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Reduction of phosphorous at WWTP combined with DAF and A2/O

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ABSTRACT

Regulation of the phosphorous (P) concentration in effluent from the Jinju wastewater treatment plant (WWTP) in southern part of Korea has recently been strengthened, with a reduction in the acceptable P limit from 2.0 to 0.2 mg/L. Various treatment processes have been introduced and applied to meet the regulation, after use of biological treatments such as conventional activated sludge, anoxic–oxic (A/O), and anaerobic–anoxic–oxic (A2/O) treatments. The present work introduces a hybrid system of A2/O and dissolved air flotation (DAF) treatment to remove P from the effluent. The total capacity of the WWTP is 190,000 m^3/d. The dimensions of the DAF basins are 8 m (width), 16 m (length), 4.2 m (height), 6 basins, and the capacity is 2,995 m^3/d. The retention time and recycling ratio are 19 min and 15%, respectively. The surface loading rate is 240 m/d. Operation of the system with A2/O+DAF has already commenced and total P was reduced from 2.18 to 0.03 mg/L. A2/O+DAF treatment improved the mean effluent concentrations of total phosphorus, chemical oxygen demand, and suspended solids by approximately 70, 29, and 27%, respectively, compared with the corresponding levels in effluent after A2/O treatment alone.

Keywords: Coagulation; Dissolved air flotation; Phosphorous removal

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1. Introduction

The regulation limiting discharge from a wastewater treatment plant (WWTP) into a river basin has recently been strengthened after significant renovations, eco-friendly, near four major rivers in Korea. The phosphorous (P) removal from effluent has increased tenfold from 2.0 to 0.2 mg/L, as shown in Table 1. Many WWTPs have established facilities to reduce P discharge to meet the new regulation. Most of them use physicochemical treatment processes, such as conventional flocculation–sedimentation, dissolved air flotation (DAF), and P adsorption. DAF offers

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Table 1
New regulation of discharge from WWTPs (mg/L)

Date	BOD mg/L	COD mg/L	SS mg/L	TN mg/L	TP mg/L
Before Jan 2012	<10	<40	<10	<20	<2.0
After Jan 2012	<5	<20	<10	<20	<0.2

many advantages, including a high efficiency to remove P within a small area and a short retention time. In recent years, DAF basins have been used to reduce P after treatment of effluent by conventional activated sludge in >30% of WWTPs in South Korea.

Regarding P removal, the conventional activated sludge process has been improved by the use of anoxic–oxic (A/O) or anaerobic–anoxic–oxic (A2/O) treatments. Enhanced biological phosphorous removal (EBPR) had been used in many plants for its efficiency [1]. If EBPR is combined with coagulation/flocculation, sedimentation and filtration, then the concentration of P in effluent could be reduced to 0.07–0.1 mg/L [2]. Where there is insufficient readily biodegradable chemical oxygen demand (rbCOD) or biochemical oxygen demand (BOD) in the influent wastewater, chemical addition is necessary to ensure sufficient P removal. Efficient concentrations of ferric coagulant are achieved at a Fe/P molar ratio of 0.2 [3]. In case of the use of membrane technology to reduce P, a membrane bioreactor (MBR) and reverse osmosis (RO) are useful to remove P (about 0.1 mg/L in an MBR and 0.008 mg/L in an RO system) [4]. Lee [5] reported that the microbubble system could attain 97% P removal, if combined with A2/O. He also reported achieving 85% P removal when the bubble flotation was combined with MBR effluent.

In this study, DAF performance was examined in the process of A2/O+DAF to reduce P in the effluent of the Jinju WWTP. Treatability orders of A2/O+DAF divided by A2/O were introduced as the ratio of effectiveness (RE) to evaluate the efficiency of treatment on water quality. Furthermore, correlations between other factors such as chemical oxygen demand (COD), total nitrogen (TN) and suspended solids (SS) were analyzed for March and August.

