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Hydraulic Characteristics of Conical Shape Diffuser for Aerobic Bioreactor

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***Abstract* — This paper mainly discussed the hydraulic characteristics of conical type air diffuser made of rigid plastic with opened hole structures using numerical and empirical method. The unique conical shape of air diffuser prevented fine air bubbles from merging after injection from air diffuser nozzle. Furthermore, opened holes structures made lower pressure drop compare than that of membrane shape of air diffuser made of EPDM in water, owing to elimination of force which was required to expand rubber membrane of EPDM air diffuser. Due to unique morphology of air diffuser, fine air bubbles showed long retention time and higher SOTE (standard oxygen transfer efficiency) comparing than that of EPDM membrane air diffuser with same blower conditions to inject air into aerobic bioreactor system.**

***Keywords*—air diffuser, aerobic bioreactor, conical shape air diffuser, high efficiency, low pressure drop**

I. Introduction

Because the aeration is the main energy consuming process in wastewater treatment plant, correct configuration of system or the air diffuser allows an optimized of costs[1]. Many studies have been shown that the energy consumption of aeration system can account for 40% ~ 60% of total energy consumption in WWTP[2,3]. Fine pore diffusers improve aeration performances determining higher oxygenation conditions, an increase of the adaptability to different oxygen requirements and a reduction in the production of aerosol[4]. The air supplied by the compressor is resisted by two forces; the one, pressure resistance owing to the depth of the water, and the other, head-loss experienced by the air trying to exit through the membrane perforations. Any increase in either depth or head-loss restrictions on the membrane will decrease overall system efficiency[5]. As the membrane hardens, becoming less flexible, there will be an increase in head-loss through the perforations. Also, shrinkage of the membrane causes the perforations to become smaller, further increasing resistance and head-loss. In addition, any biological fouling will also cause perforations to be closed[6]. All of these cause the oxygen transfer efficiency into the system to drop, increasing the power requirements on the compressor to provide more air, and increasing overall system costs[7]. Also, as the compressor air-flow drops below the designed surge line, the turbine exceeds its safe operating range increasing the likely-hood of turbine damage due to cavitation[8]. To overcome those kinds of restrictions of EPDM air diffuser, sintered polymer structure of air diffuser had been applied[9]. However, they showed low pressure drop and high oxygen transfer rate into the waste water, that air diffusers are not commercialized widely owing to production cost, mechanical stability, and plugging by sludge precipitation in air diffuser during operation.

This paper deals with the morphology effects of unique type of air diffusers applied to biological wastewater treatment both in numerical analysis and empirical method. We estimated the velocity profile in the air diffuser by fluid dynamic analysis. And the effect of nozzle direction is evaluated to prevent air bubbles from merging after injection into the water phase. Finally we compared the pressure drop and SOTE between conical type air diffuser and EPDM air diffuser in the same conditions.

II. Materials and Methods

A. *Materials*

The conical type of air diffuser (Model: UFO 327, ANT21 Co. South Korea) and membrane disk type of air diffuser (Model: MD340, ANT21 Co. South Korea) were selected for experiments, and specifications of each air diffuser are list in table 1 and showed in figure 1.

Table 1. Specifications of air diffusers used in experiments

Model	UFO327	MD340
Out diameter (mm)	327	340
Air flow rate (L/min)	80 ~130	80 ~180
Connection	20A	20A
Diffuser type	Conical	Disk
Material (Body)	[a] ABS	[b] EPDM
Material (Case)	ABS	[c] PP

[a] *ABS : Acrylonitrile-Butadiene-Styrene*
[b] *EPDM : Ethylene propylene diene monomer rubber*
[c] *PP : Polypropylene*

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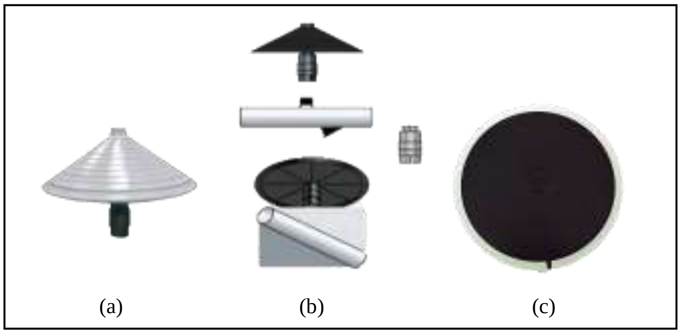


Figure 1. Pictures of (a) UFO 327 air diffuser, (b) top view and bottom view of assembled on the pipe (check valve is shown at right side), and (c) MD 340 EPDM membrane air diffuser.

