Dissolved air flotation separation for pretreatment of membrane bioreactor in domestic wastewater treatment

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ABSTRACT

Due to requiring higher water quality standards over time, new technologies are being employed for wastewater treatment. Dissolved air flotation (DAF) and membrane bioreactor (MBR) technologies are widely employed as new technologies in wastewater treatment. DAF is used due to its excellent separation capability of suspended solids as well as oily material. MBR is used because it may provide a high level of mixed liquor suspended solids in a biological system and excellent separation capability too. In the investigation, separation by DAF, without addition of coagulant, could remove chemical oxygen demand by potassium dicromate (COD_{cr}) up to over 70%, biochemical oxygen demand (BOD_5) 73%, suspended solids (SS) 83%, total nitrogen (T-N) 55%, and total phosphorus (T-P) 65% in influent of municipal wastewater. Average overall removal rates of water quality parameters by the DAF-MBR system were very high such as COD_{cr} 95.9%, BOD_5 99.7%, chemical oxygen demand by potassium permanganate) 93.6%, T-N 69.8%, NH_4-N 98.5%, T-P 78.2%, and SS 99.5%, which satisfy effluent water quality standards. Membrane separation in the MBR system produced a very low SS concentration of 1.27 mg/ℓ in the final effluent. It was proven that DAF separation is an excellent technology for pretreatment of wastewater treatment, especially for an MBR system.

Key words | DAF, MBR, membrane fouling, pretreatment, wastewater

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INTRODUCTION

The membrane bioreactor (MBR) process has been widely investigated in various wastewater treatments and even in sludge reduction (Acharya *et al.* 2006; Fun *et al.* 2009; Monclus *et al.* 2009; Sun *et al.* 2009; Buer & Cumin 2010; Yang *et al.* 2012). Although the MBR process of wastewater treatment shows high performance in removing organics and nutrients, the system has some drawbacks such as high energy consumption and membrane fouling (Fenu *et al.* 2010; Zhu *et al.* 2011). Membrane fouling, which results in increasing trans-membrane pressure with time, contributes to the high energy consumption of MBR. Various technologies to reduce membrane fouling are being employed (Schier *et al.* 2009; Gohary *et al.* 2010; Medhat & Moustafa 2011).

Meanwhile, the dissolved air flotation (DAF) system is widely used for the separation process in water and wastewater treatments (Sena *et al.* 2009; Adlan *et al.* 2011; Tansel & Pascual 2011). DAF may remove various materials in water treatment such as disinfection by-products, color, algae, and turbidity (Edzwald 2010). DAF can also remove oily material which may result in membrane fouling of the MBR system (Oliveira & Rubio 2009; Rattanapan *et al.* 2011). With the efforts to improve its performance, DAF technology has been progressed a great deal in the last decade (Kwon *et al.* 2005; Lee *et al.* 2007). Due to the various advantages in separating capability, DAF is used in pretreatment of MBR process with chemical coagulant (Gohary *et al.* 2010).

The possibility of pretreatment of wastewater was examined in the MBR process using the DAF system. It was believed that DAF removes suspended solids and oily material contained in raw domestic wastewater. Thus

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it was expected that membrane fouling would be reduced, and organic and nutrient loading rates would also be lowered in the MBR system. Coagulant was not used to prevent co-precipitation of phosphorus in wastewater influent.

EXPERIMENTAL METHODS

Experimental apparatus

As a microbial process, the MBR system was employed due to its high performance and compact system. A DAF system was used for pre-treatment of the membrane, which reduces suspended organic loading and oily material in the wastewater. The DAF system was operated every day for 1 hour. DAF-treated water was stored in a storage tank and applied to the MBR system. A schematic diagram of the whole process is presented in Figure 1.

DAF system

The DAF system may reduce loading of non-biodegradable organic waste-like oily material which is believed to cause membrane fouling due to its sticky characteristics. The DAF system could also remove suspended chemical oxygen demand material which reduces loading of the following systems. It is operated without adding coagulant to prevent loss of phosphorus in the wastewater. Details of the DAF system are presented in Table 1.

Anoxic tank

Effluent of the DAF system was pumped into the anoxic tank at the rate of 140 mℓ/min. Sludge from the aeration tank was also put into the anoxic tank to maintain appropriate mixed liquor suspended solids (MLSS) concentration of 5,000–6,000 mg/ℓ (in the anoxic tank). The size of the anoxic tank was 33.3 ℓ, and hydraulic retention time (HRT) was 4 hours. The anoxic tank was mixed for 24 hours, and its temperature was maintained at 15–21 °C.