2. Methods

2.1. Renovation to new A2/O+DAF plant in Jinju WWTP

At the Jinju WWTP, its A2/O process was renovated in 2011, with implementation of DAF as a final process (Fig. 1). A2/O+DAF comprised six basins: anaerobic, anoxic, and oxic reactors, a secondary clarifier, and flocculation and flotation basins. Poly aluminum chloride was used for coagulation of P and residuals in flash mixing before DAF basin. Each basin size and retention times are tabulated in Table 2.

2.2. Evaluation of A2/O and A2/O+DAF on March and August

The average temperatures in the Jinju region were 25℃ on August 2011 and 6℃ on March 2012 (March) Table 3. The temperature on August was four times higher than that on March, while the rainfall on August was five times higher than that on March.

The samples of raw water, A2/O and A2/O+DAF effluents were taken for analysis of BOD, COD, SS, TN, and total phosphorus (TP) on March and August. The raw water was introduced to the A2/O reactor after pre-aeration and the primary settling process. The A2/O and A2/O+DAF processes were evaluated after operation in both seasons.

$$\frac{(\mathrm{A2/O + DAF})(\mathrm{mg/L})}{\mathrm{A2/O(mg/L)}} = \mathrm{RE} \tag{1}$$

The RE factor in Eq. (1) was introduced to evaluate the effect of treatment on water quality between A2/O and A2/O+DAF. An RE value of <1.0 means that the A2/O+DAF reactor works effectively. When the RE is >1.0, the DAF reactor is ineffective to reduce the pollutants. The results of treated water quality by A2/O and A2/O+DAF on March and August were compared through removal characteristics among other factors such as COD/TN, TP, and SS.

3. Results and discussion

3.1. Pollutant removal before and after A2/O+DAF operation

Fig. 2 shows BOD, COD, SS, and TP removal levels after A2/O+DAF in August. Influent introduced to A2/O had the following pollutant concentrations: average BOD of 67.0 mg/L, COD, 42.7 mg/L, SS, 154.9 mg/L, TN, 17.7 mg/L, and TP, 2.18 mg/L. Removal of TP from influent after the process was about 99%, SS 99%, and COD 96%.

On March and August, TP concentrations of effluent after A2/O and A2/O+DAF were compared with the concentration in raw water (Fig. 3). The TP concentration after operation with DAF decreased from 2.6 to 0.03 mg/L in August and from 2.9 to 0.2 mg/L on March.

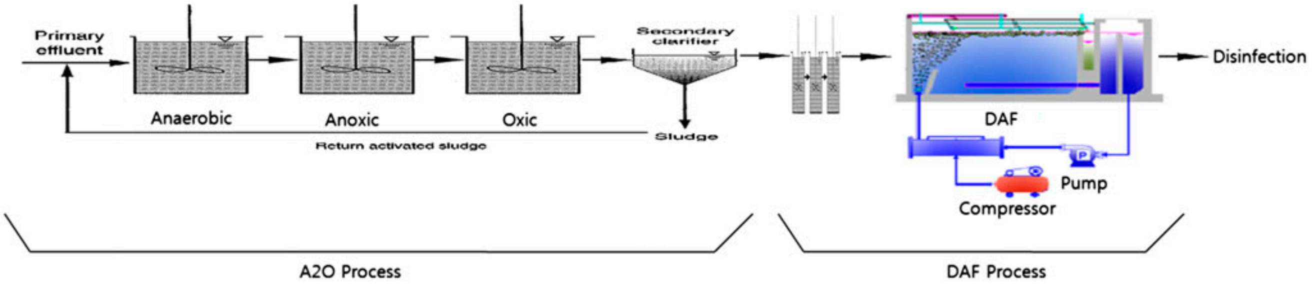

Fig. 1. Schematic diagram of hybrid A2/O and DAF treatment.

