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고도정수처리에서 사여과와 정밀여과의 유기물처리특성에 관한 연구

Treatment Characteristics of Sand Filtration and Microfiltration (MF) in Advanced Water Treatment

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Abstract

With a belief of high water quality production and less chemical usage, membrane technology including Microfiltration (MF), Ultrafiltration (UF), and Nanofiltration(NF) is being employed more and more in drinking water treatment process. However, due to higher energy consumption of UF and NF, MF is normally used for drinking water treatment especially in a plant of large scale.

In this investigation, performance ofsand filtration and membrane filtration was compared regarding removal of various water quality parameters, such as TOC, DOC, KMnO4 consumption, THMFP, and HAAFP. Two lines of pilot plant have been operated, one of which line is a traditional advanced water treatment process which includes sedimentation, sand filtration, ozonation, and activated carbon, and the other line is an alternative treatment process which includes sedimentation with inclined plate, MF membrane, ozonation, and activated carbon.

For the first about 4months of period, MF filtration showed similar or little bit higher performance than sand filtration. However, after about 4month later, sand filtration showed much higher performance in removing all parameters monitored in the investigation. It was found that sand filtration is a better option than MF filtration as far as microbial community is fully activated in sand filter bed.

Key words : Drinking water treatment, Membrane, MF, Sand filtration, THMFP, Organic matter

주제어 : 정수처멤브레인, 마이크로 필트레이션, 사여과, 트리할로메탄 생성능, 유기물

1. Introduction

Even with various limitations of membrane such as fouling, declining of production water with time, and high energy consumption membrane is attracting attention as an alternative of advanced water treatment which normally use ozone and activated carbon. Moreover, membrane is considered a substitute of a sand filtration in conventional water treatment (Mosqueda−Jimenez *et al.* 2006, Zularisam *et al.* 2006). One of the excellent advantages is that

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UF (Ultra filtration) or NF (Nano filtration) may be used for drinking water production without adding chemicals (Ericsson *et al.* 1997, Mavrov *et al.* 1998). Due to its clear cut separation capability, membrane is recommended to employ in removing humic acids, and microbial agents (Lowe *et al.* 2008, Domany *et al.* 2002, Fiksdal *et al.* 2006, Guo *et al.* 2010). It was reported that MBR (Membrane Bioreactor) which is normally used in wastewater treatment, may be employed for drinking water treatment in relatively highly polluted surface water (Li *et al.* 2003). With increasing demands, various types of membrane have been commercialized (Fiksdal *et al.* 2006, Lipp *et al.* 2005). Membrane was also suggested to be use in controlling Cryptosporidium as an alternative of sand filtration (Smith *et al.* 1999).

Many researchers tried to figure out the performances of membrane filtration as an alternative of a sand filtration in water treatment (Oe *et al.* 1996, Jegatheesan *et al.* 2009). Some obtainedthat membrane gave better results, which experiment focused on removing turbidity (Oe *et al.* 1996), while the others claimed that sand filtration illustrated higher performance on removing DBPs (Jegatheesan *et al.* 2009). Consistent results in literatureshowed that separation capability was higher in membrane process than that in sand filtration.

Basic idea of the investigation is that even if membrane has higher separation capabilitysuch as SS including various microbial agents, and provides a compact system, microbial activity in sand filtration may have potential to remove dissolved organic material. This particularinvestigation was part of pilot plant test for building an advanced water treatment plant to renovate the existing conventional plant, so that the investigation tried to figure out differences in removing characteristics of water quality parameters between membrane and sand filtration.

2. Experimental Methods

2.1. Pilot Plant

Pilot plant consists of two lines. The first line (line 1) is the traditional advanced water treatment process, and the second line (line 2) is an alternative advanced water treatment process as shown in **Fig. 1.**

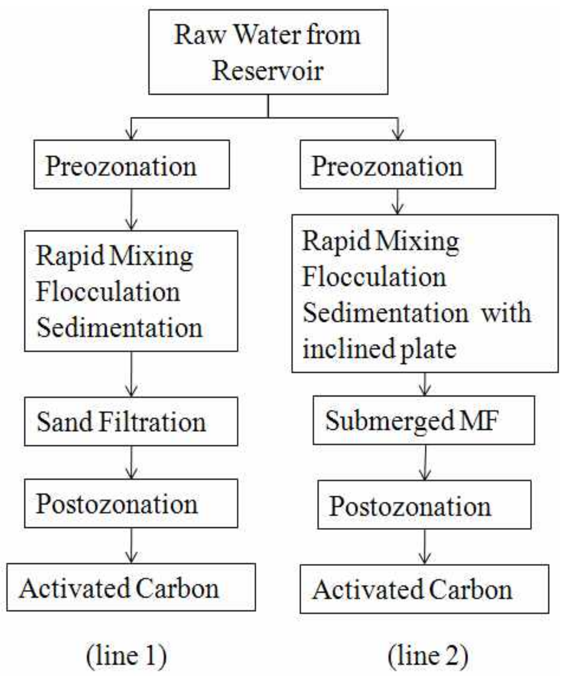

Fig. 1. Pilot plant processes used in the investigation

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Table 1. Operating condition of membrane (MF