Aerobic tank

The size of the aerobic tank was 33.3 ℓ with B 0.3 m × L 0.3 m × H 0.372 m. Average effluent flow rate of the aerobic tank was 140 ml/min with 4 hours of HRT. The recycle rate from the aerobic tank to the anoxic tank was about 200%. Concentration of MLSS in the aerobic tank was 7,000–8,000 mg/ℓ, and its temperature was maintained at 15–25 °C. Sludge used in the anoxic and aerobic tanks of the MBR system was taken from the aeration basin in Hoeya wastewater treatment plant of the City of Ulsan, Korea.

MBR system

The MBR system was utilized in the experiment as a biological process due to its wide usage around the world. Not only does the MBR system provide high performance in removing materials which represent water quality parameters (Lee *et al.* 2007; Medhat & Moustafa 2011), but the system is also compact and easy to set up in a

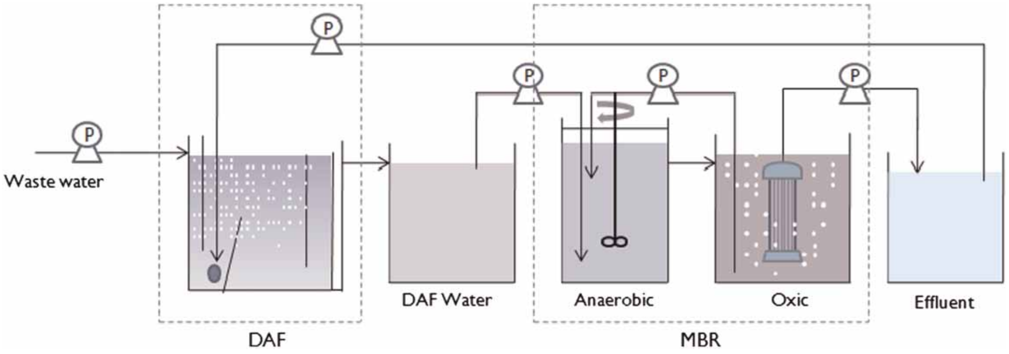

Figure 1 | Schematic diagram of the wastewater treatment system used in the study.

Table 1 | Details of DAF system and operating condition

Flow: 200 ℓ/d (=0.14 ℓ/min), operating period: 1 h/d	
Retention period	18.0 min
Recycle rate	20%
Pressure of the air dissolving tank	4.0 kg/cm^2
Surface hydraulic load (m^3/m^{2}h)	1.67
Size	B 0.2 m × L 0.6 m × H 0.6 m, volume: 72 ℓ

small area. MF (Microfilter Membrane, E&E manufactured, Korea) was used, with a pore size of 0.3–0.4 μm, in the MBR system. The membrane material was hydrophilic polyvinylidene fluoride (PVDF). A cyclic operation method was applied to the MBR system with 7 minutes operation and 3 minutes idling. After 24 hours of operation, backwash was carried out for 2 minutes with 5–6 bar of air pressure. The air blower was operated for 24 hours under the MBR system to prevent the membrane from being fouled by sludge. Details of the membrane used in the investigation are presented in Table 2.

The detailed operating condition of the MBR system is illustrated in Table 3.

RESULTS AND DISCUSSION

Operation condition of the pilot plant

Screened influent of a municipal wastewater treatment plant was used as raw water in the experiment. The experimental apparatus was set up at the wastewater treatment plant in the city of Ulsan, Korea. The wastewater was mostly from municipal sources such as apartment complexes with a small portion of industrial wastewater, from sources such as the pulp industry and small manufacturing industries. Pumped raw water was first treated using DAF without chemical addition, and effluent from the DAF system was stored in a storage tank for the influent of the following MBR system. Average raw water quality is shown in Table 4.

Raw water was treated using the series of processes shown in Figure 1. Raw water was firstly treated by DAF without chemical addition, and the DAF effluent was pumped into the MBR system. Even without coagulant addition, DAF separation showed excellent performance for lower loadings of most water quality parameters such as BOD$_5$, COD, total nitrogen (T-N), total phosphorus (T-P), and SS. Outcomes of selected parameters are presented as graphs with analysis below.

