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Design and application of a high-rate dissolved air floatation process in a drinking water treatment plant: A field study for turbidity and algae removal

정수처리장 고속 용존공기부상공정의 설계 및 적용: 탁도 및 조류 제거를 위한 현장연구

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ABSTRACT

A high-rate dissolved air flotation (DAF) process, with a surface loading rate of 20-40 $m^3/m^2/h$, was introduced at the Y-Drinking Water Treatment Plant in South Korea. First, the DAF and granular activated carbon (GAC) processes were combined in the reactor, and the pilot plant was operated at 500 m^3/day. The results from these tests demonstrated that there were significant decreases in turbidity, algae, geosmin, and 2-methylisoborneol (2-MIB) following implementation of the two processes. Then, the optimum design factors were used and the DAF system was introduced at the field-scaled plant (5,000 m^3/day). The removal rate of algae and turbidity was evaluated over 56 days in summer. The number of algae in the treated water was maintained at below 20-30 cells/mL, which represented an algae removal efficiency of 80-89%. The effluent turbidity was compared to the conventional sedimentation and DAF processes, and the average turbidity removal efficiency was 77%. These findings indicate that the high-rate DAF process is a promising method for the removal of low-density solids such as turbidity and algae during the treatment of drinking water, especially in summer. Additionally, GAC represents an acceptable treatment option to remove taste-and-odor-causing compounds (e.g., geosmin and 2-MIB).

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요약

국내 Y정수처리시설에 20-40 $m^3/m^2/h$의 표면부하율을 갖는 고속 용존공기부상공정을 도입하였다. 우선, 용존공기부상공정과 입상활성탄 공정이 결합된 반응기를 일처리용량 500 m^3/day의 조건으로 운전하였다. 운전결과는 두 공정이 원수내 탁도, 조류, 지오스민, 2-MIB를 감소시킬 수 있음을 증명하였다. 도출된 최적 설계요소를 활용하여 현장규모의 공정(5,000 m^3/day)에 용존공기부상공정을 도입하였다. 여름철 56일간 조류와 탁도 제거율을 평가하였다. 처리수 내 조류의 개체수는 20-30 cells/mL 이하로 유지되었으며, 조류 제거효율은 80-89%를 기록하였다. 침전법 및 용존공기부상공정 처리수질의 탁도 제거효율을 비교한 결과 평균 탁도 제거효율은 77%를 나타냈다. 이러한 결과들은 고속 용존공기부상공정이 여름철 음용수의 탁도 및 조류와 같은 저밀도 고형물을 제거하는데 유의미한 방법임을 나타냈으며, GAC는 맛·냄새를 유발하는 화합물(지오스민, 2-MIB)를 제거할 수 있는 공정 옵션인 것을 확인하였다.

Key words: Algae removal, Dissolved air flotation (DAF), Drinking water treatment plant, Granular activated carbon (GAC), Taste-and-odor-causing compounds

주제어: 조류제거, 용존공기부상공정, 정수처리공정, 입상활성탄, 맛·냄새 물질

1. Introduction

Blue-green algae blooms have become common events in recent years as a result of warmer temperatures due to climate change and nutrient enrichment in drainage basins (Paerl et al., 2016). Algae blooms in lakes or rivers that serve as a source of drinking water can lead to problems with coloration, taste, and odor, as well as the formation of trihalomethanes (THMs) during the drinking water treatment process (Oliver and Shindler, 1980). Additionally, the flow of algae cells into the water treatment plant can lead to clogged filters and the increased use of agents such as chlorine or activated carbon, which pose a cost burden and reduce the operating efficiency because of necessary maintenance tasks (Ghernaout et al., 2010; Price and Heberling., 2018).

Given that water quality fluctuations are expected to increase in response to the eutrophication of waters bodies, improved processes to control algae and associated taste-and-odor causing compounds, such as 2-methylisoborneol (2-MIB) and geosmin, will be necessary (Matsui et al., 2010; Soyluoglu et al., 2022). However, existing algae removal technology is typically applied to lakes or water intake towers rather than within drinking water treatment plants, and research on the effectiveness of removal technology within a water treatment plant is scarce (Gao et al., 2010; Ghernaout et al., 2010; Liang et al., 2009). To control algae in the water treatment plant, advanced water treatment methods such as oxidation technologies can be introduced, but these can lead to the generation of other toxic substances during the direct oxidation of algae cells.

Dissolved air flotation (DAF) removes contaminants by injecting air with a coagulant from the bottom of the reaction tank to float low-density suspended solids to the surface, rather than by settling to the bottom of a basin (Marvin, 2005). The advantages of DAF for flotation of low-density suspended solids via microbubbles are that it has a very compact, short hydraulic residence time, high loading rate, small flocculation tank and low construction cost (Lee et al., 2020). The floated sludge is then removed from the top of the basin by mechanical or hydraulic means, while the clarified water is removed through the bottom of the basin (Ghernaout et al., 2010). Therefore, DAF is an effective method to remove low-density solids, such as turbidity producing particles, color causing elements, and algae. This technology is advantageous in that it requires a relatively small site footprint and a short processing time of less than 30 min, and it has a higher surface load rate than a sedimentation basin, which contributes to the filtration process efficiency (Ghernaout et al., 2010).