Table 2
Design factors in terms of size and retention time at each basin of DAF system

Basin	Size	Retention time (min)
Flash mixing	W 3.0 m × L 2.5 m × H 4.4 m × 6 basins	1.3
Flocculation	W 8.0 m × L 4.5 m × H 7.4 m × 6 basins	11
DAF	W 8.0 m × L 16.0 m × H 4.2 m × 6 basins	19 (recycle ratio 15%)

Table 3
Average temperature and accumulated rainfall on March 2012 and August 2011, Jinju region

Month	Average temperature (℃)	Accumulated rainfall (mm)
March 2012	6	51
August 2011	25	274

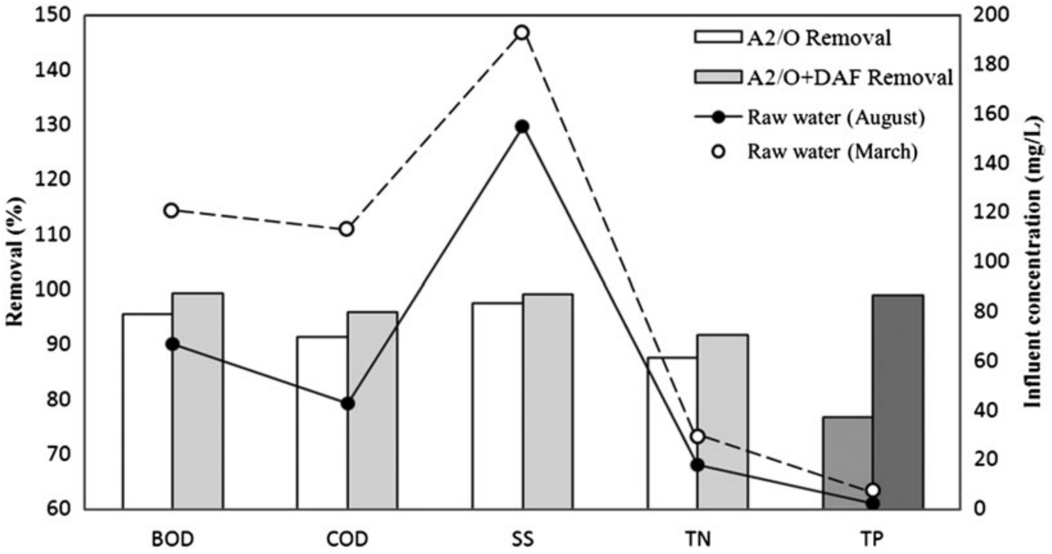

Fig. 2. Removals between raw water and A2/O, A2/O+DAF effluent in WWTP.

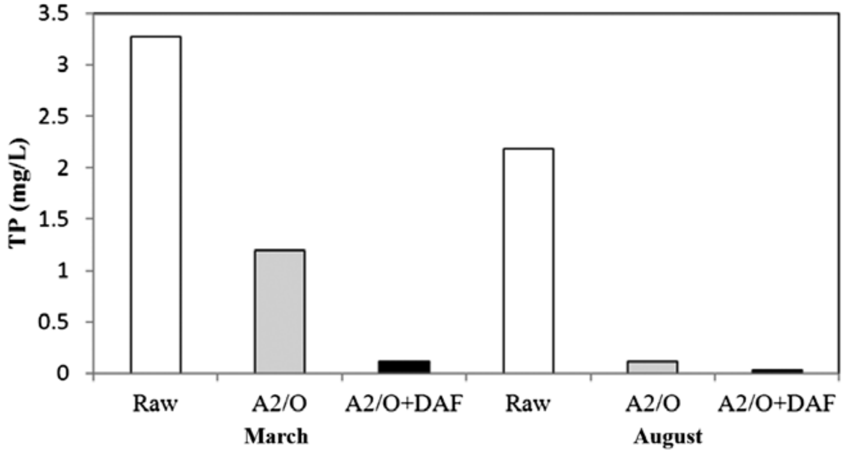

Fig. 3. TP concentration of effluent from A2/O and A2/O+DAF.

On August, TP was reduced to 0.12 mg/L by the A2/O process, which meets the limit. However, TP showed a minimum level of 1.2 mg/L on March after A2/O. With the DAF process, it could be reduced to 0.2 mg/L on March. The phosphorus removal efficiency depends on temperature [6,7]. TP removed from A2/O was above water quality standard on March whereas TP removal from A2/O+DAF met the standard on March. This means that DAF is effective for the reduction of TP at low temperature.