Table 2 | Detail of MBR

Characteristics	**Specification**	**Figure**
Type	Hydrophilic PVDF	
Pore size	0.3–0.4 μm	
Effective surface area	10 m^2	
Sealant	Urethane and Epoxy Resin	
Dimension of module	60(W) × 55(D) × 450(H)	
Strength	40–42 kgf/fil	
Operational mode	On : 7 min/Off : 3 min	
Flux (ℓ/min . m^2)	0.25	
Inner/Outer diameter (μm)	1,800/2,000	
Area (m^2)	0.8	

Table 3 | Operating condition of MBR system

Parameters	Anoxic tank	Aerobic tank
DO concentration (mg/ℓ)	< 0.3	2–5
Temperature (°C)	14–21	19–25
pH	7.4–7.5	
SRT (days)	30	
MLSS (mg/ℓ)	5,000–6,000	7,000–8,000

DO (dissolved oxygen), SRT (solids retention time).

Table 4 | Average raw water quality of the wastewater treatment plant

	COD_{cr}	COD_{Mn}	BOD_5	T-N	T-P	SS
Concentration (mg/ℓ)	314	128	190	39	8	258

COD_{cr} (chemical oxygen demand by potassium dichromate), COD_{Mn} (chemical oxygen demand by potassium permanganate), BOD_5 (biochemical oxygen demand), T-N (total nitrogen), and T-P (total phosphorus), SS (suspended solids).

Biochemical oxygen demand

Separation capability of BOD_5 in raw water by DAF was over 71%. This pretreatment of raw water lowered organic loading in the MBR system, which resulted in a very high removal rate as shown in Figure 2. Effluent concentration of BOD_5 was maintained below 2.0 mg/ℓ with over 99% removal rate regardless of raw water concentration. The micro-bubble layer in the DAF system acted as a filter bed which strained out particulate organic material in the raw water. The size of the voids in the bubble bed is just tens of microns. Thus particulate organic matter was filtered out mostly on the bubble bed. Dissolved and colloidal organic matter may escape the bubble layer, and is then removed in the MBR system. Phosphorus deficiency in the MBR system was avoided by not using coagulant in the DAF process.

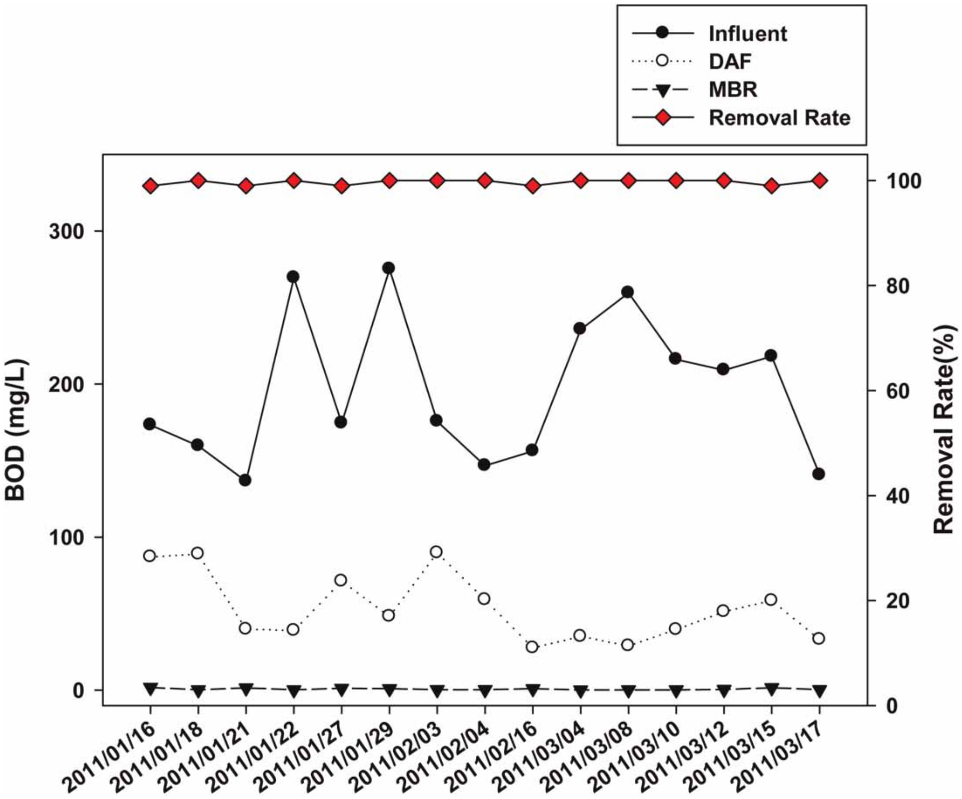

Figure 2 | BOD_5 concentrations in raw water, and DAF and MBR effluents with overall removal rate.