parameter		cleaning	Idle	filtration	Chemical cleaning	Idle (min)	Flux	Average flow rate	recovery
Operation period		30 sec	30 sec	10 min	2 min	10		–	90%
Idle period (sec)		10	–	10	10	–			
Flow rate	filtration	–	–	1.43 m^3/hr	–	–	60 $L/m^2 \cdot hr$	30 m^3/d	
	backwash	2.1 m^3/hr	–	–	2.1 m^3/hr	–		2.32 m^3/d	
	concentrated	0.14 m^3/hr	–	0.14 m^3/hr	0.14 m^3/hr	–		3.08 m^3/d	
	air	0.40 m^3/min	–	0.40 m^3/hr	0.40 m^3/hr	–		–	
	chemical	–	–	–	0.01 L/min	–		–	
Cycle		126Cycle			1Cycle			–	

Flow rate of each line was controlled with electronic flow meter (Wintec, Korea) and control valve to maintain constant and equal flow rate in sand filtration and in membranefiltration of the pilot plant ($30m^3/d$). Backwashing was made in one or every two days depending on head loss using air and water cleaning methodin the sand filtration. Ozonation and Activated carbon bed (GAC) were followed by sand filtration and membrane filtration. MF membrane produced by KOLON, Korea with membrane surface area of 20 m^2, and pore size of 0.1 ㎛ (CLEANFIL -S20HP) was used.

However, performance data of ozonation and activated carbon are excluded in this paper because the main focus is on the comparison of sand filtration and membrane filtration.

2.2 Operational Condition

Conditions of unit operations in each line were set up as the same as the conditions of the unit operations in C water treatment plant where the pilot plant is located. About 30mg/l of PAC was used as a coagulant of which concentration was decided by jar test. Ozone was applied in total 0.5~2.5mg/l of pre- and post-ozonation even though data of ozone application were not included in this paper. Operational condition of membrane filtration was based on the suggestion of the manufacturer, which is shown in Table 1.

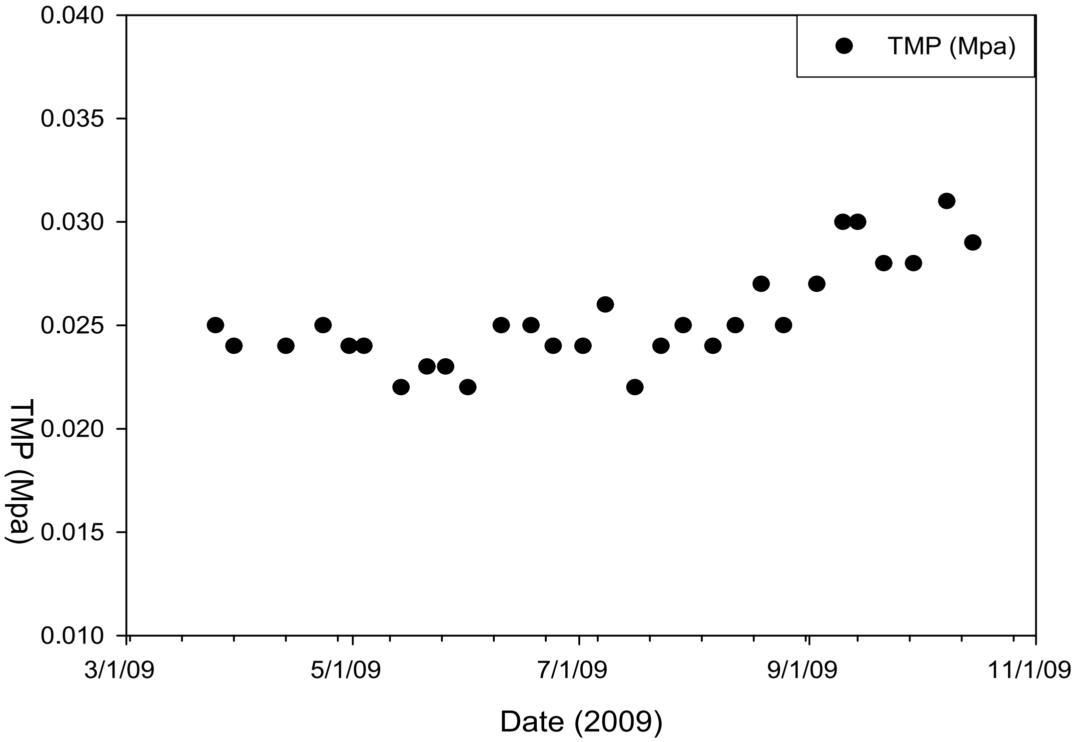

Fig. 2. Transmembrane status during the investigation

Flow rate was maintained at a constant rate of 30m^3/dby pressure pump with a constant flux of 60L/m^2·hr. Highest head loss limit was set up in 2metersfor automatic backwashing of the membrane. Backwashing was taken place in one or two days during the investigation. Chemical cleaning has also been performed continuously to prevent from increasing transmembrane pressure, such that transmembrane pressure was sustained in the range of 0.02−0.03Mpa.Transmembrane status during the investigation is shown in Fig. 2.

