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Lake Water Treatment using Ceramic Ultrafiltration Membrane System with Periodic Water-backflushing

Jin Yong Park†, Gee Yong Kyung, Song Hee Han, Hyun Woo Kim, and Hyuk Chan Lee

Department of Environmental Sciences & Biotechnology, Hallym University, Chuncheon, Kangwon 200-702, Korea

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Abstract: We treated lake water by ceramic ultrafiltration membranes and found the optimal backflushing period and trans-membrane pressure (TMP) of periodic water-backflushing system. The optimal filtration time interval at fixed BT = 3 sec was 30 for A002 membrane in all viewpoints of J/J_o, R_f, and V_T, and we could acquire the highest V_T value in the membranes used here. However, the highest V_T was acquired at FT = 60 sec for M9, and at FT = 90 sec for C005 membrane. Then the lower TMP reducedthe membrane fouling during filtration of lake water, and could maintain the higher permeate flux compared with the initial flux. However, the largest value V_T could be obtained at the highest TMP condition for M9 membrane at fixed FT = 60 sec and BT = 3 sec. The quality of treated water in our UF ceramic system was Turbidity = 0.20~4.88 NTU, COD_{Mn} = 0.00~2.58 mg/L, TDS = 18~71 mg/L, and NH_3-N = 0.004~1.689 mg/L.

Keywords: *ceramic membrane, water-backflushing, ultrafiltration, lake water, fouling*

1. Introduction

Many researchers have published the results of wastewater treatment by membrane separation. Tchobanoglous *et al.*[1] treated highly the domestic wastewater by ultrafiltration (UF), and Roorda *et al.*[2] investigated the characteristics of UF for effluents of two wastewater treatment plants. As an example of applications of ceramic membranes used in this study Li *et al.*[3] used ceramic MF membranes to separate cells from *E. coli*-containing fermentation broth. However, the economic efficiency of membrane separation for wastewater treatment should depend on the power cost of operation, the permeate flux, and the membrane lifetime. The lifetime of membranes has a deep relation with membrane fouling during the operation. It was well known that the membrane fouling was made by concentration polarization and gel layer formation on the surface of membranes, and adsorption and pore blockage in the pores inside membranes. Therefore, a lot of researches have been accomplished for solving the membrane fouling in the world. Then, the membrane backflushing is a new technology to minimize the membrane fouling, and to maintain a high permeate flux during membrane separation. Many papers related with membrane backflushing have been published nowadays. Davis *et al.*[4] built up a modeling of concentration and depolarization with high frequency backpulsing. And Kuberkar *et al.*[5] could reduce the fouling resistance of pollutant layer on the membrane by backflushing in the microfiltration of protein cell mixture (BSA, yeast). Then, we published membrane fouling control effects of periodic water-backflushing period, TMP, and flow rate using tubular carbon ceramic UF and MF membranes for recycling paper wastewater[6]. Also, we recently reported effects of periodic N_2-backflushing in paper wastewater treatment using carbon UF and MF membranes[7].

In this study we treated lake water by ceramic ultrafiltration membranes and found the optimal backflush-

†Author for all correspondences
(e-mail : jypark@hallym.ac.kr)

Table 1. Specification of Tubular UF Ceramic Membranes Used in this Study

Membrane	M9	C005	A002
Pore size (μm) or MWCO	300,000 Dalton	0.05	0.02
Outer diameter (mm)	8	8	10.5
Inner diameter (mm)	6	6	7
Length (mm)	255	250	252
Surface area (cm^2)	48.1	47.1	55.4
Company	Tech-Sep (France)	Koch (U.S.A)	Dongseo (Korea)
Material	Zirconium dioxide on silica support	Carbon fiber	Alumina on Silica support

ing period and trans-membrane pressure (TMP) of periodic water-backflushing system. Generally ceramic membranes were washable by strong acid or high pressure steam because of their high mechanical strength, and had a long life time.