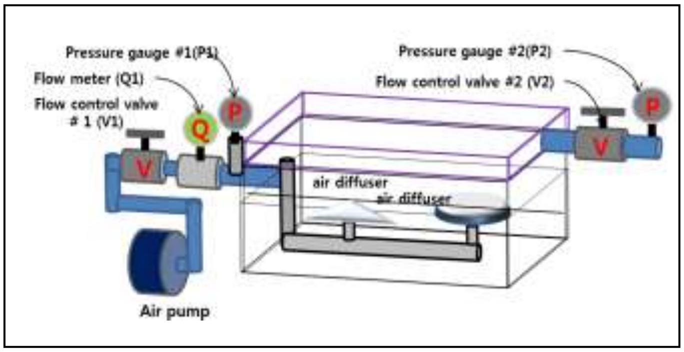


Figure 2. Experimental setup for evaluation of pressure drop at different air flow rate.

To show bubble forming behavior and pressure drop, we prepared rectangular type of water bath made of transparent acryl plate as shown in figure 2. In here, pressure gauge (Range: 0~10bar) and flow meter(Range: 0~300 L/min) were installed between air blower and air diffuser to measure pressure drop at different air flow rates conditions by flow control valve #1.

B. *Methods*

The computational grids for numerical analysis were estimated as hexagonal grid for the rapid convergence and high accuracy of flow characteristics. The model equation was 2-phase mixture model to represent the flowing behavior between air and water system. In real system, behavior of air bubbles was affected by hydraulic pressure mainly and they dissolved into the water phase with hydraulic pressure during moved into the water surface by buoyancy force against gravity direction. The general properties of air and water were selected at the 20℃ and 1 atm. condition, and standard κ-ε model was chosen to calculate each phase by using turbulent model. In this calculation, we assumed the stream pattern as fully developed flow by generated air bubbles and it had been turned to steady state also. We applied 'Fluent 6.3.26 of IBM system' as a solver which was provided from KISTI super computer center and Job command file was generated to remote control.

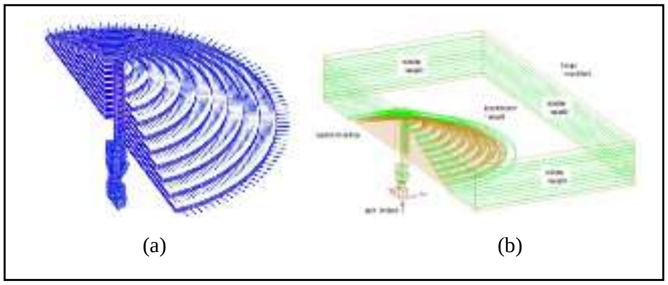


Figure 3. Grid generation and boundary condition set up for calculation of internal air flow pattern in conical air diffuser.

To investigate the internal flow behavior of air and bubble generation mechanism at the end of air diffuser, we generated grid structures of conical type of air diffuser as show in figure 3. In here, we set up the computational grid and boundary conditions to analyze air flow behavior in the air channel of air diffuser. We generated 4,860,000 of grids to calculate air flow behavior at the 1,600 of nozzles. Initial condition of air flow rate was 100L/min which was equivalent as normal operating flow rate in experimental conditions. All experiment had been performed at room temperature 25℃ and ambient pressure conditions with clean tap water.

To measure SOTE (Standard Oxygen Transfer Efficiency), we followed ASCE Standard method[2, 10]. It has been found from experimental observation that the rate at which the dissolved oxygen concentration (DO) in a body of water under aeration changes with time is proportional to the oxygen equilibrium deficit, as represented by the following equation:

$$\frac{dc}{dt} = k_L a\left(C^*_\infty - C\right) \quad (1)$$

Where,

C (mg/l): the dissolved oxygen concentration, assumed to be uniform throughout the bulk water

dc/dt : the rate of change of oxygen concentration with time; C^*_∞ (mg/l) is the equilibrium concentration (concentration reached at infinite aeration time)

k_La (t^{-1}) : the system oxygen transfer coefficient.