The TP concentration in the effluent was partly affected by suspended solid concentration. As precipitation of sludge in sedimentation basin was not properly processed at low temperature, suspended solid containing TP was coagulated and reduced by DAF process. At 3–6% P in the solids, the P contribution in an effluent having an SS concentration of 10 mg/L would be 0.3–0.6 mg/L values that are significant if the effluent standard is <1.0 mg/L of P [8]. When the metabolism was not active on March, a recycled stream from a sludge thickening or digestion process might result in the effluent containing a high P concentration. If the influent had a low rbCOD concentration, it hindered the production of volatile fatty acids (VFAs) and high concentration of P could release in effluent. Coagulation is important to remove the soluble P as well as biomass. If the metabolism on March was enhanced, to absorb P into biomass, it was possible to provide an exogenous carbon source in the reactor. In this study, carbon source was not used to alter the metabolism in the DAF process.

Table 4 shows TP removal after A2/O and A2/O+DAF. The average TP concentrations of influents on March and August were 3.27 and 2.18 mg/L, respectively. After exposure to an A2/O basin, they decreased to 1.2 and 0.12 mg/L, respectively. On March, the concentration of P in the effluent was still six times greater than that stipulated by the new regulation. However, the effluent on August could meet the new regulation. The results showed that a TP concentration reduction from A2/O+DAF could satisfy the new regulation in both seasons.

When DAF is operated on March, the total volume of air released from the saturator increases at the lower temperature. According to the solubility of air in water, the dissolved air concentration increases by a little more than 46% as the temperature decreases by 20˚C as shown in Table 5 [9]. $R_{\mathrm{sat}.T}$ means the ratio of maximum solubility at T degree over solubility at T degree. It means that 46% of bubbles could be saturated and more were released on March than on August.

Table 4
Comparison of conditions and TP removal in A2/O and A2/O+DAF

	Raw water		After A2/O		After A2/O+DAF	
Season	March	August	March	August	March	August
Avg. temp. (˚C)	6	25	6	25	6	25
Avg. TP (mg/L)	3.27	2.18	1.2	0.12	0.2	0.03

Table 5
Solubility of air in water (based on data from Edzwald, 2007)

Temp (℃)	C_{air} (mg/L)	$R_{sat.T}$
5	31.8	0.0
10	28.6	11.2
15	25.9	22.8
20	23.7	34.2
25	21.7	46.5

$R_{sat.T} = (C_5 - C_t)/C_t \times 100$ (%).
C_{air} : Solubility of air at T.
C_5 : Solubility of air at 5℃.
C_t : Solubility of air at T℃.

3.2. COD/TN vs TP

The correlations between COD/TN and TP after A2/O+DAF on August and March are shown in Fig. 4. On August, the TP concentration was reduced to 0.02~0.1 mg/L, while that of COD/TN was reduced to 1–2.5 mg/L. However, on March, TP concentration increased to 0.14–0.3 mg/L, while that of COD/TN decreased to 0.4–0.7 mg/L.

This was because TN decreased 3% on March while it increased 3% on August due to active metabolism for temperature. When biological decomposition was active on August, TP and TN of effluent could be reduced along with its performance. COD/TN increases as TN and TP decreases on August, vice versa on March. If A COD/TN ratio is greater than 3, it is essential to sustain high nitrogen removal efficiency in advanced treatment [10]. Table 6 shows that A2/O+DAF is effective to reduce P at low temperature rather than at high temperature.