In past applications, DAF was implemented at a surface loading rate of 5–15 $m^3/m^2/h$, which corresponds to an operation speed lower than the theoretical rising speed of bubbles (Kim et al., 2017). Recently, a high-rate DAF process has been described at a surface loading rate of 20–40 $m^3/m^2/h$, which is faster than the rising speed of bubbles (Edzwald, 2007; Wong, 2013). Since its introduction, there has been a massive increase in high-rate DAF applications for drinking water treatment in different parts of the world, and these plants have achieved excellent turbidity and particle removal efficiencies (Wong, 2013). For example, a plant in Tampere (Finland) was designed to operate at approximately 40 $m^3/m^2/h$, and there are plants in New York and California that have been designed to operate at a minimum of 30 $m^3/m^2/h$ (Haarhoff, 2008; Hess et al., 2019). The standard for distinguishing high-rate DAF process from low-rate DAF process has not yet been established in Korea. The Stony Brook Water Treatment Plant (WTP) in the U.S. introduced DAF with mixed media filtration to remove disinfection byproducts and algae in the late summer (Marston and VandeVenter, 2015). Various coagulants and flow rates were studied, and the DAF process showed an outstanding algae removal efficiency of over 90%. Numerous case studies have shown that the introduction of a high-rate DAF process at a WTP to improve the control of algae, organic compounds, and color can be carried out at a compact scale compared to a conventional system.

Despite the above research, studies on high-rate DAF processes at full scale have been limited in South Korea, but there are numerous laboratory-scaled studies (Edzwald, 2007; Ghernaout et al., 2010). While there are DAF plants in Korea, the surface loading rates used are below 15 $m^3/m^2/h$. Thus, there are current limits to continuous high-rate DAF operations because the flotation tanks and sedimentation basins were not designed in an optimal manner for such DAF technology.

This research aimed to develop and introduce a high-rate DAF system (30 $m^3/m^2/h$ surface loading rate) to remove algae at the Y-Drinking Water Treatment Plant (hereafter, Y-WTP) in South Korea. To effectively remove the taste-and-odor-causing compounds derived from algae, e.g., geosmin and 2-MIB, a granular activated carbon (GAC) process was also employed. The specific objectives were to (1) optimize the design parameters in a pilot-scaled high-rate DAF-GAC system, (2) apply the optimized parameters for the operation of a high-rate DAF-GAC process at a full-scale drinking WTP, and (3) evaluate the efficiency of the high-rate DAF-GAC process on the removal of turbidity and algae during summer.

2. Materials and Methods

2.1 Study site

The study site, Y-WTP, is located in Y-city, Gyeongsangbuk-do Province, South Korea. Seasonal variations are the main factors affecting the algal population growth, especially in late summer. The average number of algae cells in raw water collected from Y-WTP was 9.6 cells/mL during summer (Aug. 2015–Oct. 2015) and the predominant algae species were *Microcystis*, *Anabaena*, and *Aphanizomenon*, which are types of blue-green algae (Korea Ministry of Environment Water Information System, 2015).

Figure 1 shows a schematic diagram of the Y-WTP study site and the suggested process for high-rate DAF in the pilot plant system. The Y-WTP was constructed with a 5,000 m^3/d capacity, and it includes several conventional processes such as collection, chemical addition, coagulation/flocculation, sedimentation, filtration, and disinfection processes.

2.2 Pilot plant design

This research investigated a high-rate DAF system (30 $m^3/m^2/h$ surface loading rate) to remove algae at Y-WTP, and a granular activated carbon (GAC) process was introduced to remove the taste-and-odor-causing compounds. GAC was purchased from SAMCHULLY in South Korea (Coal, density 0.43-0.48 g/m^3, iodine adsorption 950 mg/g, specific surface area 950 m^2/g). To design the operation conditions of the pilot-scaled plant, preliminary experiments were carried out with different coagulant concentrations, water heights in the saturator, and saturator pressures. This preliminary testing for the optimization of operation conditions was carried out under the same flow rate of 27 m^3/h and a surface loading rate of 30 $m^3/m^2/h$. First, a Jar-test was conducted to obtain the optimum operation efficiency of the DAF pilot plant. The coagulant used in the experiment was 10% PAC, and the applied concentration was in the range of 0–25 mg/L. Based on the results of preliminary experiment, the DAF pilot plant system was