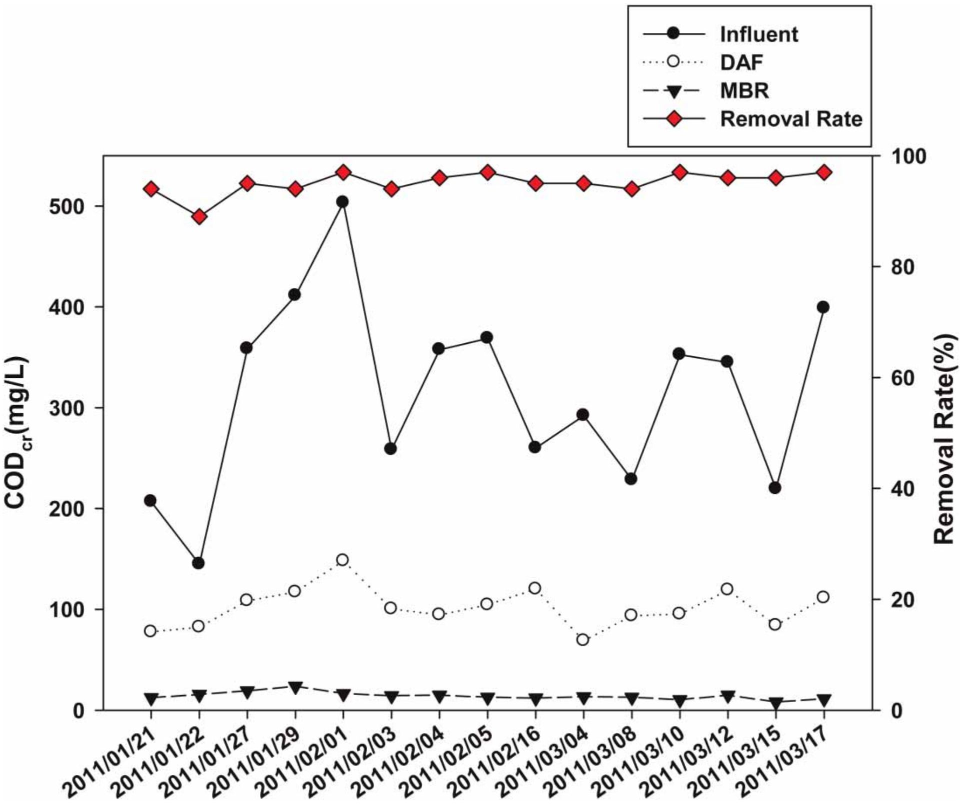

Figure 3 | COD_{cr} concentrations in raw water, and DAF and MBR effluents with overall removal rate.

The MBR system also has excellent separation capability of suspended matter. This separation capability enables the system to maintain high MLSS concentration in the MBR reactor, and to produce high quality of effluent. The range of MLSS concentrations was 7,000–8,000 mg/ℓ.

The two different types of separations by the DAF and MBR systems produced effluent with less than 2.0 mg/ℓ of BOD_5 concentration.

Chemical oxygen demand by potassium dicromate

Removal of COD_{cr} by separation in the DAF and MBR systems is presented in Figure 3. COD_{cr} concentrations in influent of DAF (raw water), and in final effluent of the MBR were 111.2 mg/ℓ and 11.2 mg/ℓ respectively. The overall removal rate was very high at over 95%. As can be seen in Figure 3, even though influent raw water concentrations of COD_{cr} fluctuated greatly, effluent concentrations show very stable values. It is believed that MBR performance was enhanced due to reduced particulate COD_{cr} loading as a result of DAF separation. The remaining colloidal and dissolved COD_{cr} could be effectively treated in the MBR system. High concentration of MLSS (7,000–8,000 mg/ℓ) in the MBR system makes it possible to remove COD_{cr} to a low level.