Even if manufacturer's manual recovery cleaning by chemicals is required when suction pressure increases up to 300mmHg ~ 500mmHg, or operation period lasts 6month to one year, after 3~4month of operation suction pressure increased up to 500mmHg. At this time turbidity was simultaneously increased in membrane filtrate. Membrane module was taken out of the basin for recovery cleaning, and the module was washed by high pressure water to clean out the attached sludge on the surface of the membrane. After cleaning by water, the module was put in chemical cleaning solution of NaOCl 0.5%, NaOH 1%, and citric Acid 1% for 12 hours or more. Operational condition of the pilot plant is presented in Table 2.

2.3. Analyses of Water Quality Parameters

Water quality of the membrane and sand filtration system was compared with that of raw water. Samples were taken at the effluent of each unit operation using sterilized bottles. pH, temperature, and turbidity were analyzed every day. TOC, DOC, $KMnO_4$, THMFP, and HAAFP were analyzed 1~2times per week. The parameters were measured by Standard Methods. Table 3 shows analyzing methods and instruments for measuring water quality parameters.

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Table 2 Operational condition of the pilot plant

Unit operation		Operating condition
Line 1	preozonation	- Retention time: 6.62min. - Ozone dose: 0.5~1mg/l
	Rapid mixing	Retention time: 2.35min.
	flocculator	Retention time: 36.41min.
	sedimentation	- Retention time: 3.86hrs - Surface flow rate: 6.21m^3/m^2/day
	Sand filtration	Filtration velocity: 120m/day
	postozonation	- Retention time: 14.5min. - Ozone dose: 0.5~2mg/l
	GAC	- EBCT: 14.8min. - Linear velocity: 10m/hr - Bed depth: 2.5m
Line 2	preozonation	- Retention time: 6.62min. - Ozone dose: 0.5~1mg/l
	Rapid mixing	Retention time: 2.35min.
	flocculator	Retention time: 36.41min
	Inclined plate sedimentation	- Retention time: 3.33hrs
	membrane	- Flux: 60L/m^2·hr
	postozonation	- Retention time: 14.5min. - Ozone dose: 0.5~2mg/l
	GAC	- EBCT: 14.8min - Linear velocity: 10m/hr - Bed depth: 2.5m

Table 3. Analyzing methods and instruments used in the measurement

parameter	analyzing method	Instrument
temperature	Direct Measurement	Thermometer
Turbidity	Turbidity meter	HACH-2100AN Turbidimeter(HACH)
TOC	Ultraviolet and photocatalyst	TOC Analyzer (Sievers 900, GE)
DOC	Ultraviolet and photocatalyst	TOC Analyzer (Sievers 900, GE)
$KMnO_4$	Standard Methods	-
THMFP	Standard Methods	GC-ECD (6890N,Agilent Technologies)
HAAFP	Standard Methods	GC-ECD (6890N,Agilent Technologies)

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3. Results and Discussion

3.1. Raw Water Characteristics in temperature and turbidity

Temperature of raw water was varied from 7.7℃at lowest to 28.4℃at highest with an average 18.3℃ Turbidity of raw water was the highest 18.8NTU, and the lowest 1.6NTU with average 4.42NTU. Turbidity was soared in rainy season, from July to mid of August. Temperature and turbidity change of raw water is shown in **Fig. 3.**

3.2. Results of the Pilot Tests

1) Turbidity

Even if variation of turbidity was great from rainy season to dry season, separation capability of sand filtration and membrane (MF) showed very good and consistent such that an average effluent turbidity was 0.14NTU with about 97% of removal in sand filtration and 0.19NTU with about 96% of removal in membrane. Experimental result regarding turbidity is presented in **Fig. 4.**

2) TOC

TOC in raw waterwas 4.05mg/l at highest level, and 2.76mg/l at lowest level with 3.365mg/L in average. TOC level was increased in rainy season of summer. TOC concentration in effluent of sand filtration was 1.99mg/l in average, while 2.07mg/l in that of membrane filtration. Removal rate of TOC was 40.8% in sand filtration, while 38.1% in membrane filtration as an average. Even though the difference of average TOC concentration was not great in effluent, the difference was growing with time. The pattern of the TOC removal is showing in **Fig. 5.** Effluent TOC concentration was steadily maintained in membrane filtration as it may be seen in Fig. 5, while that in sand filtration was tended to be decreasing as time passed. It is believed that microbial activity in sand filter bed was growing with time after about 4months later of operation.