Equation (1) has a general validity for a very wide range of aeration systems. Equation (1) may be expressed in its integrated form as follows:

$$C = C^*_\infty - \left(C^*_\infty - C_i\right)\exp\left(-k_L a\ t\right) \quad (2)$$

Where,

C_i : the initial (i.e. time zero) oxygen concentration

C : the oxygen concentration after aeration time t

The Standard oxygen transfer efficiency (SOTE) is the product of dc/dt and the water volume (V) under aeration:

$$OTR = k_L a\left(C^*_\infty - C\right)V \quad (3)$$

To compare bubble generation behavior between conical type and EPDM membrane type of air diffuser, we took picture at same condition and we perform the image analysis.

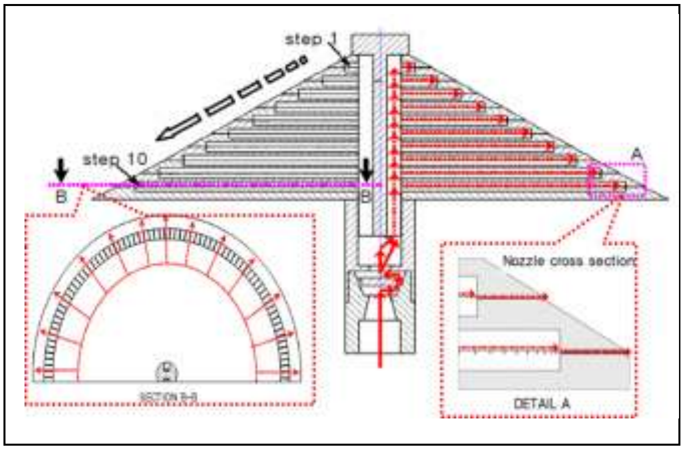


Figure 3. Cutting shape of conical type air diffuser; air flow direction in cross section and nozzle shape.

III. Results

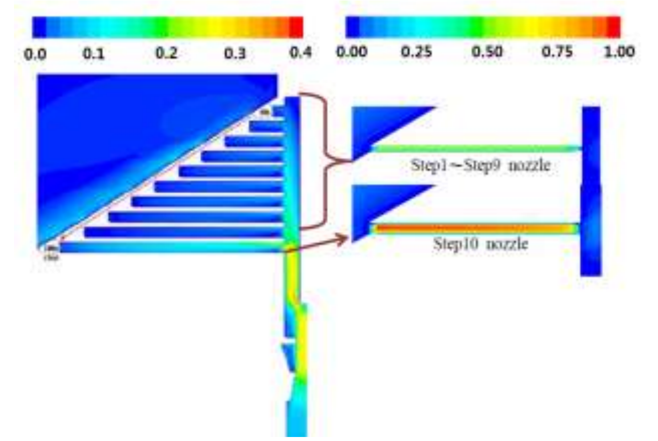
A. Design analysis of air diffuser

The conical type air diffuser consisted of 11 layers of disks with hierarchical structure as shown in figure 3, which made slop on the top of diffuser to prevent sludge from precipitating when blower system turn off. Furthermore, nozzles directions were designed orthogonally against gravity direction, which suppressed the plugging of nozzle owing to the precipitation of sludge also.

As shown in figure 3, conical type air diffuser had ten gaps formed between each disk, and dimension was 0.3 mm from step 1 to 9, and 0.6 mm at step 10,which carried out the formation of air bubbles. Compressed air from the pipe flowed into the center of air diffuser indicated red arrows, and divided into each channel to be turn into the bubbles until blower stop. When blow stopped, check valve in the middle of center blocked the inflow of water by hydraulic pressure into pipe manifolds to restrain the contamination or filling water. When the sludge or particles flowed into the air diffuser, it can be expelled by pressurize air through the gap step 10 which is wider than the other gabs.

B. Numerical analysis of internal flow behavior of air diffuser

We performed numerical analysis to investigate internal flow patterns of air in conical diffuser, and velocity profiles are expressed different color which is calculated by dimensionless numbers divided by maximum velocity in figure 4. Numerical analysis had been performed with half of air diffuser, because it has symmetric structure as shown in figure 1(a). As illustrated in figure 4, the fastest velocity profile was observed at the bottom of center channel in which check valve installed in main channel made a very narrow gab.