2. Theory

The resistance-in-series filtration equation shown in equation (1) was applied to analyze the experimental data of this research. The equation was known well in the application field of membrane separation. Carrene *et al.*[8] investigated the resistance of membrane, cake of bacterial cell, adsorption, and concentration polarization of solution by using equation (1).

$$J = \Delta P \ / \ (R_m + R_b + R_f) \quad (1)$$

Where J was the permeate flux through membrane, P was TMP (trans-membrane pressure), R_m the resistance of membrane, R_b the resistance of boundary layer, and R_f the resistance of membrane fouling.

For filtration of pure water, R_b and $R_f$did not exist because of no boundary layer by concentration polarization and no membrane fouling by pollutants. The equation (1) could be simplified to equation (2).

$$J = \Delta P \ / \ R_m \quad (2)$$

Now R_m could be calculated from the experimental data of permeate flux for pure water using equation (2). Then, the plot of R_b+R_f vs. t (operation time) could be obtained from the permeate flux data using waste- water. The intercepting value of y-axis (t=0) in this plot using only initial 2 or 3 data was R_b because of no R_f at the initial time of filtration, and finally R_f could be calculated using equation (1).

3. Experiments

3.1. Ceramic Membranes

Here we used carbon membranes CARBO-COR C005 (pore size 0.05 μm, carbon fiber, Koch), M9 (MWCO 300,000, zirconium dioxide coating on carbon, Tech-Sep), and alumina membrane A002 (pore size 0.02 μm, alumina coating on silica, Dongseo). Table 1 showed the characteristics and specifications of tubular ceramic membranes used in this research. The tubular membranes were used here for making a cross-flow to reduce the membrane fouling.

3.2. Lake Water Source

The lake water was sampled at the end of Gongjee-river in Chuncheon City, andquality of the lake water was shown in Table 2. The quality was varied a little depending on the condition of lake and branch of Gongjee-river. However, a set of experiments to see one of effects on the membrane fouling was done using the lake water sampled at the same time.

3.3. Experimental Procedures

As shown in Fig. 1. we designed and made the ce-

Table 2. The Quality of Lake Water Used in this Study

Membrane	Experimental Conditions		Turbidity (NTU)	COD_{Mn} (mg/L)	TDS (mg/L)	NH_3-N (mg/L)
M9	Effect of FT	Range	2.86~12.78	1.29~2.21	44~113	0.359~1.129
		Average	6.89	1.91	66	0.718
	Effect of TMP	Range	4.20~6.38	1.10~3.44	41~89	0.871~2.219
		Average	5.13	2.42	55	1.510
C005	Effect of FT	Range	8.63~19.80	2.02~9.20	62~80	0.303~0.923
		Average	13.33	5.30	70	0.485
A002	Effect of FT	Range	5.68~11.36	0.92~4.97	40~129	0.051~1.592
		Average	7.98	3.28	65	0.623

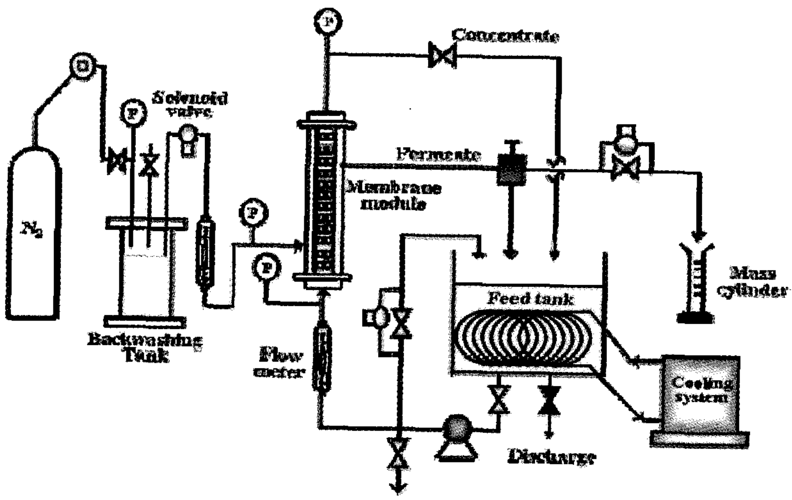

Fig. 1. Apparatus of ultrafiltration with periodic water-backflushing system.

ramic membrane module and ultrafiltration apparatus with periodic water-backflushing system in our laboratory. The feed tank was filled with 5 L of lake water, and it flowed to the inside of the tubular ceramic membrane. The permeate flow and the concentrate flow were recycled to the feed tank to maintain the concentration of the feeding lake water almost constant during operation. The backflushing water flowed periodically to the outside of the tubular membrane.