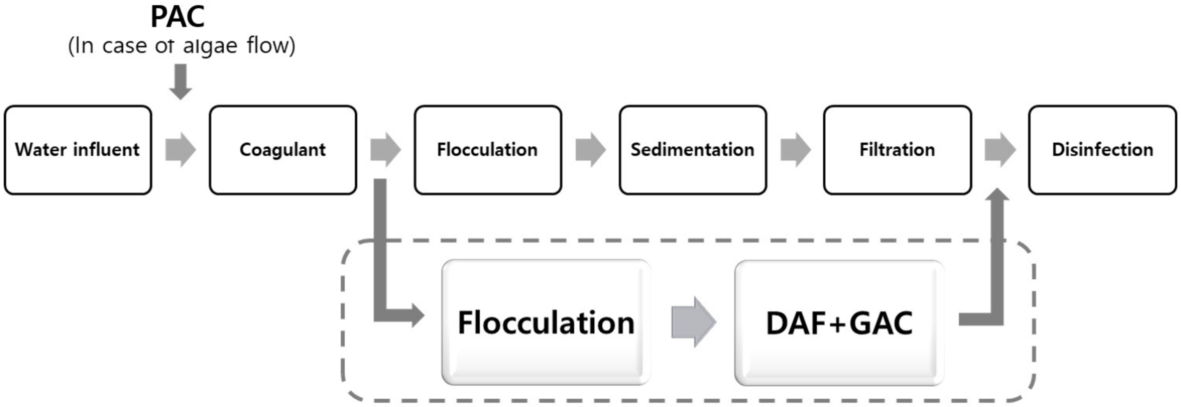


Fig. 1. Schematic diagram of the treatment process used at the study site (Y-WTP) and suggested process for the high-rate DAF system.

Table 1. Design and operation conditions of the Pilot Plant at the Y-WTP

Process	Parameter	Condition
General	Flow rate	500 m^3/day.
	Operating time	24 h/day
	pH	7.5
	Turbidity	5 NTU
	SS	5–10 mg/L
Coagulation	Specific surface area	3.6 m^3
	Type	Rectangle
	Flow type	Weir
	Hydraulic residence time (HRT)	$3.6 \times 60 / 20 = 10.8$ min
Flotation	SS	5–10 mg/L
	HRT	15–25 min
	Surface loading rate	30 m^3/m^2•h (499 L/m^2•min)
	Depth	2.50–2.60 m
Saturator	Size	0.3 D × 0.95 H
	Area	0.077 m^2

designed as shown in Table 1. The process had a 500 m^3/day of capacity and included pre-coagulation/flocculation, the DAF process, and the filtration process with GAC. Granular activated carbon was introduced to remove certain chemicals, particularly organic chemicals, and it can also remove chemicals that give objectionable odors or tastes to water (Kim et al., 2014). This pilot DAF plant was designed to have a high-rate DAF surface loading rate of 30 $m^3/m^2/h$ (Kim et al, 2017).

To optimize the high-rate DAF process, the DAF pilot plant (500 m^3/d) was designed with two pump diffusion units consisting of a mixing pump, jet spray nozzle, and chemical diffusers. Moreover, the floating tank's height was designed at 4 m, and it was installed at this dimension to improve the control of sludge treatment by the scraper. The DAF reactor was designed to have the perforated plate at the bottom of the DAF reactor to generate a flow so that the generated bubbles could remain in suspension for a long time to improve the high-rate DAF efficiency.

2.3 Pilot plant operation

Table 1 shows the detailed operation conditions of the 500 m^3/d pilot plant system. The flow rate into DAF was operated at 27 m^3/day, and the flocculation process, which consisted of two stages, had 10 min of residence time for each stage. The residence time in the floating tank was approximately 20 min, and the recycle flow rate of the plant was conducted in the range of 10–20%. The amount of coagulant injection was determined according to the turbidity of raw water measured in Jar-tests, and the final injection range was 10–30 mg/L of 10% PAC (poly aluminum chloride, Al_2O_3). The treatment standard for turbidity and suspended solids (SS) was designed according to the average annual turbidity and SS at the Y-dam, which is the source of raw water sent to the Y-WTP. The GAC filtration operation was highly dependent on the raw water algal population. The GAC filtration process was operated only when blue-green algae cells amounted to more than 500 cells/mL in raw water. The measurement of geosmin and 2-MIB was analyzed based on the Standard method 6040D (2001), with solid-phase micro-extraction (SPME)-GC/MS with a Finnigan Trace GC Ultra with a Trace DSQ mass spectrometer (Thermo Electron Corp., Austin, TX, USA). The sample volume was 10 mL, and 2.5 g of NaCl was used for extraction salt. Pre-treatment was employed to adsorb geosmin and 2-MIB with solid phase micro extraction (SPME), followed by hydrofluoric acid (30 min, 65℃) and desorption (4 min, 260℃) in the headspace. For turbidity measurement, portable measurement (M-3000, Korea) was employed, and the optic probe was thoroughly cleaned between samples.

2.4. Field plant operation

A full-scaled DAF plant was constructed by selecting a suitable site in the Y-WTP. This field-scaled plant included coagulation, flocculation, DAF, GAC filtration, and disinfection processes. The flow rate into the plant was 5,000 m^3/d, and other details of the design and operating conditions are summarized in Table 2. The surface loading rate was set to 30 $m^3/m^2/h$ for the DAF reactor and 10 $m^3/m^2/h$ for the DAF-GAC process. To control the taste-and-odor causing compounds associated with algae outbreaks, the GAC process was introduced and was operated according to the presence of algae (>500 cells/mL) in the raw water. The flotation tank consisted of two parts, namely, the DAF part and the DAF-GAC part. Therefore, the following two types of operating modes were used to strategically control the treatment of high turbidity and algae levels: (1) the entire process with DAF-GAC, and (2) the entire process with DAF (without GAC). In this experiment, coagulation was used prior to the DAF process at doses of 25–30 mg/L (PAC). The recycle ratio of the saturator was maintained at 10%, while the pressure of the saturator was maintained 3.5–5 kg_f/cm^2.

