Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.922282

54 (2015) 3502–3510
June

Taylor & Francis
Taylor & Francis Group

A study on pond purification capacity evaluation using micro bubble clarifier

Seong Mi Kim, Sang Woo Kim, Yong Keol Oh, Chul Hwi Park*

Department of Environmental Engineering Graduate School, University of Seoul, 163 Siripdaero (90 Jeonnong-dong), Dongdaemun-gu, Seoul 130-743, Republic of Korea, email: chpark@uos.ac.kr (C.H. Park)

Received 15 January 2014; Accepted 14 March 2014

ABSTRACT

This study intended to evaluate the pond purification capacity using micro bubble clarifier. Also, in order to confirm the optimal pressure condition, analysis was performed for each pressure level at 1–4 kg_f/cm^2. It would be the most proper to operate at 3 kg_f/cm^2 and carry out speculation experiments. Pilot plant experiments were conducted in a water tank of approximately 8 m^3. Raw water was obtained at the ponds of S University and a Golf course in full scale with volumes of 1,800 and 1,500 m^3, respectively. Pilot plant results showed that the maximum saturated DO concentration rose up to 40 mg/L at the Pilot plant; and removal efficiencies of COD_{Cr}, BOD_5, T-N, T-P, SS and Chl-a were 46.6, 31.2, 34.3, 69.2, 82.8 and 69.1%, respectively. Then, a full-scale experiment was also carried out for the comparison with control site. According to the analysis of results, considerable treatment efficiencies were obtained for COD_{Cr}, BOD_5, T-N, T-P, SS and Chl-a with a high DO concentration because of the micro bubble. Water purification with a micro bubble clarifier is an environment-friendly purification method that can increase the natural purification capacity of natural water systems without the use of treatment facilities and chemicals for removing pollutants.

Keywords: Micro bubble; Eutrophication; Dissolved oxygen; Algae; Water purification

1. Introduction

In rural areas, non-contaminated sources flowing into streams along with sewage from households and livestock farming play a major role in causing eutrophication and an abundance of algae. Dominating rate of streams and reservoirs in Korea are showing such signals, thus making it difficult to maintain water quality. Eutrophication of reservoir leads to oxygen-depleted water in bottom layer, wither of a phytobenthos with algae growth. In order to solve this problem, pre-researches have been conducted on a method of aeration in deep-layer, the obstruction of stratification and algae growth in lake. If aeration supply is sufficient at the bottom layer, reservoirs are needed to improve water purification through removal of organic matter and nutrient at the bottom layer.

Recently, micro bubble clarifier was introduced to the oxygen supply method at the bottom layer. Micro bubbles are tiny bubbles with a few 100 micro sizes in diameter [1]. Micro bubble clarifier has oxidizing power, purifying water by its excellent removal efficiency of suspended solid [2].

*Corresponding author.

Presented at the 5th IWA-ASPIRE Conference, 8–12 September 2013, Daejeon, Korea

In this study, analysed change of DO concentration in water was measured as performance for micro bubble clarifier and removal efficiencies of COD_{Cr}, BOD_5, SS, T-N, T-P, DO and Chlorophyll-a attempts to evaluate the pond purification capacity of micro bubble clarifier.

2. Methods

Pilot plant experiments were conducted in a water tank of approximately 8 m^3. Change of water quality was observed for 5 d after maximum super-saturation by a micro bubble clarifier. Full scale was conducted at the ponds of S University and a Golf Course. The two ponds were each 1,800 and 1,500 m^3 in volume. In the full scale, water samples were collected at the sampling points located in influent, effluent, middle distance and long distance along the length. Table 1 shows the base of the length for each site. In Table 1, middle and long distances were divided with a fixed distance from the effluent. At the pond of S University, the efficiency of water pollutant removal by the clarifier was measured by comparing the comparison group to control group for two months. At the pond of a Golf Course, the removal efficiency was measured by comparing the group with clarifier, operating for 15 d intermittent periods to the group without clarifier, operation over the course of two months. Water samples were measured for Chlorophyll-a, COD_{Cr}, BOD_5, T-N and T-P which can indicate the efficiencies of algae, organic matter and nutrient removal. Water samples were analysed by Standard Methods and water pollution official test method.