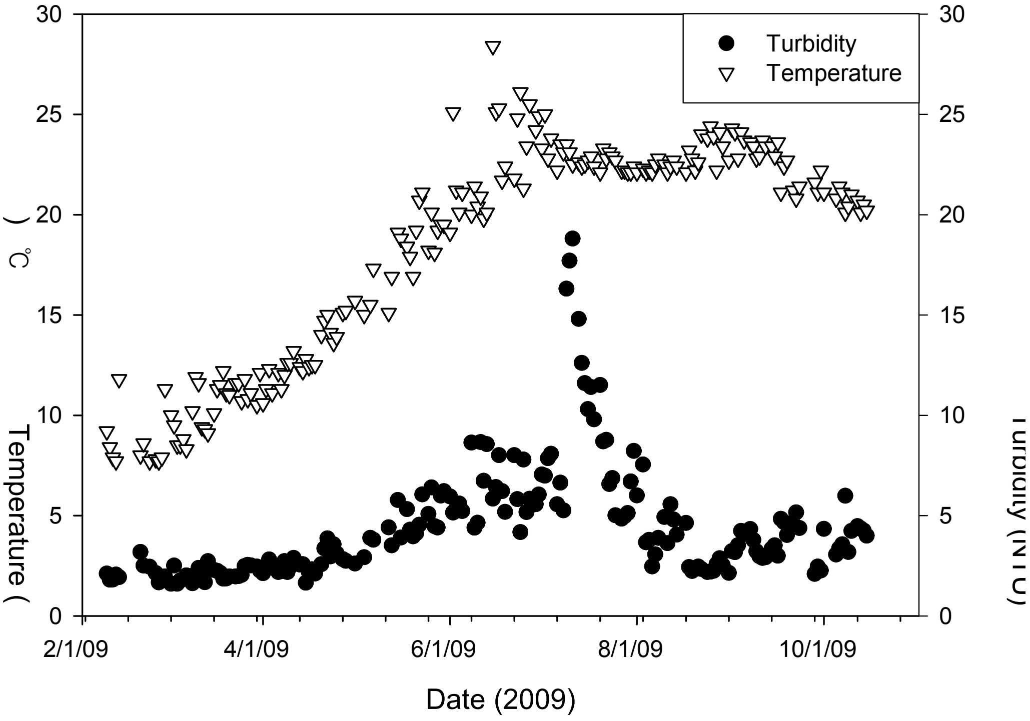

Fig. 3. Temperature and turbidity change of raw water

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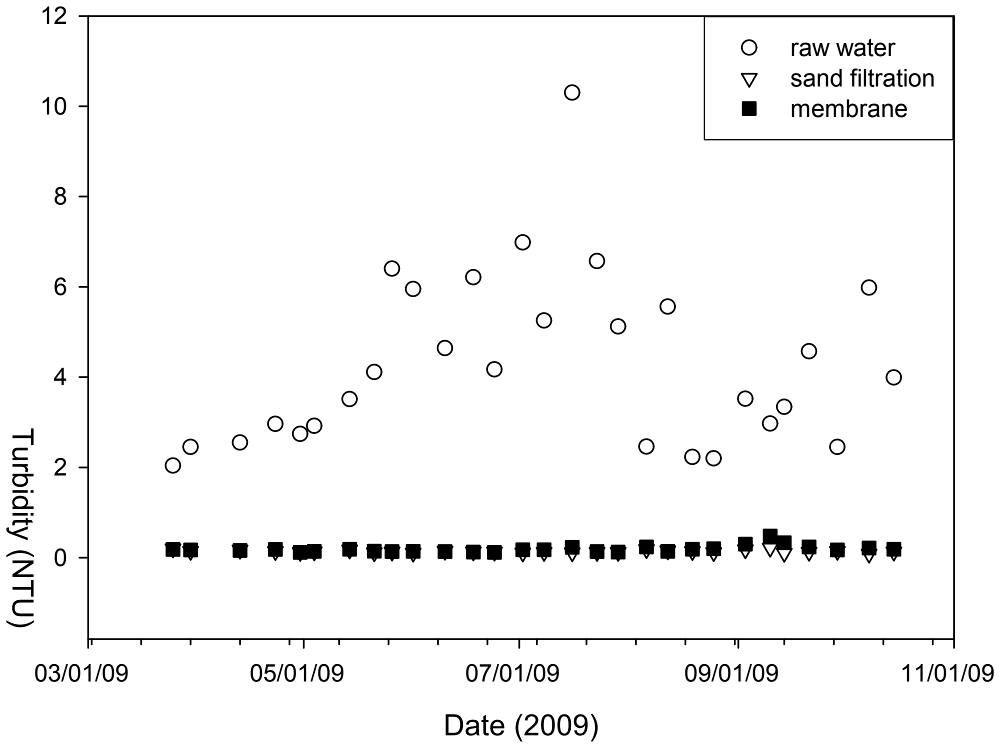

