Project, UN Water International Conference, June 2012, Zaragoza, Spain.
4. Heo W. M. and Kim B. (2004) The effect of artificial destratification on phytoplankton in a reservoir, Hydrobiologia, 524: 229–239.
5. Lewis M.E. (2006) Handbooks for Water-Resources Investigations, volume 9, chapter 6.2. Dissolved oxygen, pages 35-37. US Geological Survey TWRI.
6. Liu L., Liu D., Johnson D. M., Yia Z. and Huanga Y. (2012) Effects of vertical mixing on phytoplankton blooms in Xiangxi Bay of Three Gorges Reservoir: Implications for management, Water research, 46, 2121-2130.
7. Oh K. H., Jeong D. H., Yang S. Y., Jeon T. W. and Cho Y. C. (2013) Effects of submerged aerator on the growth of algae in Daechung Reservoir, J. Kor. Soc. Environ. Eng., 35(4), 268-275.
8. Sadatomi M., Kawahara A., Matsuura H. and Shikatani S. (2012) Micro-bubble generation rate and bubble dissolution rate into water by a simple multi-fluid mixer with orifice and porous tube, Experimental Thermal and Fluid Science, 41, 23–30.
9. Tekile A., Kim I.H. and Kim J.S. (2015) Mini-review on river eutrophication and bottom improvement techniques, with special emphasis on Nakdong River, J. Env. Sci. 30, 113-121.