2.1. Micro bubble clarifier

M. Sadatomi invented a micro bubble generator with a spherical body in a flowing liquid tube and with a lot of drilled small holes on the tube for gas suction [3]. This study similar to principle of micro bubble clarifier using by pressurizing water and oxygen mixture. Micro bubble clarifier, which is shown in Fig. 1 consists of water entry point and oxygen supply. Micro bubble clarifier process generally has two steps. The first step resolve organic matter into low molecular by mixing water and second step is biodegradation of low molecular by releasing oxidation power until reaching the surface of water.

Table 1
The base of the length about influent, effluent, middle distance and long distance

	A Golf	S University
Influent	–	–
Effluent	0 m	0 m
Middle distance	3 m	2 m
Long distance	5 m	4 m

2.2. Micro bubble size

The analysis of particle size was performed for each pressure level at 1–4 kg_f/cm^2 to set the operating pressure before Pilot plant. FEM-2000 analysed for micro bubble size and number of micro bubbles. Sampling was taken by connected nozzle in micro bubble clarifier.

3. Results and discussion

3.1. Bubble size

To investigate micro bubble size and range, following each pressure, we analysed the bubble size by FEM-2000. It was performed for each pressure level at 1–4 kg_f/cm^2 to set the operating pressure before full-scale experiment. Fig. 2 shows the micro bubble size following each pressure. The result of optimum pressure was determined by 3 kg_f/cm^2. In comparison with the other pressures, bubble size in 3 kg_f/cm^2 pressure was distributed within 10 μm, which similar to micro bubble size. Also, we got DO concentration maintained at 40 mg/L of saturated concentration, when an instrument was operated at 3 kg_f/cm^2. We judged that it would be most proper to operate at 3 kg_f/cm^2 and carry out speculation experiments.

Fig. 1. Micro bubble clarifier.

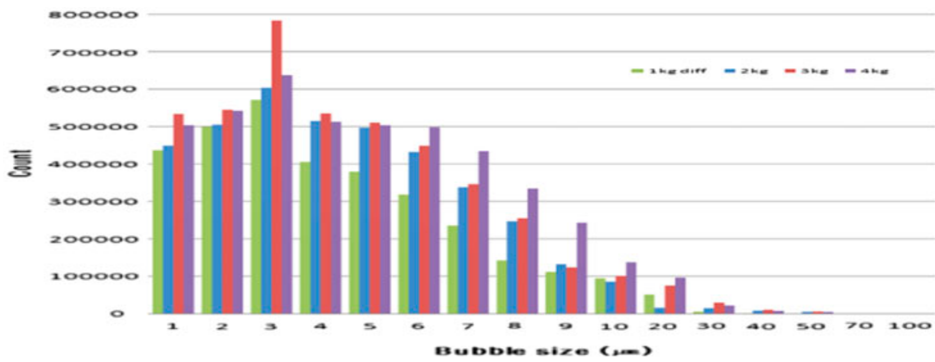

Fig. 2. Bubble size and counts by generator.

3.2. The results of pilot plant

Changes of water quality were observed for 5 d after maximum super-saturation with a micro bubble clarifier. Fig. 3 shows the change of DO at pilot plant for 210 h. The maximum saturated DO concentration rose up to 40 mg/L and DO concentration maintained its super-saturation status to 25 mg/L even 5 d later at the pilot plant. We judge that micro bubble clarifier has considerable oxidative power potential. During operation periods, the removal of organic matter and nutrient were conducted on the experiment at the pilot plant [4].

Fig. 4 shows the change of water quality. Initial concentrations of COD_{Cr}, BOD_5, T-N, T-P, SS and Chlorophyll-a were 26.67, 9.24, 1.66, 0.13, 49.5 and 105.5 mg/L, respectively. After operating for 5 d, measured concentrations were 14.23, 6.35, 1.09, 0.04, 8.5 and 32.5 mg/L, respectively. Total removal efficiencies of COD_{Cr}, BOD_5, T-N, T-P, SS and Chlorophyll-a were 46.6, 31.2, 34.3, 69.2, 82.8 and 69.1%, respectively.