Fig. 4. Removal capabilities of turbidity of sand filtration and membrane (MF)

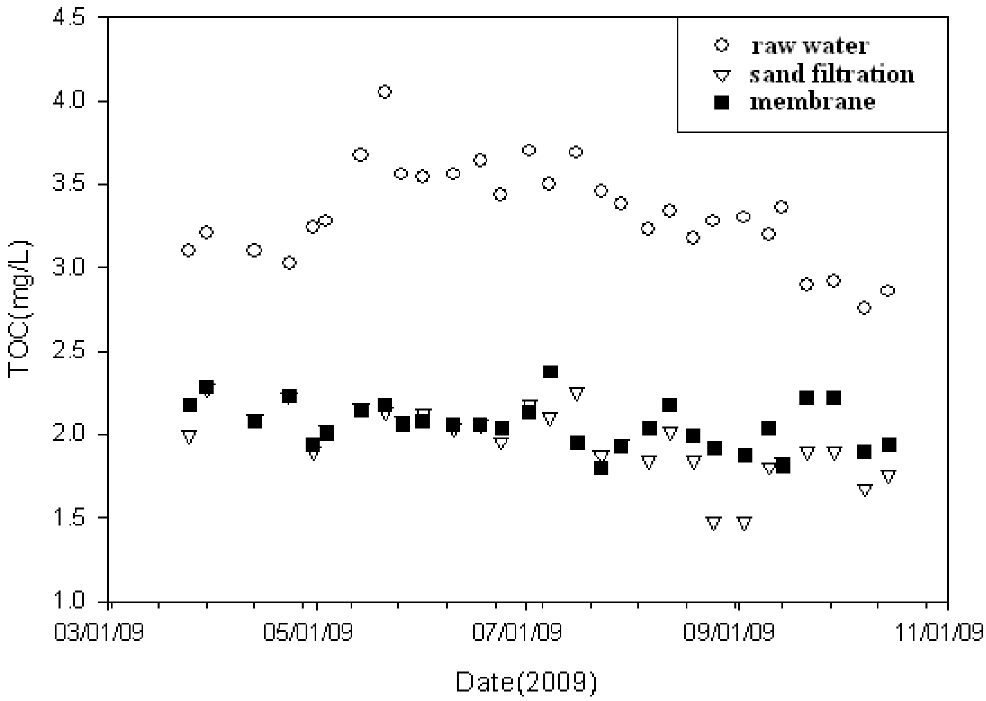

Fig. 5. Effluent concentrations of TOC in sand filtration, and membrane filtration (MF)

3) DOC

DOC concentration in raw water was 3.52~2.44mg/l with 3.01mg/l of an average. DOC concentration in sand filtration was 1.90mg/l, while that in membrane was 1.97mg/l as an average. Removal rate of DOC in sand filtration was 37.4%, and that in membrane was 35.0% as a whole. As in TOC, removal efficiencies of DOC was enhanced with time in sand filtration, while that in membrane stayed in similar rate as shown in **Fig. 6.** Removal rate was being enhanced from around July in sand filtration, which is believed that microbial community began to be activatedin sand filter bed. Before July, removal rate of DOC was slightlyhigher in membrane filtration, probably because performance of filtration was better in membrane. Once microbial community has been formed in sand filterbed, filtration performance of microbial community in sand filter bed seemed to be higher than that of membrane.

4) KMnO4 consumption

KMnO4 consumption or KMnO4 demand is usually used as an indicator of organic matter in water even if KMnO4 may oxidize inorganic material like Fe and Mn. KMnO4 consumption in raw water was 12.39mg/l at maximum level, and it was 5.63mg/l at lowest level with 8.43mg/l of an average. It was reduced down to 3.06mg/l in sand filtration, and 3.36mg/l in membrane as an average. If it is estimated forremoval rate, 63.7% of KMnO4 consumption was removed in sand filtration, while 60.2% was removed in membrane as an average. As a similar reason in other parameters like TOC and DOC, removal rate of KMnO4 consumption was being increased with time as shown in **Fig. 7.**

5) THMFP

THMFP is an indicator of possible production of THM by disinfection process in water treatment. Range of THMFP concentration in raw water was