To find optimal filtraition time interval (FT), backflushing time (BT) was fixed at 3 sec and only FT was controlled from 15 to 90 sec. And TMP also was fixed at 1.55 kg_f/cm^2, water-backflushing pressure at 1.00 kg_f/cm^2, feed flow rate at 0.5 L/min. Then BT was fixed at 3 sec and FT at 60 sec, and only TMP was controlled from 0.7 to 2.2 kg_f/cm^2 to see effect of TMP.

4. Results and Discussions

The experimental results were compared with others in the viewpoints of dimensionless permeate flux (J/J_o) (J: permeate flux at a given time, J_o: initial permeate flux at t=0), total permeate volume (V_T), and resistance of membrane fouling (R_f) after 3 h filtration of lake water. The resistances of boundary layer (R_b), membrane (R_m) and $R_f$were calculated from experimental values of permeate flux using the resistance-in-series filtration model of equation (1).

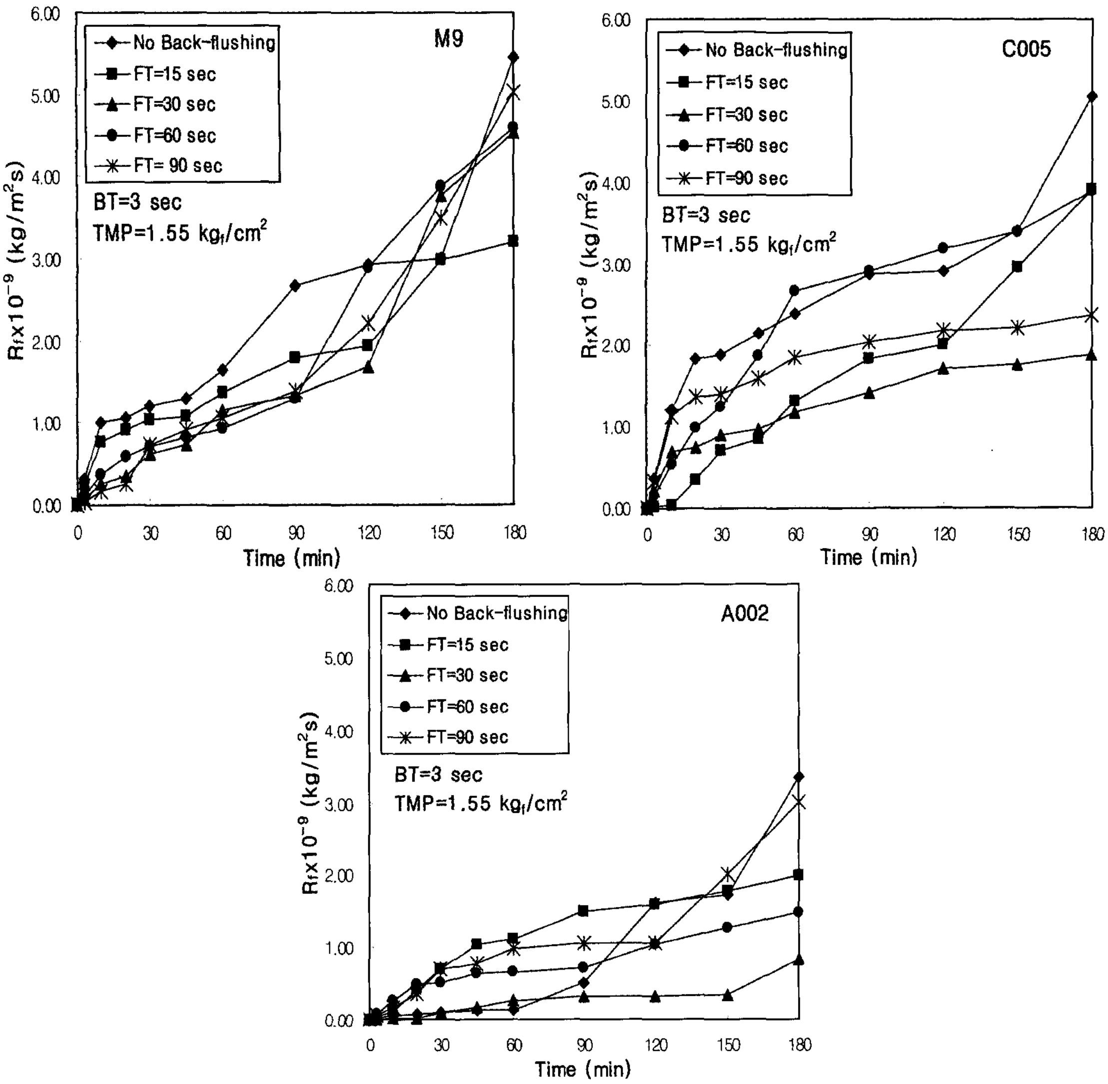

Fig. 2. Effect of filtration time interval on resistance of membrane fouling for M9, C005, and A002 membranes at BT = 3 sec and TMP = 1.55 kg$_f$/cm^2.

4.1. Effect of Filtration Time Interval

The effect offiltration time interval (FT) with periodic 3 sec water-backflushing on membrane fouling resistance R_f was shown in Fig. 2 for M9, C005, and A002 membranes. In Fig. 2 the lowest values of R_f could be maintained at FT = 15 sec for M9, and at FT = 30 sec for C005 and A005 membranes. In case of M9 membrane the shorter FT was more effective to reduce membrane fouling compared with C005 and A002 membranes. Then the absolute values of membrane fouling for A005 was much lower than those of M9 and C005 membranes. Therefore Korean membrane A005 was most excellentfor reduction effect of membrane fouling by water-backflushing in membranes used in our experiments.

Also, the highest value of the permeate flux on time (J) vs. the initial permeate flux (J_o) could be found at FT = 15 sec for M9, and at FT = 30 sec for C005 and A005 membranes. It means that FT = 15 sec for M9, and FT = 30 sec for C005 and A005 membranes were the most effective filtration time interval at BT = 3 sec to maintain high permeate flux during filtration with periodic water-backflushing in our lake water treatment system.