3.3. The results of S University pond

To investigate the removal efficiency of organic matter in micro bubble clarifier, the instrument was operated on elapsed time. The samplings were operating group and control group (no operating group). Figs. 5 and 6 show that COD_{Cr} and BOD_5 concentrations compare each distance to control. In operating site, initial concentrations of COD_{Cr} were 91.1, 80.8, 71.2 and 64.3 mg/L for influent, effluent, middle distance and long distance, respectively. After operating, individual concentrations were 38.3, 35, 31.1 and 26.2 mg/L Following that, the initial concentrations of BOD_5 were 7.46, 7.32, 7.16 and 7.08 mg/L following influent, effluent, middle distance and long distance. After operating, the results were 4.32, 4.21, 4.1 and 3.92 mg/L. Removal efficiencies of COD_{Cr} were 60.5, 57.3, 56 and 58.9% and removal efficiencies of BOD_5 were 41.7, 42.3, 41.6 and 43.3%, respectively. Consequentially, effluent concentration was lower than initial concentration. In case of the control group, as time passes, its show that the concentration of COD_{Cr} and BOD_5 rose up. For that reason, stream-breeding with increasing temperature causes a growth of organic matter.

Figs. 7 and 8 show that T-N and T-P of operating group and control group were measured for the efficiency of nutrient as per time in micro bubble clarifier. In operating site, initial concentrations of T-N were 4.75, 4.42, 4.31 and 4.18 mg/L, respectively, following

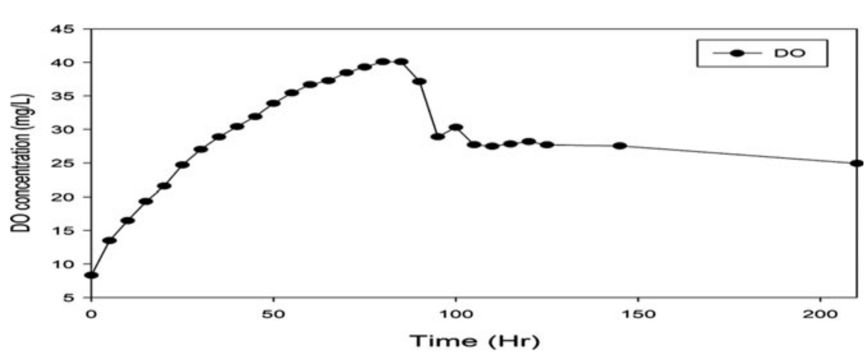

Fig. 3. DO concentration during operation periods.

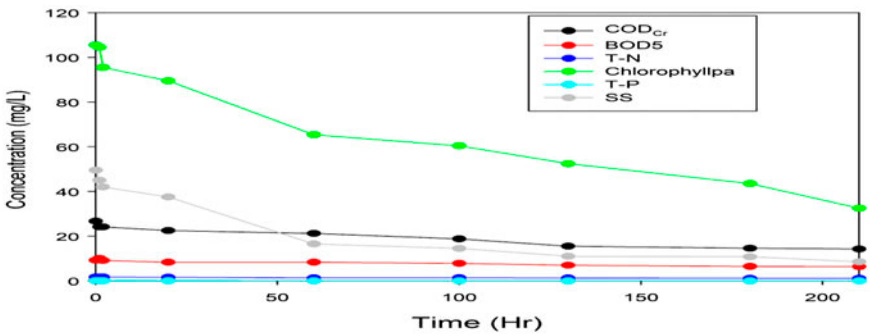

Fig. 4. COD_{Cr}, BOD_5, T-N, T-P, SS, Chl-a concentration during operation periods.

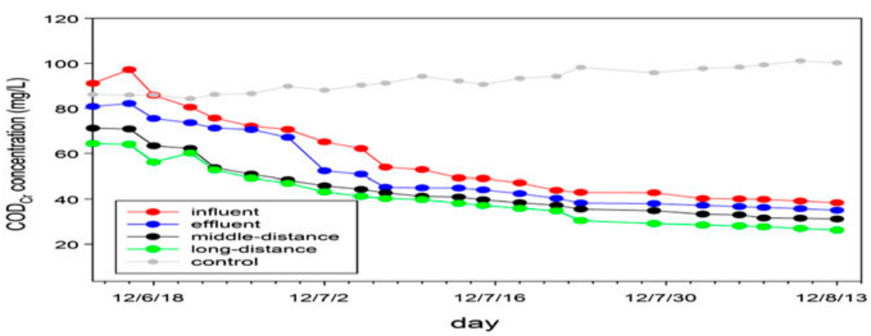

Fig. 5. Comparison of COD_{Cr} concentration with each distance and control.