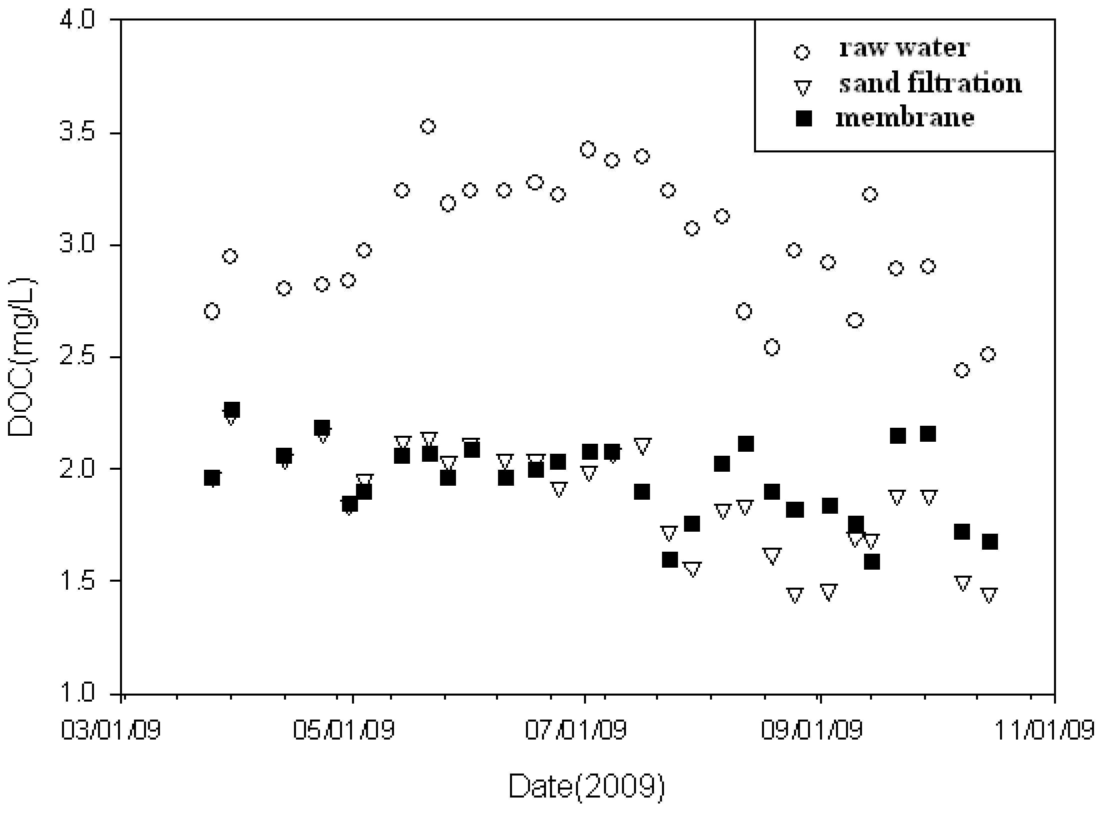

Fig. 6. Effluent concentrations of DOC in sand filtration, and membrane filtration (MF)

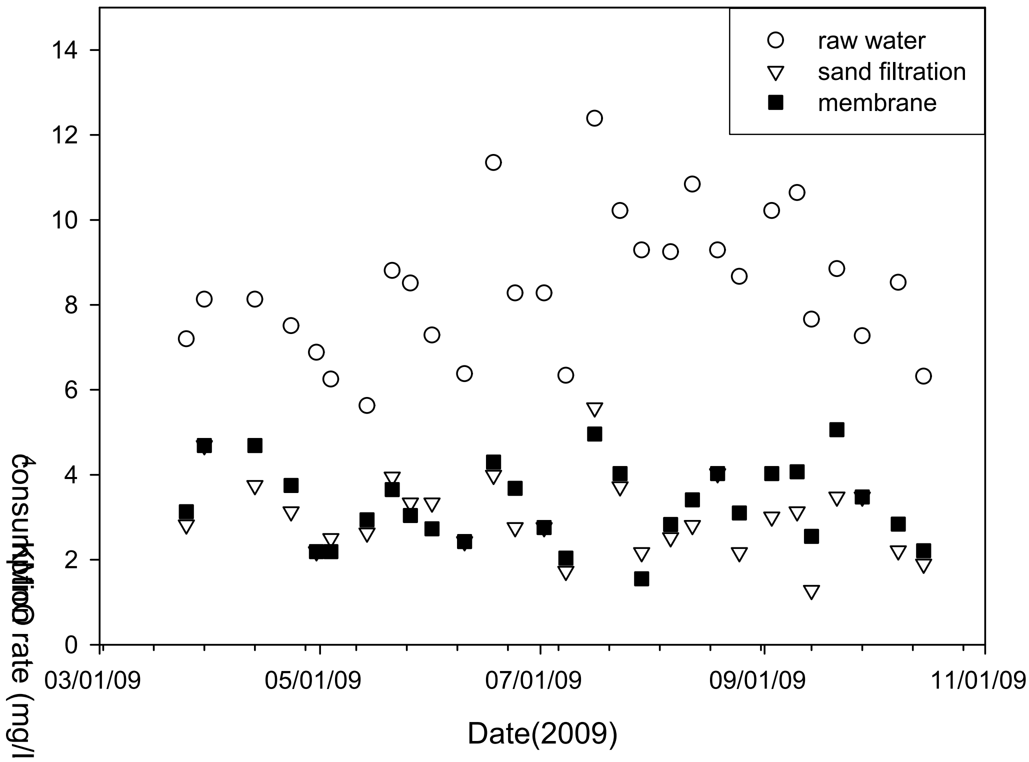

Fig. 7. Effluent concentrations of $KMnO_4$ in sand filtration and membrane filtration (MF)

