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Water Treatment of High Turbid Source by Tubular Ceramic Microfiltration with Periodic Water-back-flushing System

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Abstract: We performed periodic water-back-flushing using permeate water to minimize membrane fouling to enhance permeate flux in tubular ceramic microfiltration system for water treatment of high turbid source. The filtration time (FT) = 2 min with periodic 6 sec water-back-flushing showed the highest value of dimensionless permeate flux (J/J_o), and the lowest value of resistance of membrane fouling (R_f), and we acquired the highest total permeate volume (V_T) = 6.805 L. Also in the result of BT effect at fixed FT = 10 min and BT (back-flushing time) = 20 sec showed the lowest value of R_f and the highest value of J/J_o, and we could obtain the highest V_T = 6.660 L. Consequently, FT = 2 min and BT = 6 sec could be the optimal condition in water treatment of high turbid source above 10 NTU. However, FT = 10 min and BT = 20 sec was superior to reduce operating costs because of lower back-flushing frequency. Then the average quality of water treated by our tubular ceramic MF system was turbidity of 0.07 NTU, COD_{Mn} of 1.86 mg/L and NH_3-N of 0.007 mg/L.

Keywords: *microfiltration, ceramic membrane, water treatment, high turdity, water-back-flushing*

1. Introduction

According to pollution deterioration of drinking water source due to various organic and inorganic matters, turbidity, and pathogens, both interests and applications of advanced water treatment have increased in order to remove effectively those pollutants of undesirable drinking water source. Recently researches of water treatment by using membrane separation have achieved actively. Fiksdal and Leiknes [1] could remove viruses in drinking water by MF and UF membrane filtration combined with pre-coagulation/flocculation. And Malek *et al.* [2] investigated photooxidation as a pretreatment to break down the natural organic matter in surface water, and could reduce fouling in microfiltration systems for drinking water treatment.

However, the application of membrane process to drinking water treatment has the problem of membrane fouling and decline of permeate flux, and it shortens membrane lifetime. Membrane fouling was made by inorganic particles (e.g., iron, silica and suspended solids) and organic compounds (e.g., humic substances, polysaccharides, proteins and microorganisms) [3,4]. And it caused concentration polarization and gel layer formation on the surface of membranes, and adsorption and pore blockage in the pores inside the membranes.

Therefore, many researchers have been accomplished for solving the membrane fouling effectively to maintain high permeate flux during membrane filtration. Then, membrane back-flushing is a general technology both minimizing the membrane fouling and maintaining a high permeate flux during membrane separation. Many papers related to membrane back-flushing have been published nowadays. Davis *et al.* [5] built up a modeling of concentration and depolarization with high frequency back-flushing. And Kuberkar *et al.* [6] could

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Table 1. The Quality of Source Water Used in this Study

Experimental conditions		TDS (mg/L)	Turbidity (NTU)	COD_{Mn} (mg/L)	NH_3-N (mg/L)	T-N (mg/L)	T-P (mg/L)
FT = 2~10 min BT = 6 sec	Range	31	10.38~12.92	2.72~3.31	0.009~0.021	1.327~1.691	0.018~0.024
	Average	31	12.11	2.94	0.014	1.487	0.022
BT = 6~20 sec FT = 10 min	Range	31	11.67~13.30	2.31~2.78	0.013~0.018	1.160~1.474	0.019~0.021
	Average	31	12.47	2.49	0.015	1.288	0.020

reduce the fouling resistance of pollutant layer on the membrane by back-flushing in the microfiltration of protein cell mixture (BSA, yeast). Then, we published membrane fouling control effects of periodic water-back-flushing using tubular ceramic UF membranes for recycling paper wastewater and lake water treatment [7,8]. Also, we recently investigated the effect of periodic N_2-back-flushing in paper-wastewater treatment using multichannels ceramic MF membranes [9].

In this study we performed periodic water-back-flushing using permeate water to minimize membrane fouling and to enhance permeate flux in tubular ceramic microfiltration system for water treatment of high turbid source. And, we tried to find optimal operating conditions by investigating the effects of water-back-flushing period and back-flushing time.

2. Theory

The resistance-in-series filtration model in equation (1) was applied to analyze experimental data for calculating filtration resistance and permeate flux (J) in this research. The equation was known well in the application field of membrane separation [10],

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

where J was the permeate flux through membrane, ΔP 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 wastewater. 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. Materials and Methods

3.1. Membrane and Lake Water Source

Tubular ceramic MF membrane used in the study was coated with α-alumina on supporting layer of α-alumina. We purchased the membrane from Nano Pore Materials Co. in Korea, and its surface area was 47.5 cm^2, its pore size 0.1 μm, O.D. 8 mm, I.D. 6 mm, length 252 mm, and its thickness 1 mm. The source water used here was sampled at discharged position of Soyang Dam located in Chuncheon city at 18th March 2007, and water quality was arranged in Table 1. Its turbidity was relatively higher than the value at the normal condition of Soyang Dam.