3.3. Suspended solid vs. TP

Temperature also influenced gas transfer rates as well as the settling of biological solids. Active metabolism influenced the growth of micro-organisms, related to biomass concentration in the treatment reactor. Volatile suspended solid (VSS), in a reactor consisted of more than active biomass at high temperature. DAF could reduce VSS as biomass produced in the process was active. Regarding removal characteristics by DAF between SS and TP, reduction ratio of TP at low temperature was greater than that at high temperature. Fig. 5 shows that effluent SS were in the range 0.45–8.2 mg/L after A2/O and A2/O+DAF on August, although the P concentration was as low as <0.3 mg/L. DAF was effective in removing SS in the final process on March. SS showed two trends of low and high P concentration in both seasons because that on March could not be decomposed actively unlike on August. SS from A2/O increased to 6.6–13.7 mg/L, of which P was 0.5–2.6 mg/L. After the A2/O+DAF process, SS were 2.0–6.0 mg/L, while P was 0.1–0.27 mg/L. The performance of A2/O+DAF was twice that of A2/O in terms of P removal on March. The SS amount was a critical factor in deciding on a DAF system to reduce P.

3.4. A2/O vs. A2/O+DAF

Fig. 6 shows that concentrations of P and SS in effluent were compared after A2/O and A2/O+DAF on March and August. After A2/O, on March, P was 0.4–1.0 mg/L and after A2/O+DAF, on August, P was 0.1–0.3 mg/L. After A2/O, in March, SS were 6.2–12.4 mg/L and after A2/O+DAF, on August, SS were 0.7–5.7 mg/L. P removal after A2/O+DAF on March was

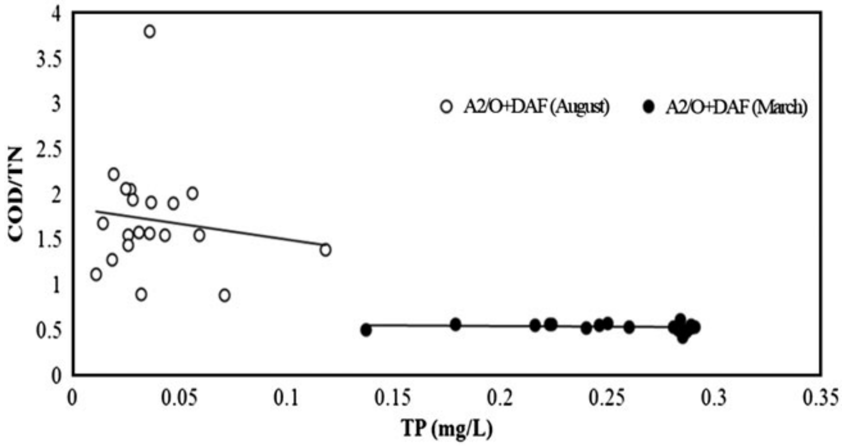

Fig. 4. Correlation between COD/TN and TP in A2/O+DAF on March and August.

Table 6
Average concentration of raw water, A2/O and A2/O+DAF on March and August

	Raw water		After A2/O		After A2/O+DAF	
Factors (mg/L)	March	August	March	August	March	August
BOD	121.1	67.0	8.2	1.7	3.3	0.7
COD	115.5	42.7	13.3	5.5	9.9	3.9
SS	193.3	154.9	9.0	4.1	4.1	2.9
T-N	31.3	17.8	19.0	2.4	18.4	2.5
T-P	3.3	2.2	1.16	0.1	0.24	0.03

Table 7
Ratio of effectiveness (RE) factors on March and August

Average	BOD	COD	SS	TN	TP
RE (March)	0.39	0.74	0.45	0.97	0.24
RE (August)	0.41	0.72	0.73	1.04	0.30

improved 4.5 times when compared with A2/O effluent. On March, characteristics of SS removal were similar to those of P removal (see Fig. 6). The P concentration also decreased when it was coagulated with poly aluminum chloride and removed on the surface by microbubble. At this moment residual SS and P were coagulated and collected by DAF efficiently. The metabolism was not fully active. P release could occur in an anaerobic basin. To reduce the release of P, an additional carbon source, such as acetate, could be provided to produce VFAs to activate metabolism. Then soluble P could be accumulated in biomass.