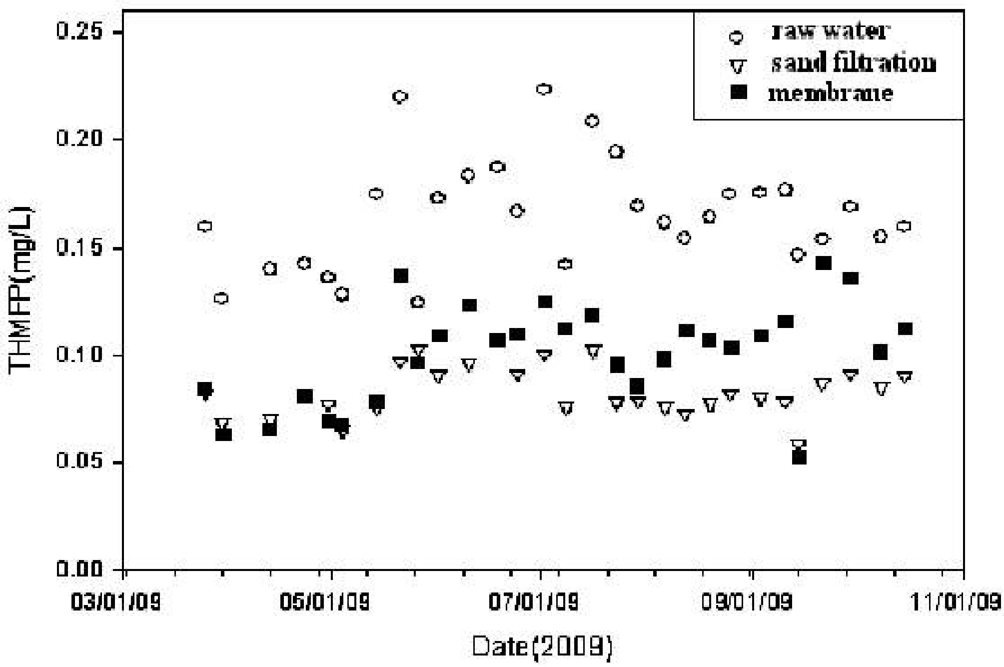

Fig. 8. Effluent concentrations of THMFP in sand filtration and membrane filtration (MF)

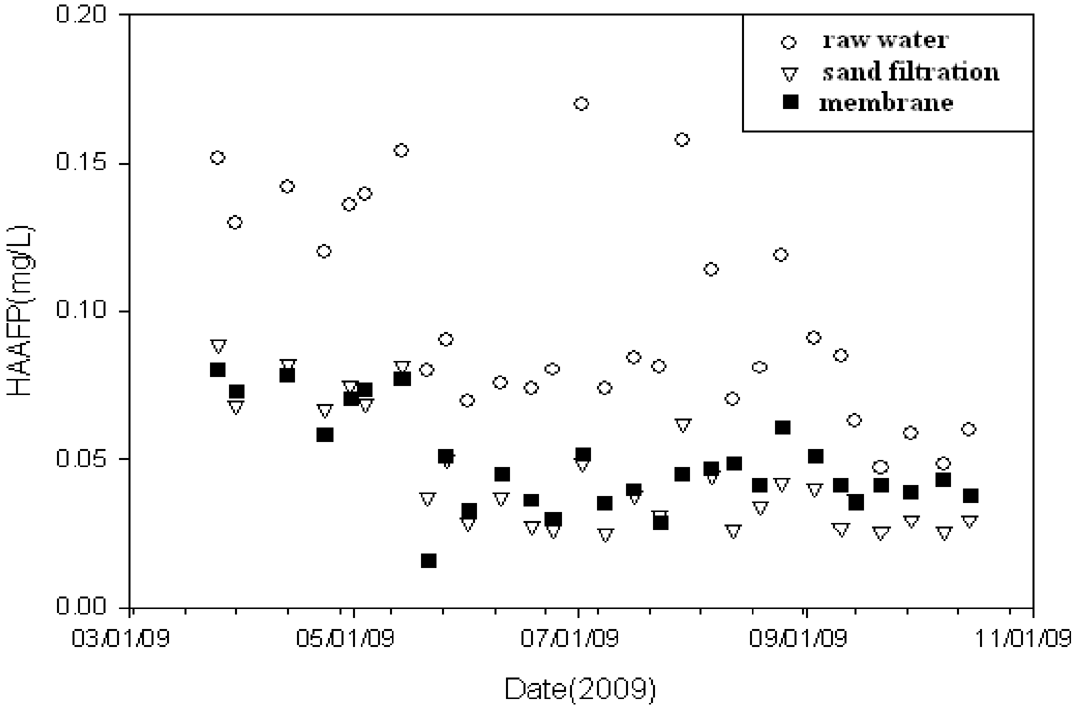

Fig. 9. Effluent concentrations of THMFP in sand filtration, and membrane filtration (MF)