3.2. Experimental Procedures

In this study we performed periodic water-back-flushing using permeate water to minimize membrane fouling in tubular ceramic MF system for water treatment of high turbid source. And crossflow microfiltration with water-back-flushing system used here

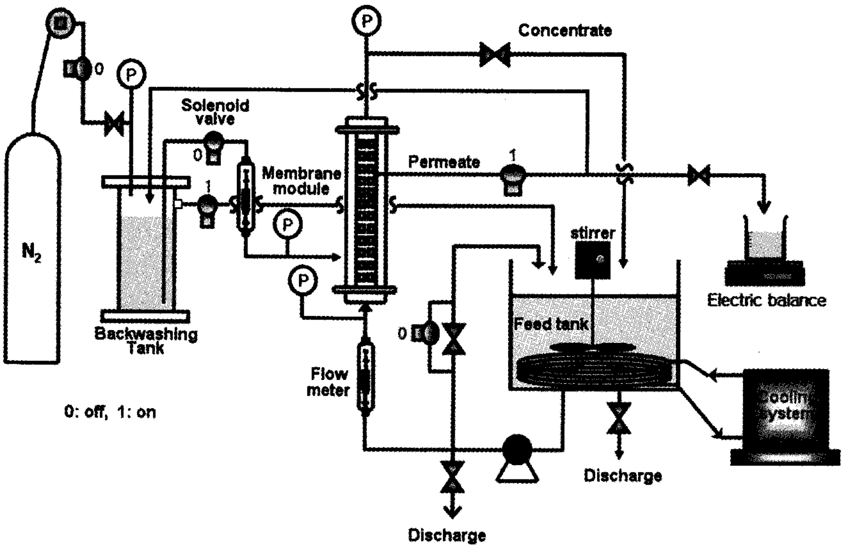

Fig. 1. Apparatus of microfiltration with periodic water-back-flushing system.

was shown Fig. 1. The feed tank was filled with 15 L of source 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 source water in the feed tank was continuously mixed with a stirrer. The back-flushing water flowed periodically to the outside of the tubular membrane. And a part of permeated water was automatically filled up to the back-flushing water tank using solenoid valves.

Back-flushing time (BT) was fixed at 6 sec and filtration time (FT) was changed as 2, 4, 6, 8 and 10 min to see the effect of back-flushing period. Also, FT was fixed at 10 min and BT was changed as 6, 10, 15 and 20 sec to inspect effect of BT. At both two experimental conditions, TMP was fixed at 1.77 bar, water-back-flushing pressure at 1.96 bar, feed flow rate at 1.0 L/min, and feed water temperature at 20°C.

Then, we measured permeate flux (J) during 3 hours' operation, and calculated the resistance of membrane fouling (R_f) using equation (1) and (2). Then we could acquired total permeate volume (V_T) by integrating J from starting time to 3 hour [9]. And we analyzed TDS (total dissolved solid), Turbidity, COD_{Mn} (chemical oxygen demand), NH_3-N, T-N and T-P of supplied and permeate water by standard method of water analysis.

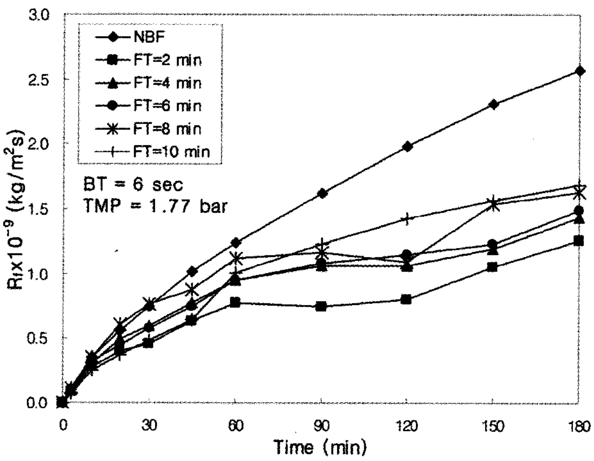

Fig. 2. Effect of back-flushing period (FT) on resistance of membrane fouling.