3. Results and Discussion

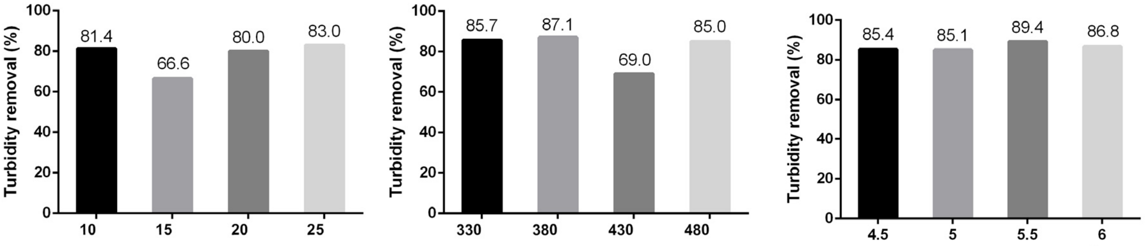
3.1. Optimization of the pilot-scaled DAF plant

To investigate the operation conditions of the pilot-

Table 2. Design and operation conditions of the field plant in the Y-WTP

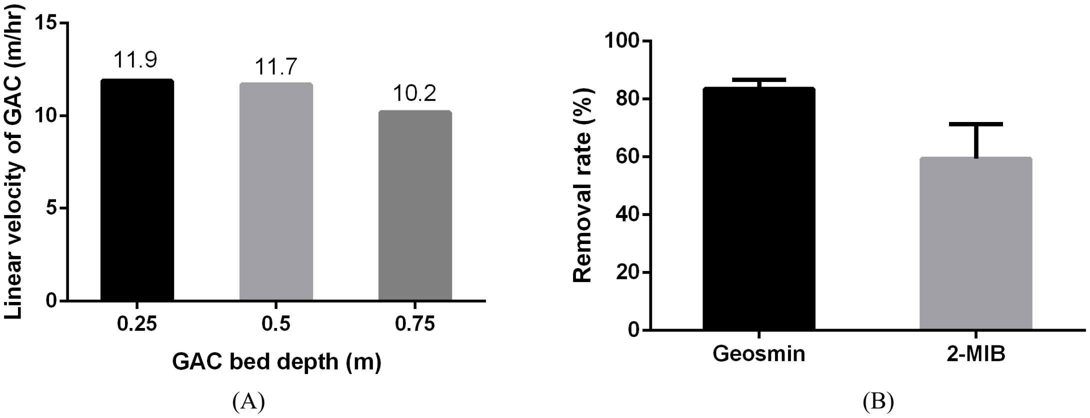
Process	Parameter	Condition
General	Flow rate	5,000 m^3/d
	Operating time	24 h/day
Coagulation	Type	Rectangle, two stages
	Coagulants	PAC (10.5%), 25–30 mg/L
	Mix	30–100 per second
	HRT	10–20 min
Flotation	Type	Rectangle, two ea. (DAF, DAF-GAC)
	Depth	2.5 m
	HRT	20 min
	Surface loading rate	10–40 $m^3/m^2/h$
GAC filtration	Linear velocity	10–20 m/h
	Backwash	10 min

scaled plant, preliminary experiments were carried out. The turbidity removal efficiency was measure according to coagulant concentrations, water heights in the saturator, and saturator pressures (Fig. 2). The turbidity removal efficiency for different coagulant amounts was measured through jar test, and removal rates showed 56–62% (Fig. 2A). DAF pretreatment consists of coagulant addition and flocculation. Given that pretreatment is directly related to form efficient particle size and short flocculation time, optimal coagulant amount is important. In consideration of the operating costs for flocculent injection, an injection concentration of 10 mg/L was determined to be the optimal injection concentration. Figure 2B illustrates the turbidity removal rate according to the saturator water volume. The saturator used in this study was cylindrical with a height of 100 cm, and different water volumes were used inside the saturator, with heights of 330, 380, 430, and 480 mm. The raw water turbidity was 2.17 NTU, and the turbidity decreased to 0.28 NTU (380 mm) and 0.67 NTU (430 mm) during the treatment. These results were equated to a 69–87.1% removal rate, in which no significant differences in the turbidity removal rate were observed in accordance with the changes in saturator water volume. However, the percent air saturation with different pressures may have affected the results because of the differences in the driving force for the retention of air (Manjunath, 2000). The amount of bubbles is the key operating parameter in DAF, and the pressure of the saturator controls the bubbles and can influence the turbidity removal efficiency. Figure 2C shows the turbidity removal rate after exposure to different saturator pressures in the range of 4.5–6.0 kg_f/cm^2. The results in this figure show that removal efficiency did not significantly change, and values of 85.1–89.4% were achieved when the pressure changed from 4.5 to 6



(A) (B) (C)

Fig. 2. Variation of the turbidity removal efficiency in relation to the (A) coagulation concentration, (B) saturator water level, and (C) saturator pressure (Jung et al. 2017).