124.2~223.2㎍/l with 165.6㎍/l as an average. It was lowered down to 83.4㎍/l in sand filtration, and 100.3 ㎍/lin membrane as an average. Average removal rate of THMFP was 49% in sand filtration, while that was 39.4% in membrane. As it can be seen in **Fig. 8,** removal of THMFP was lowered with time in membrane filtration. It is thought that the decreasing of THMFP removal with time in membrane occurred due to increasing trans−membrane pressure. Membrane fouling continuously took place by accumulating suspended solids in membrane tank. Even though backwashing has been made in regular basis, it could not be possible to avoid membrane fouling. In contrast, removal of THMFP was enhanced with time in sand filtration as other parameters as it may be seen in **Fig.8.**

At the beginning of the operation, removal of THMFP was higher in membrane than that in sand filtration. However removal efficiencies between sand filtration and membrane filtration were reversed around mid of June,from which microbial activity began to be important.

6) HAAFP

Range of HAAFP in raw water was 47.5~169.7㎍/l with an average of 98.9㎍/l. As an average, concentration of HAAFP in effluent of sand filtration was 46.4㎍/l, and that of membrane filtration was 49.4 ㎍/l. Slightly lower average concentration of HAAFP was produced in sand filtration. An average removalrate of HAAFP in sand filtration was 54.6%, and that in membrane filtration was 49.7%. At the beginning of operation, removal rate of HAAFP was higher in membrane filtration, for which microbial community was believed not to be fully activated. After microbial activity was initiated, removal rate of HAAFP was getting higher in sand filtration as illustrated in **Fig. 9.**

Removal characteristics of water quality parameters in two different processes, which are sand filtration and membrane filtration (MF) are arranged in Table 4. Removal performances are separated in two periods. The first period for which microbial activity was not fully activated, lasted about 4months after operation. In the first period, average

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Table 4. Effluent concentrations and removal rates of sand filtration and membrane filtration(Pilot plant were operated from early February, 2009)

parameters	comparison	3/25～6/24		7/2～10/15	
		Sand filtration	Membrane filtration	Sand filtration	Membrane filtration
TOC	Conc.(mg/l)	2.09	2.11	1.87	2.02
	Removal rate(%)	39.0	38.4	42.5	37.9
DOC	Conc.(mg/l)	2.05	2.03	1.743	1.89
	Removal rate(%)	33.5	34.0	41.4	36.3
KMnO4	Conc.(mg/l)	3.19	3.43	2.87	3.31
	Removal rate(%)	58.6	56.7	68.1	63.2
소—레	Conc.(mg/l)	85.3	91.7	82.4	108.1
	Removal rate(%)	46.2	42.1	51.6	36.6
HAAFP	Conc.(mg/l)	56.9	55.7	35.5	43.1
	Removal rate(%)	48.7	49.8	59.5	50.9

removal rates of the water quality parameters did not much differ in two processes as it can be seen in Table 4. However in the later second period for which it is believed that microbial activity was fully activated, removal rates were higher in sand filtration for all water quality parameters. It is known that microbial agents are activated in activated carbon in about 3-4months depending on the system conditions such as water temperature and organic contents in water (Son *et al.*, 2009, Servais *et al.,* 1994, Griffini *et al.*,1999) Priorfindings regarding activation of microorganism in activated carbon are similar with the outcome of the investigation. Especially extent of removal was profound in THMFP and HAAFP.It is believed that removal of dissolved organic such as DOC was higher in sand filtration, so that source material of THMFP and HAAFP was removed more in sand filtration. Even if separation capability is greater in MF than in sand filtration, it may not be guaranteed in higher removal of major water quality parameters in MF for drinking water treatment (Jegatheesan *et al*, 2009).

4. Conclusion

Membrane filtration is being thought to be an alternative of sand filtration in water treatment. Micromembrane(MF) is the realistic option out of various filters because of energy consumption. In this paper, operating performances of sand filtration and membrane filtration (MF) were compared in advanced water treatment using $30m^3$/d of pilot plant.

Sand filtration showed better performance in removing water quality parameters like TOC, DOC, KMnO4 consumption, THMFP, and HAAFP. At the beginning of the operation of the pilot plant, a couple of parameters like DOC and HAAFP were removed better in membrane filtration. However, as time passes removal of the parameter were getting higher in sand filtration especially after about 4months of operation. It is believed that it took about 4months for microbial community to be fully activated in san filter bed.

It was revealed that microbial filtration was an important mechanism to remove various organic materials in water. Even if membrane filtration has higher separation capability than sand filtration, overall removal efficiency of water quality parameters was higher in sand filtration, so that membrane filtration may not be a good alternative of sand filtration in water treatment.

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