Suspended solids

The removal rate of SS was obtained close to 99% due to separation by DAF, and the membrane in the MBR system. SS removal in the final effluent is closely related to the pore size of the membrane in the MBR system, which was around 0.3–0.4 μm in this investigation. Average SS concentration in the raw water was 258.43 mg/ℓ, which was then reduced to an average 42.62 mg/ℓ by DAF separation with 82% removal rate. Particulate organic matter is removed with SS suspension on the bubble layer of the DAF system. This separated particulate organic matter may contain BOD_5, COD, T-N, and T-P, which are the major parameters in the system. Final effluent SS concentration is obtained by membrane separation in the MBR system. Average final effluent SS concentration at the very low level of 1.33 mg/ℓ could be achieved, as shown in Figure 4.

T-N and T-P

Even if excellent organic removal rates were achieved during the experimental period, nutrient (T-N and T-P) removals differed depending on operational conditions. To obtain the maximum nutrient removal rates, optimal operating conditions were found in the given experimental system. Maximum removal rates were achieved at an inner recycle rate of 200% with average removal rates of T-N 75%, and T-P 64%. Removal of nitrogen and phosphorus is nothing to do with separation by the membrane in the MBR system. Their removals are dependent on the operating condition of the MBR system. Concentrations and removal rates of T-N and T-P are presented in Figure 5.

Average concentrations of each process are shown in Table 5. As shown in Table 5, removal rates of water quality parameters are very high, for example removal rate of COD_{cr} was over 95%, BOD_5 99%, T-N 75%, and T-P 64%. Even if coagulant was not used in DAF separation, loading rates of water quality parameters were remarkably reduced. Removal of SS might contribute to removal of other water quality parameters contained within SS. Effluent of the DAF system was pumped into the MBR system which further lowered the remaining concentrations of water quality parameters. The remaining colloidal and dissolved organic material was removed to a very low concentration by the MBR system as shown in Table 5. Solids in the aeration tank were separated by the membrane of the MBR system, which produced very low concentrations of suspended solids in the effluent.

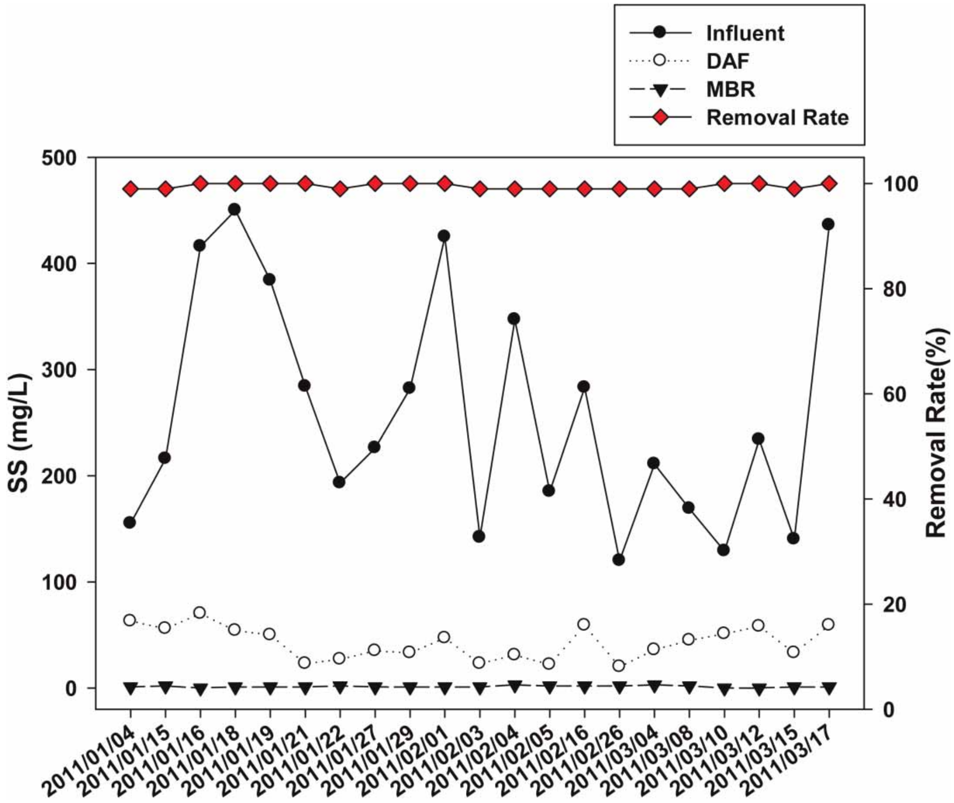

Figure 4 | SS concentrations in raw water, and DAF and MBR effluents with overall removal rate.