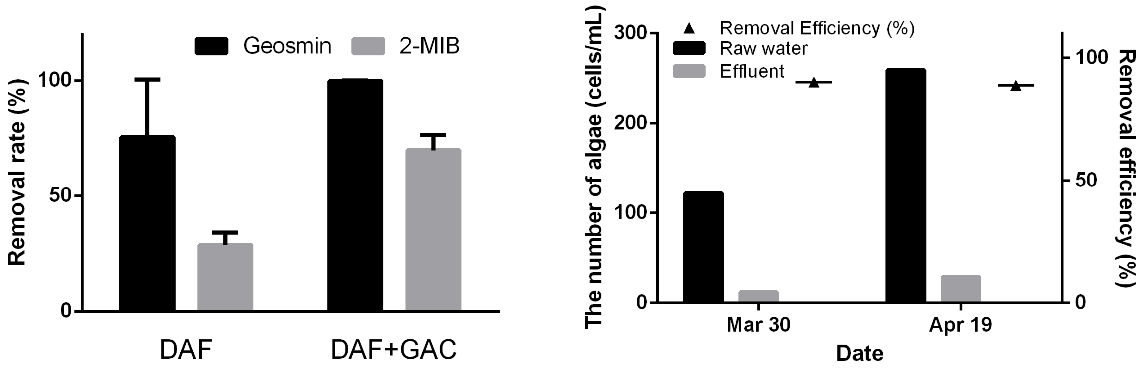
(A) (B)

Fig. 3. (A) Filtration linear velocity of the GAC according to the filtration depth, and (B) the removal rate of geosmin and 2-MIB over three cycles of GAC filtration.

kg_f/cm^2. However, it was observed that when the surface loading rate increased from 30 to 40 $m^3/m^2/h$ under 5.5 kg_f/cm^2, the removal efficiency decreased significantly to 49.3%. These results suggest that as the flow rate increases in response to the increased surface loading rate, the sludge floatation efficiency may decrease.

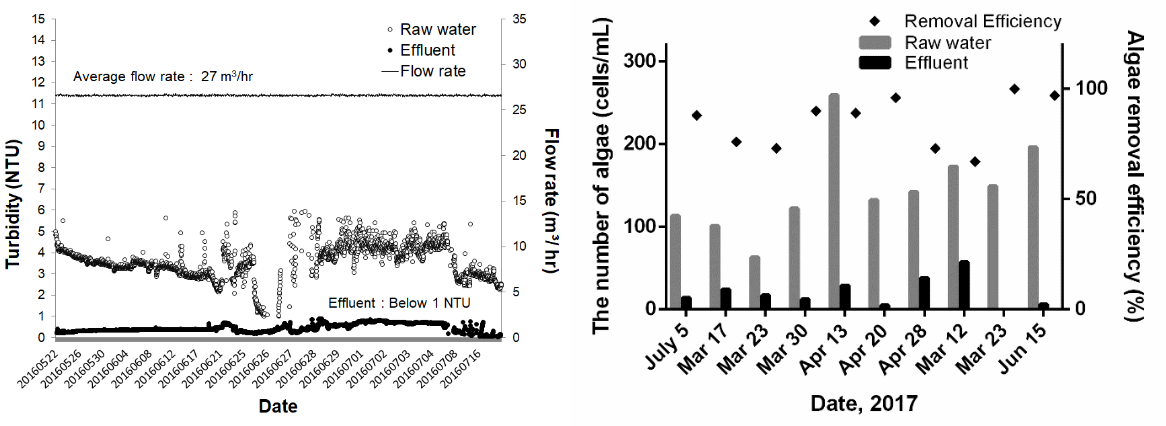
To optimize the GAC filter condition, different GAC bed depths were applied to evaluate the linear velocity of filtration (Fig. 3A). Specifically, a 100 m^3/day flow rate was passed through different GAC depths (0.25, 0.5, and 0.75 m). As the GAC bed depth increased, the filtration linear velocity tended to decrease, as shown in Fig. 3A. However, there was no considerable difference in the linear velocity within the GAC bed depth range of 0.25–0.75 m. Therefore, the influence of the filtration depth on the linear velocity of GAC filtration may be insignificant.

Figure 3B shows the experimental results for the removal rate of 2-MIB and geosmin, which are important taste-and-odor causing compound. This experiment was conducted with a 0.5 m GAC depth and 160 L/min flow rate, and tests were carried out in triplicate. The initial concentrations of geosmin and 2-MIB were 561 and 193 ng/L, respectively. The geosmin removal rate was 83.5%, and the 2-MIB removal rate was 59.4% in terms of the average value. Previous research has shown that geosmin has a greater tendency to adsorb to activated carbon than 2-MIB (Matsui et al., 2010; Kim et al., 2014). This may be due to the difference of structure between geosmin and 2-MIB. Geosmin has a lower solubility and molecular



(A) (B)

Fig. 4. Removal rates of (A) geosmin and 2-MIB during the DAF and DAF-GAC treatments and (B) algae during the DAF treatment.