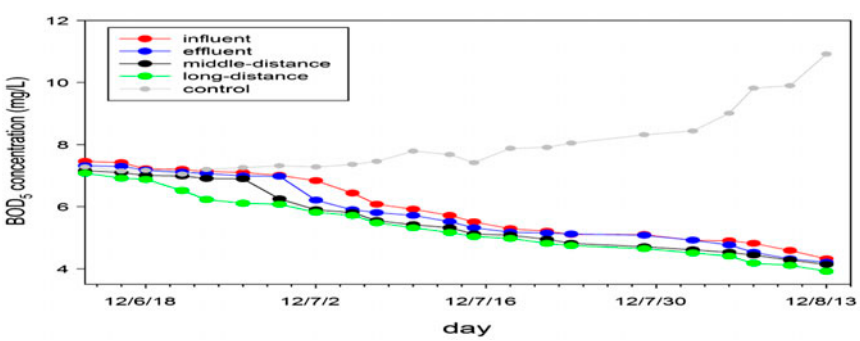

Fig. 6. Comparison of BOD_5 concentration with each distance and control.

influent, effluent, middle distance and long distance. After operating, individual concentrations were 3.25, 3.12, 3.19, 2.82 mg/L and initial concentrations of T-P were 0.23, 0.22, 0.21 and 0.2 mg/L along influent, effluent, middle distance and long distance. After operating, individual concentrations were 0.12, 0.12, 0.11 and 0.11 mg/L, respectively, according to distance. Consequently, removal efficiencies of T-N were 30.1, 29, 25.4, 30.1% and removal efficiencies of T-P were 42.8, 42.8, 47.6 and 42.1%, respectively. The removal efficiency of T-P was higher than the removal efficiency of T-N. The reason was that T-P particles were floated to the surface of the water with micro bubble which adsorbed the suspended solids [5].

Figs. 9 and 10 show that initial concentrations of SS were 307.67, 264.21, 231.24 and 208.32 mg/L following influent, effluent, middle distance and long distance. Initial concentrations of Chlorophyll-a were 150.43, 148.78, 130.73 and 114.3 mg/L according to influent, effluent, middle distance and long distance. As removal efficiencies, SS were 52.9, 48.9, 49.3, 47.8% and Chl-a were 14.6, 42.8, 46.2, 47.4%, respectively,

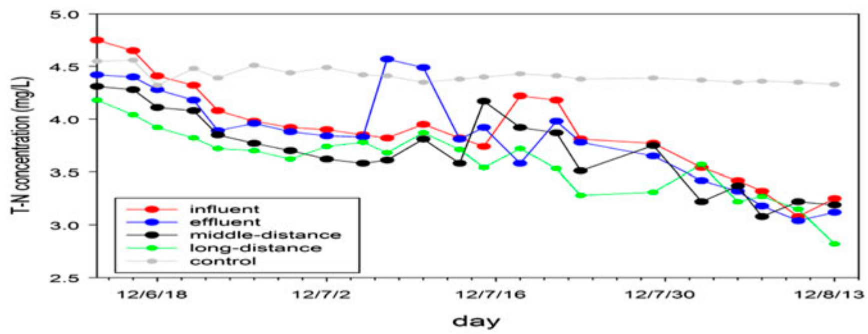

Fig. 7. Comparison of T-N concentration with each distance and control.

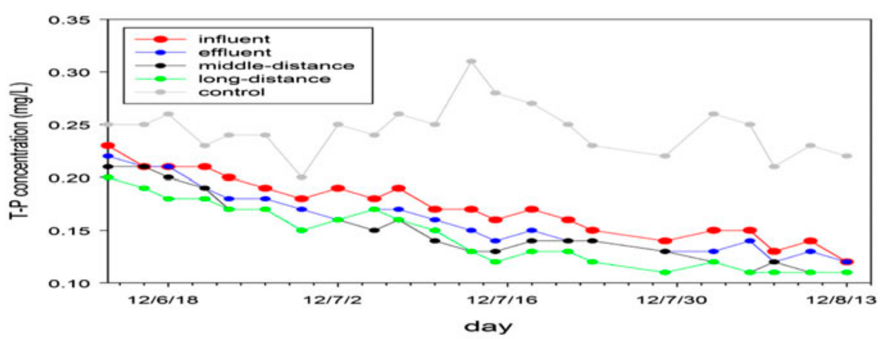

Fig. 8. Comparison of T-P concentration with each distance and control.