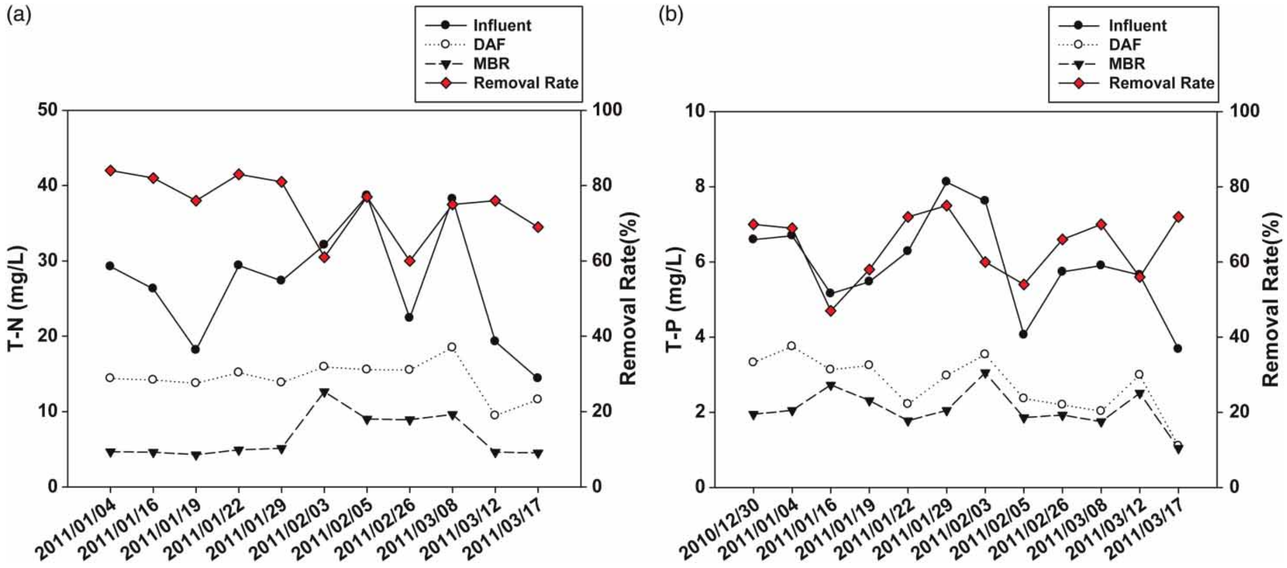

Figure 5 | T-N (a) and T-P (b) concentrations in raw water, and DAF and MBR effluents with overall removal rate.

Table 5 | Results of wastewater treatment processes of the experiment

Item	Influent (mg/ℓ)	DAF effluent (mg/ℓ)	MBR effluent (mg/ℓ)	Removal rate (%)
COD_{cr}	314	102	14	95
BOD_5	196	53	1	99
COD_{Mn}	135	62	9	93
T-N	27	14	7	75
NH_4-N	10	8	0.2	98
T-P	5.9	2.7	2.1	64
SS	258	43	1	99

CONCLUSIONS

- Municipal wastewater was stably treated with high removal rates by combined separation of the DAF-MBR system in the pilot experiment. Overall average removal rates of water quality parameters were COD_{cr} 95%, BOD_5 99%, chemical oxygen demand by potassium permanganate (COD_{Mn}) 93%, T-N 75%, NH_4-N 98%, T-P 64%, and SS 99%. Concentrations of the parameters satisfied the effluent water quality standards.
- Even without using coagulant, DAF separation could remove over 66% COD_{cr}, 71% BOD_5, 51% COD_{Mn} and 82% SS along with 44% T-N and 53% T-P in influent of municipal wastewater.
- Membrane separation in the MBR system made it possible to produce excellent effluent water quality with SS concentration of 1.33 mg/ℓ.
- It was proved that DAF separation is a good technology in the pretreatment of domestic wastewater especially for pretreatment of an MBR system.

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