If P is released from the anaerobic basin, it can be removed by a coagulation process combined with DAF. Soluble P could be released in an anaerobic process and could be coagulated in a flocculation basin, after which it is floated and removed by DAF. It has been reported that sludge at WWTPs, where biological P removal is used, contains 4.5% P by dry weight compared with 1.5% P for flocs that use chemicals [11]. On August, even though bubble volume concentration was low, DAF played a role in the removal of biomass. On March, if soluble P is released from an anaerobic basin with biomass, DAF could remove the P coagulated in flotation basin easily. This is because the saturated bubble volume in pressurized water increased.

3.5. TP removal for A2/O and A2/O+DAF on August

Fig. 7 shows the TP removal by A2/O and A2/O+DAF on August. A2/O+DAF improved TP removal from an average of 55 to 91%. When it comes to TP removal on August, A2/O and A2/O+DAF satisfied, as shown in Fig. 3, water quality regulation of TP. A2/O and A2/O+DAF results were 0.1 and 0.03 mg/L, respectively. It means that A2/O+DAF showed

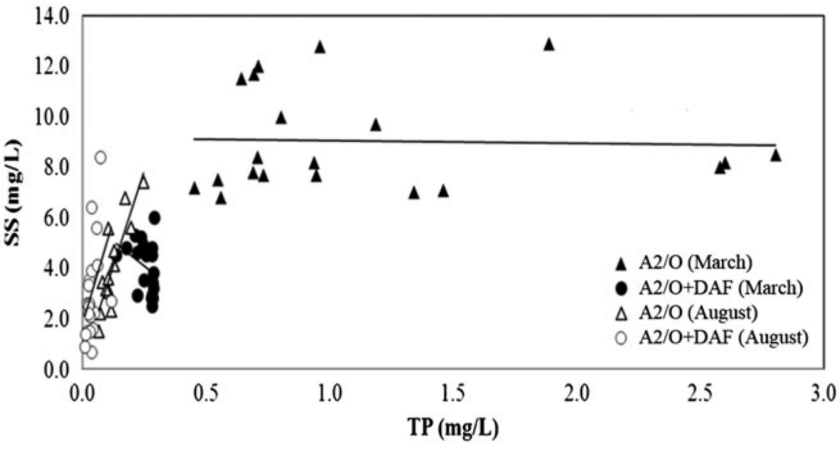

Fig. 5. A2/O and A2/O+DAF performance of TP vs. SS.

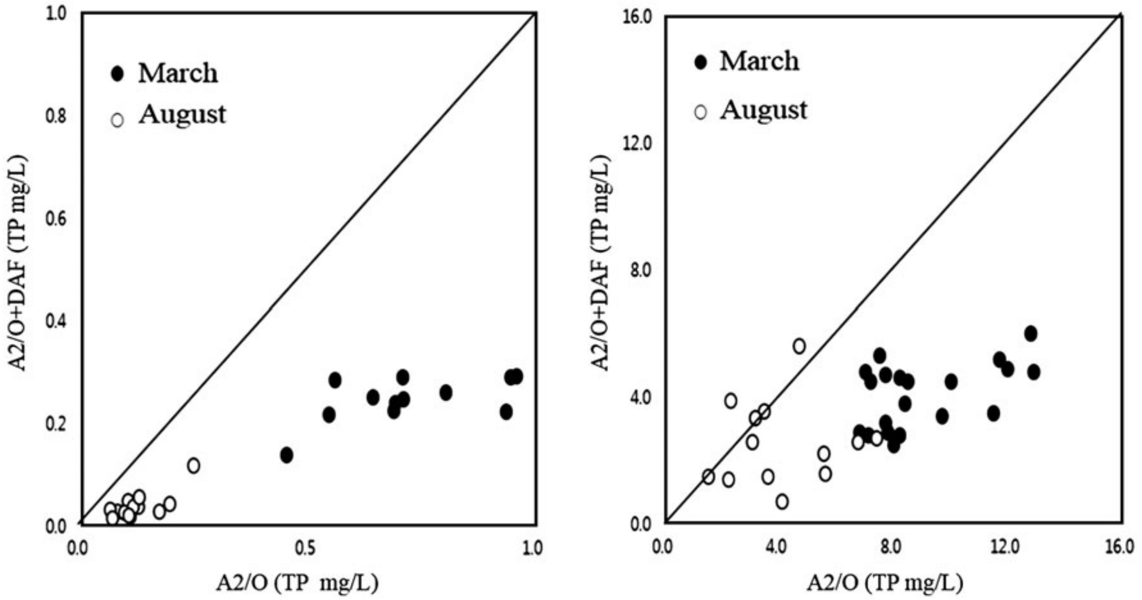

Fig. 6. Comparison of A2/O and A2/O+DAF performance for removal of TP and SS.