(a) (b)

Figure 4. Dimensionless velocity profiles of at the different internal position of conical air diffuser: (a) velocity profiles of half of air diffuser, and (b) is comparison of velocity profiles between step1~9th nozzles and step 10th nozzle.

Those narrow gab increase the pressure resistance which make high pressure drop, therefore this structure should be modified to reduce the velocity of air stream.

According to the analysis, velocity profiles from step 1 to 9 showed similar results, which means the size distributions of air bubbles were constant at the end of nozzle, that is very important property in air diffuser. Because, if each channel has different velocity profile, bubble size will be different which makes low mass transfer rate of oxygen into water phase. In case of step 10 channel, it showed 2 times higher velocity profiles compare than that of other channel, which is occurred by difference of nozzle gap and channel height. This different ration enhanced the turbulent in the air channel, that made high shear force such as jet stream between channel surface and air stream. This shear force can emit the sludge or particles precipitated inside air diffuser when blow turn off.

C. Morphology effect of air diffusers

To compare the morphology effect between conical shape and flat disk shape air diffuser, we observed bubble moving phenomena at the same conditions. As shown in figure 5, bubble groups generated from EPDM disk type air diffuser were concentrated into center during elevation to surface by buoyancy force, owing to water stream from side of air bubble. Those kind of water stream was generated by convection phenomena originated by air bubbles. Because, the direction of nozzles are vertical to the top. Therefore, the moving direction of air bubbles changed into center by summation of each vector stream, and then each bubble merged with near bubble to form large bubble. These merging of bubbles made shorter retention time owing to higher buoyancy force of large bubbles than that of small bubbles. Therefore, it made poor SOTE value in case of waste water treatment process.

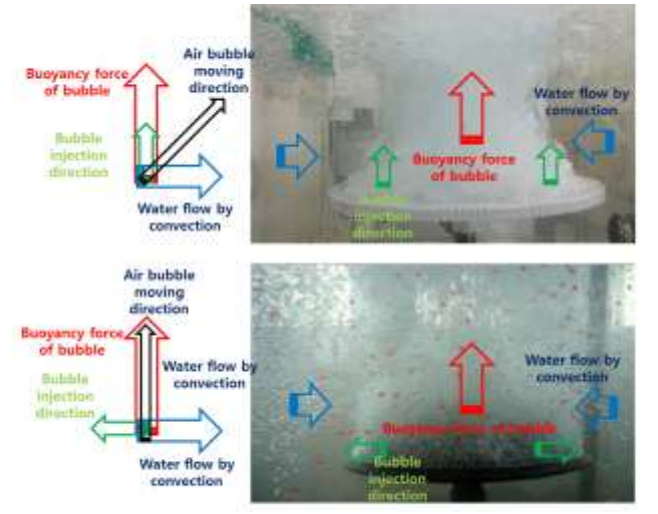


Figure 5. The comparison of bubble moving behavior depending on the air diffuser shape; Top image represents that of EPDM membrane air diffuser, bottom image does conical type air diffuser, and left images indicate the vector summation to represent air bubble moving direction.

On the contrary, air bubbles from conical shape air diffuser moved up directly without focus into the center direction as shown in bottom of figure 5. As it discussed in previously, conical shape air diffuser had nozzles opened to orthogonal direction from the surface, which made bubbles generated to outer direction from the nozzle. Left images in figure 5 represents the summation of each vector of bubble, water convection, buoyancy force, and bubble injection at the end of nozzles. Those effect prevents air bubbles from merging together, which enhance the better SOTE compare than that of disk type air diffuser.

D. *Comparison of pressure drop and SOTE*

The pressure drops of each air diffuser were evaluated at same conditions with different flow rate range as shown in figure 5.