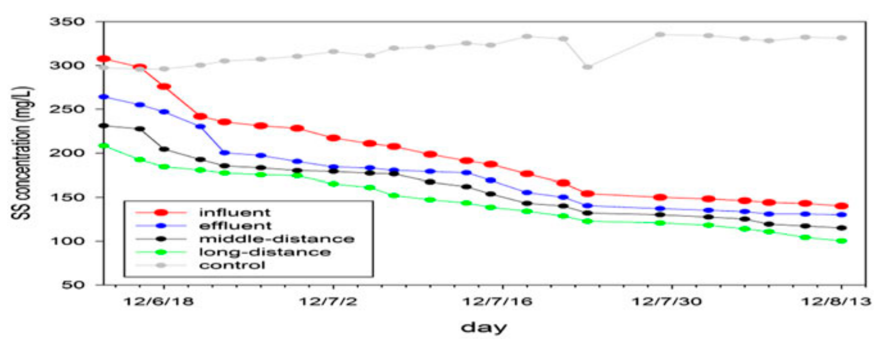

Fig. 9. Comparison of SS concentration with each distance and control.

according to the distance. SS was removed by floatation with adsorption between suspended solid taking on positive and bubble taking on negative charge [6]. Table 2 summarize the result of pond in S University about each site.

3.4. The results of a Golf pond

Total volume of pond is 1,500 m^3 and total efficiency was compared after maximum super-saturation for two months. The difference from operating S University pond was as follows: After stopping operation for 15 d from 9 November to 23 November, we were confirmed how to treat pollutant matter if micro bubble clarifier restarted operating [7] and sampling site were influent, effluent, middle distance and long distance like S University sampling.

Figs. 11 and 12 show the change of analysed COD_{Cr}, BOD_5. Initial concentrations of COD_{Cr} were 55.29, 45.88, 60 and 52.94 mg/L for influent, effluent, middle distance and long distance. After operating, individual concentrations were 24.5, 18.2, 19.2 and

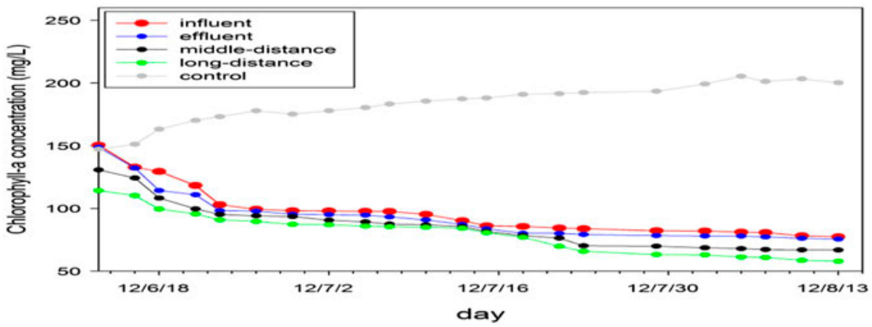

Fig. 10. Comparison of Chlorophyll-a concentration with each distance and control.

Table 2
The result of S University pond about influent, effluent, middle distance and long distance

	COD_{Cr}	BOD_5	T-N	T-P	SS	Chlorophyll-a
Influent	40–97(60.5)	4.9–7.5(41.7)	3.5–4.8(30.1)	0.1–0.2(42.8)	148–308(52.9)	82–150(14.6)
Effluent	37–82(57.3)	4.9–7.3(42.3)	3.4–4.6(29)	0.1–0.2(42.8)	135–264(48.9)	78–149(42.8)
Middle distance	33–71(56)	4.6–7.2(41.6)	3.2–4.3(25.4)	0.1–0.2(47.6)	128–231(49.3)	69–131(46.2)
Long distance	29–64(58.9)	4.5–7.1(43.3)	3.3–4.2(30.1)	0.1–0.2(42.1)	118–208(47.8)	63–114(47.4)

Note: Minimum–maximum: concentration, mg/L, (): removal efficiency, %.