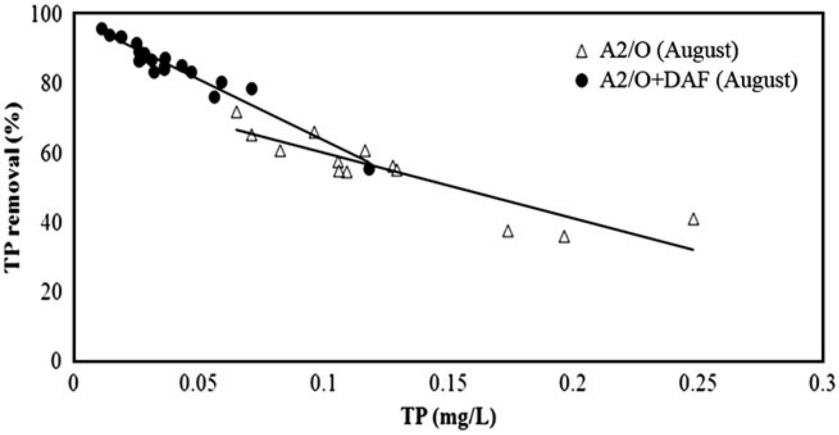

Fig. 7. TP removal by A2/O and A2/O+DAF on August.

efficiency over 70% when compared with A2/O even at high temperature. However, in order to satisfy water quality regulation of TP on March, A2/O+DAF could obtain results lower than 0.2 mg/L whereas A2/O could not obtain.

Using the DAF process, Ross [12] showed very good TSS and BOD removals (>98%), total Kjehldahl nitrogen removal, including NH_3–N (average 86.2%) and TP removal (98.8%), to yield a final effluent TP concentration of 1 mg/L (average) from an influent with 80 mg/L TP. Elder [13] reported that the use of DAF, in conjunction with chemical coagulants and flocculants, could offer 95% P removal.

In this study, the RE factor was calculated for evaluation of treatability. The RE equals the effluent concentration of A2/O+DAF divided by that of A2/O. When the RE factor is <1.0, it means that the A2/O+DAF reactor works well. Because the RE factor was >1.0 here, the A2/O reactor alone was sufficient to reduce the pollutants. Table 7 shows RE factors, on March and August, for BOD, COD, SS, TN, and TP.

The following order is evident: 0<TP<BOD<SS<-COD<TN<1.0. This means that effective TP removal was achieved in the A2/O+DAF reactor, but TN removal was ineffective in the DAF reactor.

4. Conclusions

Performances of the A2/O and A2/O+DAF systems were evaluated in terms of reducing COD, TN, and TP during August and March at a WWTP in Jinju. After DAF, the TP concentration decreased from 2.18 to 0.03 mg/L on August and from 3.27 to 0.2 mg/L on March. On August, TP was reduced to 0.12 mg/L by the A2/O process, a value that satisfies the new regulation. However, on March, the minimum level after A2/O was 1.2 mg/L. After additional DAF, it could be decreased further, to 0.2 mg/L on March. This means that DAF is more effective in reducing TP at low temperature than at high temperature. In particular, DAF could remove SS and TP on March. Treatability was evaluated by using RE. Values for the RE factor show the following A2/O+DAF treatability order as TP>BOD>SS>-COD>TN RE factor. If RE factor is less than 1.0, it means that A2/O+DAF reactor works better than A2/O. A2/O+DAF plays an important role in reducing TP and SS on March, even though it is not so effective on August.

Acknowledgments

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