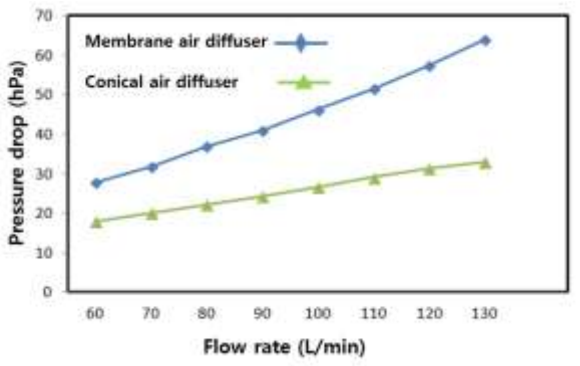


Figure 5. The comparison of pressure drops between conical shape and EPDM membrane type air diffuser at different flow rates.

As the flow rates into the both air diffuser increased, pressure drops of each case increased also owing to increase of resistance at the small diameters of nozzles. However, slope of increments of conical shape of air diffuser lower than that of EPDM air diffuser. Because there is no resistance of head-loss experienced by the air trying to exit through the membrane perforations in case of conical air diffuser. This is one of advantage to decrease the operating cost of waste water treatment plant.

In case of measurement of SOTE with both air diffuser system, conical type air diffuser showed 35% of SOTE, that is higher value than EPDM air diffuser. Summarized data are listed in table 2.

Table 2. Comparison of conical type and EPDM membrane type air diffusers

Items	Conical type	EPDM disk type
Material (Body)	ABS	EPDM
Pressure drop in water (hPa)	18~33	28~65
SOTE (%)	35	30
Check valve for flowing backward	(O)	(X)

IV. Conclusions

We evaluated the hydraulic characteristics of conical type air diffuser made of rigid plastic with opened hole structures using numerical and empirical method. The conical shape of air diffuser prevented fine air bubbles from merging after injection from air diffuser nozzle. The conical shape air diffuser had nozzles opened to orthogonal direction from the surface, which made bubbles generated to outer direction from the nozzle. Furthermore, opened holes structures made lower pressure drop compare than that of membrane shape of air diffuser made of EPDM in water, owing to elimination of force which was required to expand rubber membrane of EPDM air diffuser. Due to unique morphology of air diffuser, fine air bubbles showed long retention time, lower pressure drop and higher SOTE comparing than those of EPDM membrane air diffuser with same blower conditions to inject air into aerobic bioreactor system..

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References

[1] C. Liu, S. Li, F. Zhang, "The oxygen transfer efficiency and economic cost analysis of aeration system in municipal wastewater treatment plant", Energy Procedia, vol.5, pp.2437–2443, 2011.

[2] A. L. Eusebi, P. Battistoni, "Behaviour of air diffusers and oxygen transfer efficiencies in the biological treatment of matrices at thigh alkalinity concentraion:Experimental and full scale application", Chem. Eng. J., vol. 255, pp, 274-281, 2014.

[3] G. Olsson, J. F. Andrews, "Dissolved oxygen control in the activated sludge process", J. Wat. Sci. Tech., vol. 13, pp.341-347, 1981.

[4] P. Duchène, E. Cotteux, S. Capela, "Applying fine bubble aeration to small aeration tanks", Water Sci. Technol.vol. 44, pp. 203-210, 2001.

[5] D. Rosso, J. A. Libra, W. Wiehe, M. K. Sterstrom, "Membrane properties change in fine-pore aeration diffusers: Full-scale variations of transfer efficiency and headloss", Water Research, vol.42, pp.2640-2648, 2008.

[6] Y. K.. Kim, W. C. Boyle," Mechanisms of fouling in fine-pore diffuser aeration", J. Environ. Eng., Vol.119, pp.1119-1138, 1993.

[7] A. Kaliman, D. Rosso, S. Y. Leu, M. K. Stenstrom, "Fine-pore aeration diffusers: Accelerated membrane ageing studies", Water Research, vol.42, pp.467-475, 2008.

[8] E. J. Hansen, M. A. Estevez, O. S. Es-Said, "On the shrinking and hardening of EPDM rubber membranes in water sanitation filtration tanks", Engieering Failure Analysis, vol. 11, pp.361-367, 2004.

[9] A. Poranek, T. Winnicki, " Oxygenation phenomena as a function of sintered polymer structure of air diffuser", Desalination, vol. 48, pp.85-93, 1983.

[10] ASCE, 2007. Measurement of Oxygen Transfer in Clean Water (2-06). American Society of civil Engineering Editor.