(A) (B)

Fig. 5. Results for the (A) turbidity changes over 1 year and (B) the number of algae cells over 4 months in the DAF-GAC pilot plant.

weight, which may contribute to higher adsorption.

To further investigate the effect of GAC filtration on the removal of taste-and-odor causing compounds in the DAF reactor, the removal rates of geosmin and 2-MIB were measured in the DAF system with and without GAC filtration. Figure 4A shows the removal rate of geosmin and 2-MIB in the DAF pilot plant with and without GAC (500 ton/day). The results for geosmin adsorption showed that the removal rate in the DAF-GAC process was higher (99.8%) than that in the DAF process (75.6%). The results for 2-MIB adsorption also showed that the removal rate in the DAF-GAC process (69.9%) was higher than that in the DAF process (28.7%). These results indicate that GAC filtration after DAF will be useful for improving the removal rates of geosmin and 2-MIB.

Figure 4B shows the number of algae cells in raw water and effluent after the DAF-GAC process. The pilot plant experiment was conducted in March and April 2017. In general, the occurrence of algae was insignificant until May, but blue-green algae such as Aphanizomenon were continuously observed, and research on the period was conducted. The algae counts decreased from 122 cells/mL to 12 cells/mL after DAF treatment, which represents a 90.2% algae removal rate by March 30. Furthermore, the number of algae cells decreased from 259 cells/mL to 29 cells/mL on April 19, which represents an 88.8% removal rate at this time.

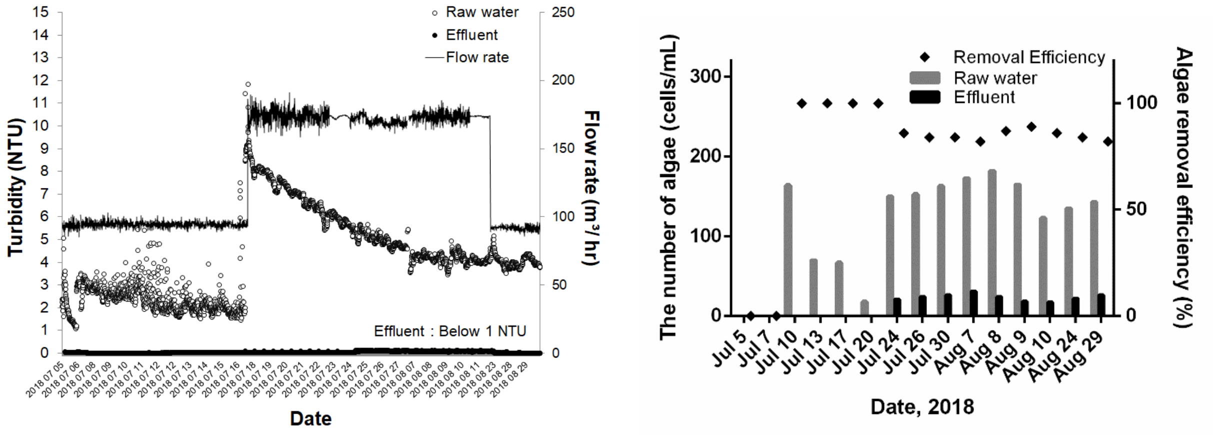
3.2. Operation and evaluation of the pilot-scaled DAF plant

Based on the results of preliminary experiments, the DAF-GAC pilot-scaled plant was operated over a long duration to investigate the turbidity and algae removal efficiency. The pilot plant system's design and operation conditions are shown in Table 1, and the plant was operated continuously for 367 days from May 22, 2016, to May 24, 2017. Figure 5 shows the results of turbidity and algae cells in the pilot plant during the operation. The flow rate into the process was set to 27 m³/day, and the recycle rate was 15% for the operations. The continuous operation was monitored every minute, and data were saved in HMI automatically.

Figure 5A shows the turbidity of raw water and the turbidity after the DAF-GAC treatment in the pilot plant. The inflow raw water had a turbidity of 1–15 NTU, and the results for the turbidity change during this hybrid DAF-GAC plant's continuous operation were 0.48–2.0 NTU. Although the effluent turbidity results were affected by the raw water quality, the turbidity of the treated water was maintained at 1 NTU or less during the operation period. High-rate DAF technology into plant indicates flocculation times can be shortened and hydraulic loading rates significantly increased without loss of performance. Other research carried out examines under winter temperatures (3-5℃), turidities and TOC were also low and constant with 0.66-0.74 NTU and TOC in 2.9-3.3 mg/L (Hami et al., 2007). Reali and Marchetto performed high-rate pilot scale DAF system for treating a colored and low turbidity raw water. With higher coagulant dosages (20-35 mg/L of aluminum sulfate), it was obtaining good flotation performance in surface loading rate at 8 $m^3/m^2/h$ (Khiadani et al., 2014). Figure 5B illustrates the number of algae cells per 1 mL of raw water and treated water from February 2017 to June 2017. According to the algae analyses, the number of algae in treated water was 20 cells/mL on average, while the number of algae in raw water was 145 cells/mL on average. There was a significant increase in the number of algae cells in the raw water during April 2017, and this change was related to an increase in water temperatures. On April 17, 2017, the results indicated there were 259 cells/mL in raw water, and the removal efficiency was approximately 89%, in which the values decreased to 27 cells/mL. The overall removal efficiency of algae cells was in the range of 67-100%, and it was 84.9% on average after the DAF-GAC process.