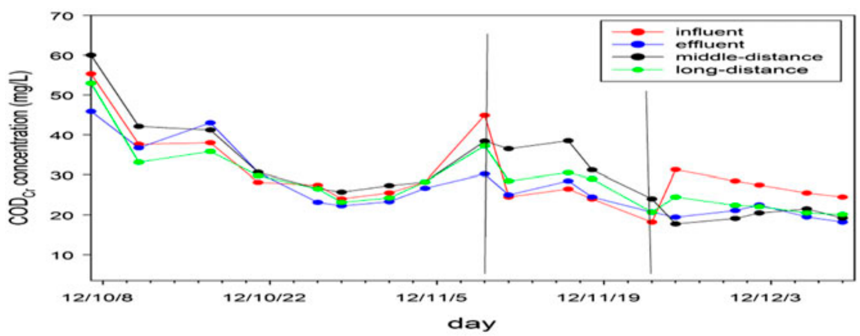

Fig. 11. Comparison of COD_{Cr} concentration along each site.

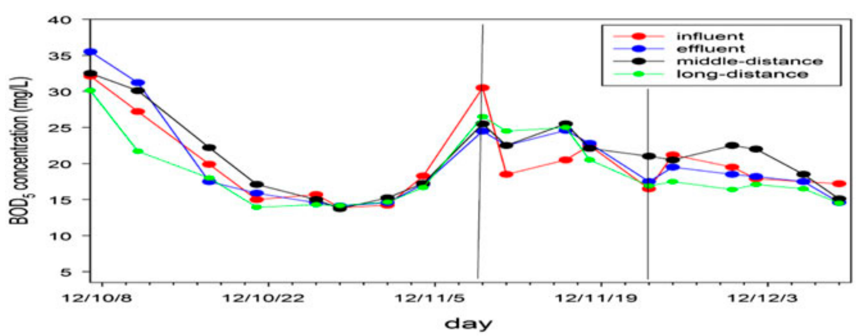

Fig. 12. Comparison of BOD_5 concentration along each site.

20.1 mg/L. Following that, initial concentrations of BOD_5 were 32.12, 35.5, 32.5 and 30.12 mg/L following influent, effluent, middle distance and long distance. After operating, the results were 17.2, 14.6, 15.1 and 14.5 mg/L. The removal efficiencies of COD_{Cr} were 55.6, 60.3, 68 and 62% and removal efficiencies of BOD_5 were 46.4, 58.8, 53.5 and 51.8%. Consequentially, in intermittent operating, concentrations of COD_{Cr} and BOD_5 rose up. We judge that it has not effect on the removal of organic matter when micro bubble clarifier not operated.

Figs. 13 and 14 were the change of T-N and T-P. Initial concentrations of T-N were 2.26, 2.81, 3.31 and 3.92 mg/L along the influent, effluent, middle distance and long distance. After operating intermittent, its concentration of intermittent results were 1.65, 1.84, 2.42 and 1.95 mg/L. So, the removal efficiencies of T-N were 26.9, 34.5, 26.8 and 50% and the removal efficiency of T-P were 57.2, 46.4, 46.9 and 54.8%, respectively. T-N removal was directly related to operating micro bubble clarifier, but the results of experiment show the difference between operating and

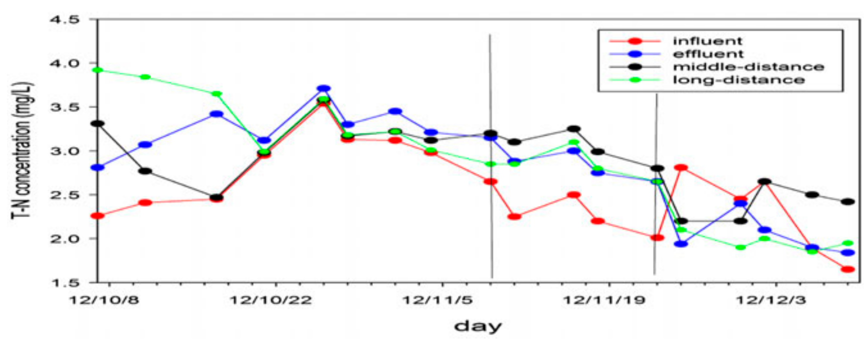

Fig. 13. Comparison of T-N concentration along each site.