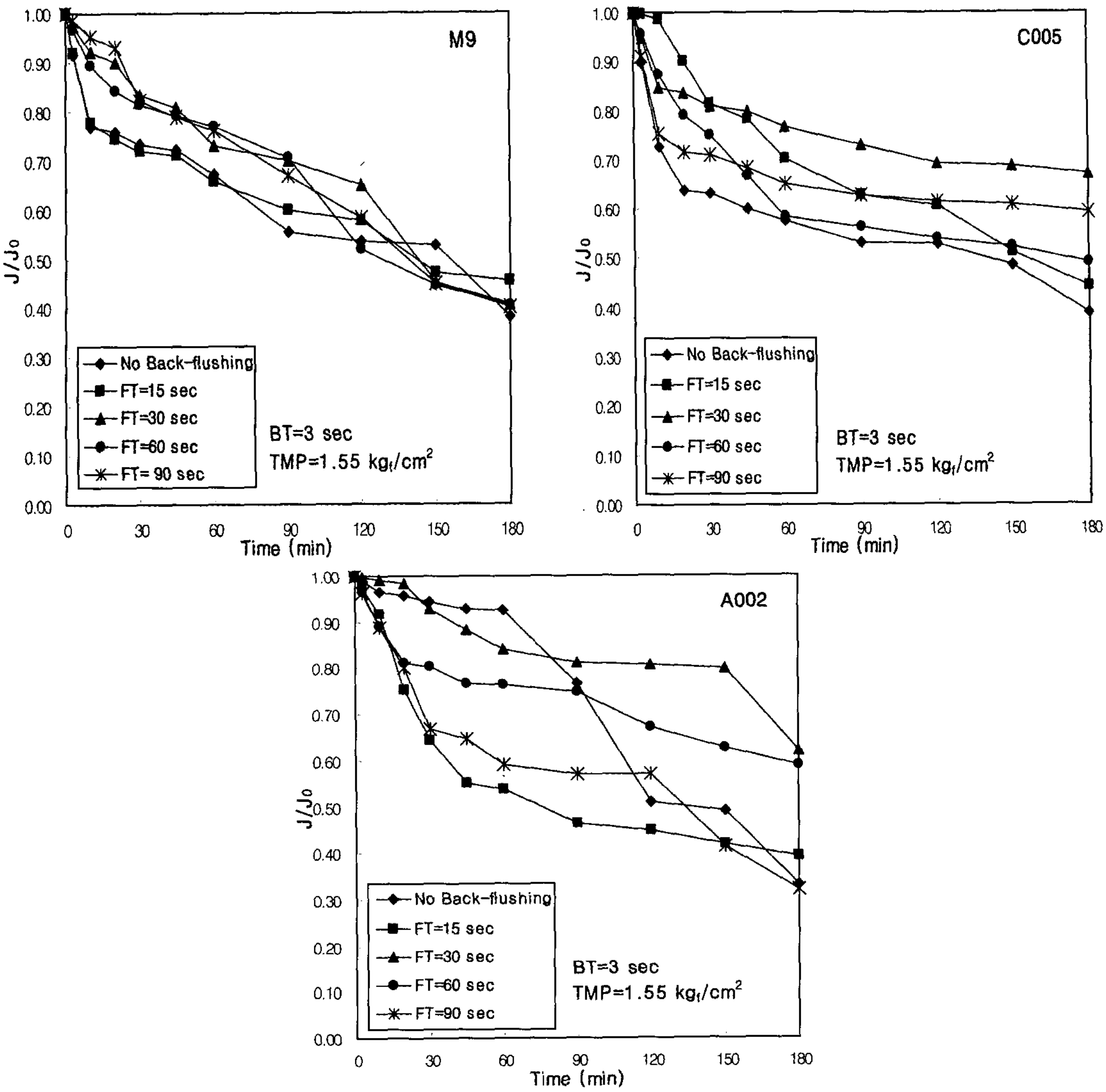

Fig. 3. Effect of filtration time interval on dimensionless permeate flux for M9, C005, and A002 membranes at BT = 3 sec and TMP = 1.55 kg_f/cm^2.

Then the highest total permeate volume (V_T) of 1.551 L was acquired at FT = 60 sec and BT = 3 sec for M9 as shown in Table 3. And the highest V_T was 1.422 L at FT = 90 sec for C005, and 4.327 L, which was the highest volume in the membranes used here, at FT = 30 sec for A002 membrane. Therefore in all viewpoints of J/J_o, R_f, and V_T, the optimal FT was 30 sec for A002. This means that frequent water-back-flushing should give a little chance for pollutant particles to be accumulated on the membrane surface, and could break a boundary layer of concentration polarization. However, the shorter FT should reduce the more total filtration time, and the optimal FT condition depended on the characteristics of each ceramic membrane as its pore size or materials of active layer.