3.3. Operation and evaluation of the field-scaled DAF plant

Full-scaled DAF plant was constructed based on the pilot-scaled DAF plant operation. The flow rate into the plant was 5,000 m³/d, and other details of the design and operating conditions are illustrated in Table 2. To evaluate the efficiency of the field-scaled high-rate DAF plant, this experiment measured the concentrations of turbidity and algae cell counts in raw water and treated effluent from July 5 to August 9 in 2017. An initial stabilization was performed with 2,500 m³/d of raw water for 14 days. Figure 6 shows the results of turbidity and algae cells in the field-scaled plant during the summer season. The flow rate into the DAF process was set to 100 m³/h for stabilization during the first 14 days, and then, the plant was operated continuously at the target flow rate of 200 m³/h. Figure 6A shows the turbidity of raw water and the turbidity after treatment in the field-scaled plant. The average turbidity of the effluent during the continuous operation was 0.52 NTU after the DAF-GAC process. The turbidity of raw water increased to over 10 NTU in response to seasonal changes during the summer, but the effluent turbidity was maintained at 1 NTU or less. Figure 6B shows the number of algae cells in raw water and that in effluent. Because the number of algae cells in raw water did not exceed 500 cells/mL, the GAC filtration process was not implemented during this time. Again, the field-scaled plant was operated continuously during the summer of 2018 and no excessive amounts of algae cells were detected in the raw water entering the Y-WTP, which



(A) (B)

Fig. 6. (A) Turbidity and (B) algae cells in raw water and treated water collected during the field-scaled DAF-GAC process over 56 days in summer.

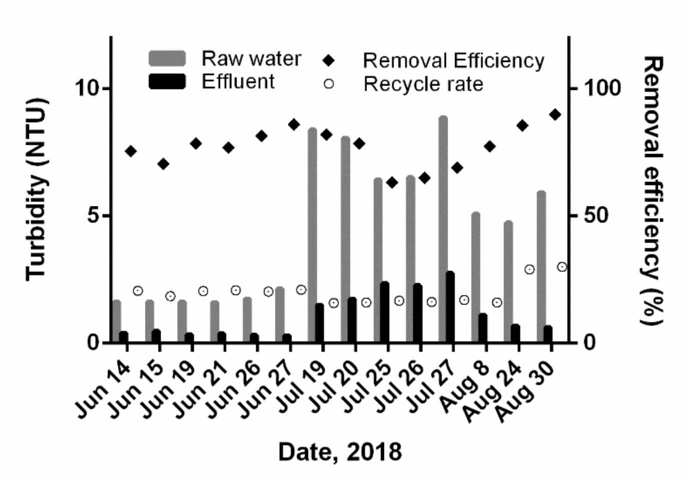


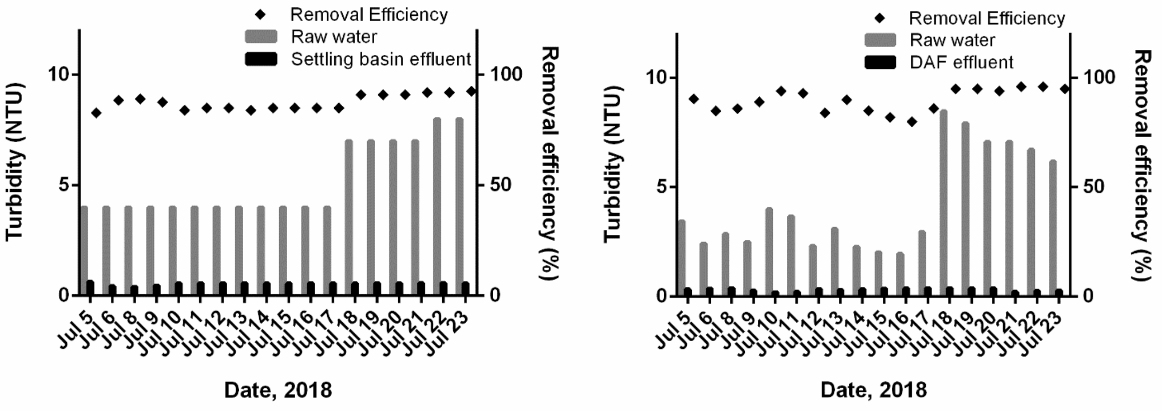
Fig. 7. Removal rate of turbidity and recycle rate for the continuous operation of the field-scaled DAF plant over 56 days in summer.

means that GAC filtration was not implemented. From the end of July to August, the number of influent algae amounted to 125–180 cells/mL. The number of algae in the treated water was maintained below 20–30 cells/mL, which represents an algae removal efficiency of 80–89%. During the summer of 2018, the turbidity removal efficiency was monitored and the average was 77%; the recycle rate for the continuous operation was 20% on average, as shown in Fig. 7.