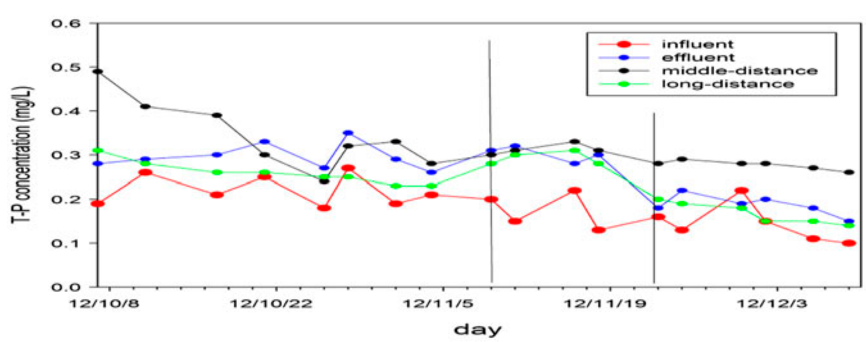

Fig. 14. Comparison of T-P concentration along each site.

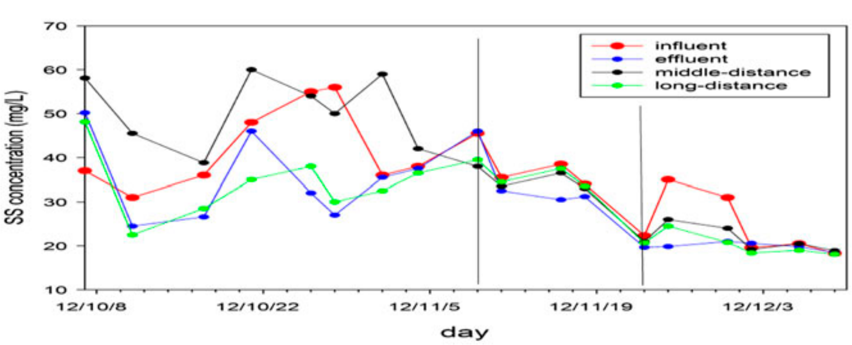

Fig. 15. Comparison of SS concentration along each site.

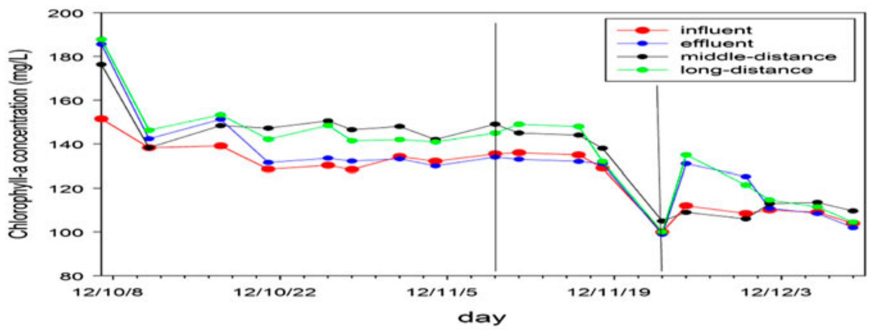

Fig. 16. Comparison of Chlorophyll-a concentration along each site.

Table 3
The result of a Golf pond about influent, effluent, middle distance and long distance

	COD_{Cr}	BOD_5	T-N	T-P	SS	Chlorophyll-a
Influent	18–55(55.6)	14–32(46.4)	1.7–3.5(26.9)	0.1–0.3(57.2)	18–56(50.5)	104–152(31.3)
Effluent	18–46(60.3)	14–36(58.8)	1.8–3.5(34.5)	0.1–0.4(46.4)	19–50(63)	99–186(45)
Middle distance	18–60(68)	14–33(53.5)	2.2–3.6(26.8)	0.3–0.5(46.9)	19–59(67.4)	105–176(37.8)
Long distance	20–53(62)	14–30(51.8)	1.9–3.9(50)	0.1–0.3(54.8)	18–48(62.3)	100–188(44.6)

Note: Minimum–maximum: concentration, mg/L, (): removal efficiency, %.

intermittent. During intermittent, concentration of nutrient was no change and for operating, treatment efficiency was better than concentration of influent. Consequentially, T-P removal effects cause floatation with SS under the operating micro bubble clarifier [8].