4.2. Effect of Trans-membrane Pressure

We tried to find an optimal trans-membrane pressure (TMP) for M9 membrane at the fixed FT = 60 sec and BT = 3 sec, which was the optimal filtration time interval in our experiments of FT effect. The lowest value of membrane fouling resistance could be found at

Table 3. Filtration Factors in the Experiments for Effect of FT at BT=3 sec using M9, C005 and A002 Membranes

Filtration Factors	Membrane	No backflushing	FT (sec) 15	30	60	90
$V_T \times 10^3$ (m^3)	M9	14.04	1.493	1.535	**1.551**	1.518
	C005	13.36	1.392	1.368	1.210	**1.422**
	A002	33.17	2.663	**4.327**	2.529	3.067
$R_{f,180} \times 10^{-9}$ (kg/m^2s)	M9	5.45	**3.21**	4.53	4.59	5.03
	C005	5.06	3.92	**1.89**	3.89	2.36
	A002	3.35	1.98	**0.83**	1.47	3.01
$J_0 \times 10^5$ (m/s)	M9	4.54	5.72	4.89	4.89	4.48
	C005	4.70	4.90	3.96	4.08	4.42
	A002	9.11	11.78	11.20	7.18	10.71
$J_{180} \times 10^5$ (m/s)	M9	1.73	**2.59**	1.99	1.97	1.81
	C005	1.83	2.17	**2.65**	2.00	2.62
	A002	3.03	4.64	**6.96**	4.23	3.43

Table 4. Filtration Factors in the Experiments for Effect of TMP at FT=60 sec and BT=3 sec using M9 Membranes

	TMP (kg_f/cm^2)	0.7	1.0	1.55	2.0	2.2
M9 (MWCO:300,000 Daltons)	$V_T \times 10^3$ (m^3)	1.137	1.309	1.627	2.000	**2.076**
	$R_{f,180} \times 10^{-9}$ (kg/m^2s)	**0.91**	1.85	4.01	4.22	4.32
	$J_0 \times 10^5$ (m/s)	2.80	4.05	5.56	6.52	**7.23**
	$J_{180} \times 10^5$ (m/s)	2.04	2.29	2.25	2.71	**2.95**

TMP = 0.7 kg_f/cm^2, which was lowest TMP in our experimental conditions, as shown in Fig. 4. Also, we got the highest J/J_0 values at the same TMP = 0.7 kg_f/cm^2 as shown in Fig. 5. It means the lower TMP should reduce the membrane fouling during filtration of lake water, and could maintain the higher permeate flux compared with the initial flux.

However, TMP was driving force in our lake water filtration system, and the largest value V_T of 2.076 L could be obtained at the highest TMP condition of 2.2 kg_f/cm^2 as shown in Table 4. These results of TMP effect in lake water treatment were almost same with the results of our previous work[9], which was paper wastewater treatment with periodic N_2-backflushing using multi channels ceramic microfiltration.

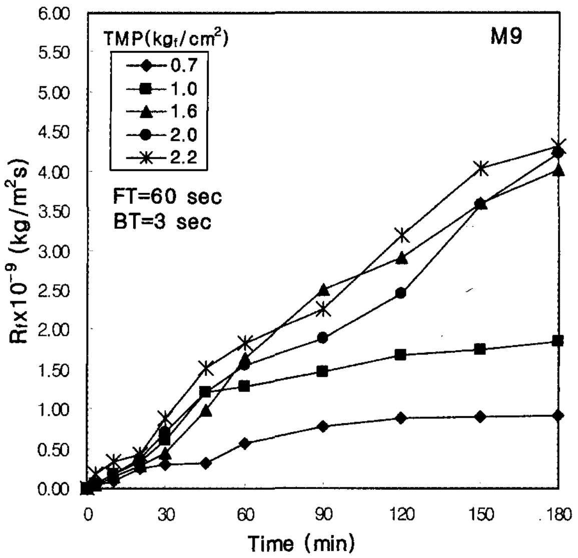

Fig. 4. Effect of trans-membrane pressure on resistance of membrane fouling for M9 membrane at FT = 60 sec and BT = 3 sec.