Figure 8A and 8B compare the turbidity and turbidity removal efficiency of sedimentation at the settling basin effluent and DAF effluent collection points. This turbidity analysis was carried out by sampling treated water after the sedimentation basin in the Y-WTP conventional water treatment process (Fig. 8A). The average turbidity of raw water was 4.9 NTU, and it decreased to 0.5 NTU after the settling basin, which translates to a removal efficiency of 87.8% on average during the operation. Figure 8B shows the turbidity changes before and after the DAF process in the effluent of the field-scaled DAF plant. The average turbidity of raw water was 4.9 NTU, and that of DAF effluent was 0.32 NTU, which indicates that a 90.1% removal efficiency was achieved. These findings may indicate that the adsorption of activated carbon is considerable. Hami et al. investigated that the effects of powdered activated carbon on the performance of the DAF unit, and the addition of activated carbon was found to reduce the BOD and COD concentrations of effluent (Hami et al., 2007). Furthermore, the improvement in effluent water quality increased with increasing the concentration of activated carbon added, related to the Freundlich and Langmuir adsorption.

Thus, other studies have shown that a DAF system has a higher removal efficiency and requires less coagulant than conventional systems (Khiadani et al., 2014; Kwon et al., 2004). These results show that DAF is a promising technique to incorporate in a WTP to control its turbidity.

To operate the high rate DAF efficiently, we developed the DAF system operation scenarios according to the raw water quality of the Y-WTP; temperature, turbidity, pH, EC, algae cell counts. Scenarios of Y-WTP were divided three based on raw water quality conditions; scenario 1 (<10℃, <2 NTU, < 500 cells/mL), scenario 2 (10-20℃, 2-5 NTU, 500-1,000 cells/mL), scenario 3 (>20℃, >5 NTU, >1,000 cells/mL). Coagulation and flocculation operating conditions were designed depending on each scenario, and the operation factors were the amount of coagulant injection and the stirring speed. DAF process operation factors consisted of the saturation tank water level, recycle ratio, nozzle, and skimmer. In addition, by analyzing the produced water quality, the algorithm verify whether the algae was less than 100 mg/L, and the geosmin&2-MIB removal achieved 50%. Depending on the water quality result, an



(A) (B)

Fig. 8. Comparison of turbidity levels (NTU) after (A) sedimentation and (B) the DAF-GAC process.

algorithm was designed to re-operate the process according to the scenario.

4. Conclusion

This study introduced a high-rate DAF process with GAC filtration to remove algae and organic compounds in the Y-Drinking Water Treatment Plant in South Korea. One of the most important findings of this research was that integration of the high-rate DAF technology at a surface loading rate of 30–40 $m^3/m^2/h$ was found to be feasible for treatment operations at the field scale. Use of high-rate DAF at the drinking water treatment plant resulted in an algae removal rate of 80–89%. The turbidity removal efficiency was 77% on average, and levels were maintained at 0.52 NTU.

This research also showed that the GAC bed in the DAF tank is suitable for a high-rate DAF treatment plant. Along with the high-rate DAF process, the removal of taste-and-odor-causing compounds produced by algae was aided by a GAC filter, which was merged with the DAF reactor. This treatment design resulted in a geosmin removal efficiency of 99.8%, while the removal efficiency after DAF alone was 75.6%. In regard to the 2-MIB adsorption, the removal rate increased from 28.7% to 69.9% when GAC filtration was applied after DAF.

Given that the results showed that effective removal of organic matter was possible, this high-rate DAF process is expected to serve as an alternative clarification process ideal for treating raw water with low amounts of particles such as algae or color-causing organics. Moreover, application of the DAF system would have economic advantages because the process requires lower capital costs and a smaller plant footprint. The flocculants consumption when using this high-rate DAF system could be reduced by about 55% compared to the Y-WTP conventional water treatment process. In addition, it was possible to reduce about 30% of the saturator operating cost, because this high-rate DAF system was able to operate at low pressure. Therefore, it is expected to have an economic effect as facility and operation cost can be reduced compared to existing DAF system when demonstration facilities for high-rate DAF process. While the implementation of a DAF-GAC system at WTPs could be promising, additional studies on factors such as the filtration duration, efficiency comparisons with other processes, and economic feasibility would be worthwhile. The current findings presented in this study are important for increasing the body of knowledge on the effectiveness of high-rate DAF technology in drinking water treatment plants.

Abbreviations

Dissolved air flotation (DAF); Granular activated carbon (GAC); Hydraulic residence time (HRT); 2-Methylisoborneol (2-MIB); Nephelometric turbidity units (NTU); Poly aluminum chloride (PAC); Suspended solids (SS); Trihalomethanes (THMs); Water treatment plant (WTP)

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