Figs. 15 and 16 the change of SS, Chl-a concentrations are observed. Initial concentrations of SS were 37, 50.2, 58.1 and 48.1 mg/L following influent, effluent, middle distance, and long distance. Chlorophyll-a initial concentrations were 151.5, 185.6, 176.3 and 187.8 mg/L according to influent, effluent, middle distance, and long distance. As removal efficiencies, SS were 50.5, 63, 67.4, 62.3% and Chl-a were 31.3, 45, 37.8, 44.6% according to the distance. SS was removed by flotation with adsorption between SS taking on positive and bubble taking on negative charge. And in intermittent period, SS and Chl-a were unremoved. On the other hand, they were removed for operating [9]. Table 3 was summarized of the result of pond in a Golf about each site.

4. Conclusions

We investigated the operating parameters and removal efficiency of micro bubble clarifier for the evaluation of pond purification capacity. Through the analysis of micro bubble size by operating pressure of clarifier, optimum pressure of $3\,kg_f/cm^3$ was determined due to the high DO concentration of 40 mg/L, which is generated from smaller bubble than 10 μm [10]. In pilot plant, the removal efficiencies of COD_{Cr}, BOD_5, T-N, T-P, SS and Chl-a were 46.6, 31.2, 34.3, 69.2, 82.8 and 69.1%, respectively. In full scale experiments of S University and a golf pond, many sites were selected for sampling by the distance from micro bubble clarifier. Overall removal efficiency of pollutants was almost like pilot plant results with only micro bubble clarifier. Organics like BOD_5, COD_{Cr} were removed by flotation, in case of suspended and colloidal particle and then by biodegradation in case of dissolved constituents. SS and Chl-a were removed by flotation and enmeshment with rising bubble. Nutrients are the most limiting substrate in natural pond because of the eutrophication. T-P was removed with SS by sorption mechanism. T-N was also removed with other pollutants with same mechanism like flotation and biodegradation. But, the most important mechanism for T-N removal is nitrification/denitrification reaction. Nitrification is the biological oxidation of ammonia to nitrate with DO concentration, so it was very easy in high DO concentration with micro bubble in pond. And then denitrification was generated in anaerobic zone in pond, which is called simultaneously nitrification/denitrification mechanism. In this experiment, it was found that micro bubble clarifier is a natural, environment friendly and on-site treatment technology for water purification without treatment facility and added chemical.

References

[1] F. Matsuyama, S. Kanazawa, M. Sadatomi, A. Kawahara, K. Kano, Optimum design of a new microbubble generator and its applications to industries, Prog. Multiphase Flow Res. 1 (2006) 25–32.

[2] H. Ohnari, Fisheries experiments of cultivated shells using micro-bubbles technique, J. Heat Transfer Soc. Jpn. 40 (2001) 2–7.

[3] M. Sadatomi, A Kawahara, Fluids Mixer and Fluids Mixing Method, Japanese Patent, 2008.

[4] R.T. Rodrigues, J. Rubio, DAF-dissolved air flotation: Potential applications in the mining and mineral processing industry, Int. J. Miner. Process. 82 (2007) 1–13.

[5] G.C. Lee, Characteristics of Phosphorus Removal in Treated Sewage using Micro bubble Flotation System, MA thesis, Department of Environmental Engineering Graduate School, University of Seoul, Republic of Korea, 2011.

[6] M.R. Teixeira, Comparing dissolved air flotation and conventional sedimentation to remove cyanobacterial cells of *Microcystic aeruginosa*: Part I: The key operating conditions, Sep. Purif. Technol. 52 (2007) 84–94.

[7] T. Pichler, R. Brinkmann, G.I. Scarzella, Arsenic abundance and variation in golf course lakes, Sci. Total Environ. 394 (2008) 313–320.

[8] E.N. Peleka, K.A. Matis, Application of flotation as a pretreatment process during desalination, Desalination 222 (2008) 1–8.

[9] V. Sarrot, Z. Huang, D. Legendre, P. Guiraud, Experimental determination of particles capture efficiency in flotation, Chem. Eng. Sci. 62 (2007) 7359–7369.

[10] M. Sadatomi, A. Kawahara, H. Matsuura, S. Shikatani, Micro-bubble generation rate and bubble dissolution rate into water by a simple multi-fluid mixer with orifice and porous tube, Exp. Therm. Fluid Sci. 41 (2012) 23–30.