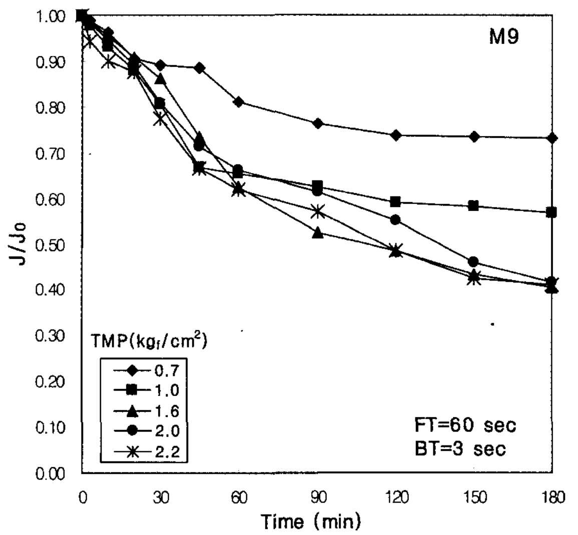

Fig. 5. Effect of trans-membrane pressure on dimensionless permeate flux for M9 membrane at FT = 60 sec and BT = 3 sec.

4.3. Rejection Rate of Pollutants

Average rejection rates of turbidity, COD_{Mn}, TDS, and NH_3-N were arranged in Table 5, where the rejection rate of turbidity was above 86.9%, that of COD_{Mn} above 43.1%, that of TDS above 27.8%, and that of NH_3-N above 34.1%. Then C005 membrane

Table 5. Average Rejection Rates of Tubular UF Ceramic Membranes used in this Study

Membrane	Rejection rate	Turbidity (%)	COD_{Mn} (%)	TDS (%)	NH_3-N (%)
M9 (500,000 Daltons)	Effect of Filtration Time	86.9	43.1	29.5	41.5
	Effect of TMP	89.49	52.3	28.2	34.1
C005 (0.05 μm)	Effect of Filtration Time	96.7	65.9	42.9	77.8
A002 (0.02 μm)	Effect of Filtration Time	87.6	71.9	27.8	35.6

could reduce turbidity to 96.7%, TDS to 42.9% and NH_3-N to 77.8%, and A002 membrane could do COD_{Mn} to 71.9%. Therefore C005 membrane showed most excellent rejection rates in the ceramic UF membranes used here.

The quality of treated water in our UF ceramic system was Turbidity = 0.20~4.88 NTU, COD_{Mn} = 0.00 ~2.58 mg/L, TDS = 18~71 mg/L, and NH_3-N = 0.004~1.689 mg/L, which also depended on the characteristics of each membrane. So our treated water was not satisfied with drinking water standard of turbidity lower than 2 NTU, and it could be used asindustrial water.

5. Conclusions

In our lake water treatment using ceramic UF membrane with periodic water-backflushing the optimal filtration time interval at fixed BT = 3 sec was 30 for A002 membrane in all viewpoints of J/J_o, R_f, and V_T, and we could acquire the highest V_T value in the membranes used here. However, the highest V_T was acquired at FT = 60 sec for M9, and at FT = 90 sec for C005, which were the optimal filtration time interval at fixed BT = 3 sec.

Then the lower TMP should reduce the membrane fouling during filtration of lake water, and could maintain the higher permeate flux compared with the initial flux. However, TMP was driving force in our lake water filtration system, and the largest value V_T of 2.076 L could be obtained at the highest TMP condition for M9 membrane at fixed FT = 60 sec and BT = 3 sec, which was the optimal filtration time interval in our experiments.

The quality of treated water in our UF ceramic system was Turbidity = 0.20~4.88 NTU, COD_{Mn} = 0.00 ~2.58 mg/L, TDS = 18~71 mg/L, and NH_3-N = 0.004 ~1.689 mg/L which also depended on the characteristics of each membrane. And our treated water could be used as industrial water because of low turbidity.

Nomenclature

BT : Backflushing time [s]
FT : Filtration time interval [s]
J : Permeate flux at a given time [m/s]
J_o : Initial permeate flux at t=0 [m/s]
J/J_o : Dimensionless permeate flux [dimensionless]
ΔP : TMP (Trans-membrane pressure) [kg_f/cm^2]
R_b : Resistance of boundary layer [kg/m^2s]
R_f : Resistance of membrane fouling [kg/m^2s]
R_m : Resistance of membrane [kg/m^2s]
t : Operation time [min]
V_T : Total permeate volume [m^3]

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