4. Results and Discussions

4.1. Effect of Water-back-flushing Period

We investigated the progress of membrane fouling according to water-back-flushing period and time in water treatment of high turbid source using tubular ceramic MF membrane. The result of back-flushing period effect was given in Fig. 2 at fixed 6 sec of back-flushing time. As shown in Fig. 2, the lowest values of

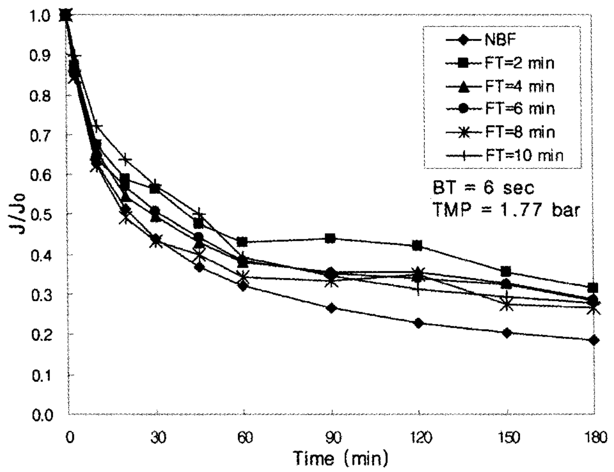

Fig. 3. Effect of back-flushing period (FT) on dimensionless permeate flux.

Table 2. Filtration Factors in the Experiments for Effect of Back-flushing Period at BT = 6 sec

Experimental conditions		Filtration factors			
FT (min)	BT (sec)	V_T (L)	$R_{f,180} \times 10^{-9}$ (kg/m^2 · s)	Jo × 10^5 (m/s)	$J_{180} \times 10^5$ (m/s)
NBF		4.964	2.57	29.89	5.58
10		5.712	1.69	27.08	7.54
8	6	5.737	1.63	30.02	7.96
6		6.145	1.49	29.94	8.49
4		6.160	1.44	30.09	8.71
2		**6.805**	**1.26**	30.38	**9.58**

R_f was represented at FT = 2 min and BT = 6 sec, in which membrane fouling could decrease to 51.0% of R_f in No-back-flushing (NBF) condition. And FT = 2 min was the shortest back-flushing period, thus it means that the shorter back-flushing period was more effective to reduce membrane fouling.

Also, the highest value of the permeate flux on time (J) vs. the initial permeate flux (J_o) could be found at FT = 2 min and BT = 6 sec, as shown in Fig. 3. It means FT = 2 min was the most effective back-flushing period to reduce membrane fouling and to maintain high permeate flux during 3 hours' operation in our MF system. Then the highest total permeate volume (V_T) of 6.805 L could be acquired at FT = 2 min, as arranged in Table 2.

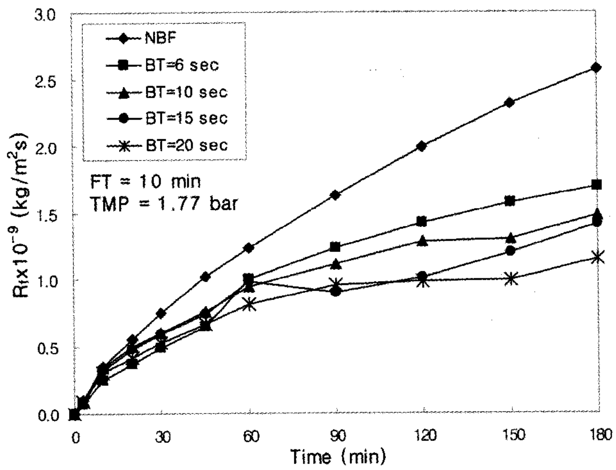

Fig. 4. Effect of back-flushing time (BT) on resistance of membrane fouling.

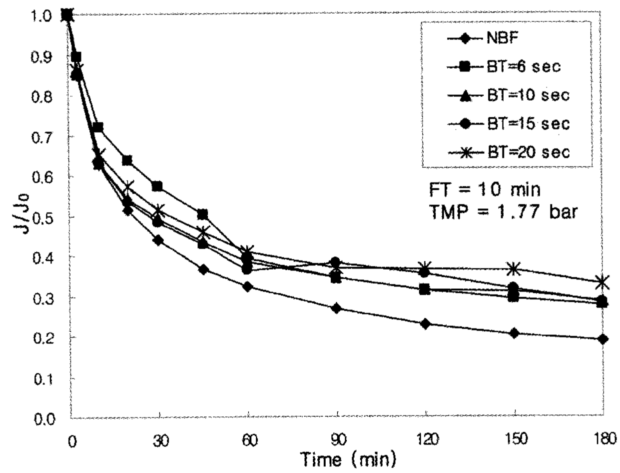

Fig. 5. Effect of back-flushing time (BT) on dimensionless permeate flux.

4.2. Effect of Water-back-flushing Time

At the fixed FT = 10 min, which was the longest back-flushing period, back-flushing time (BT) were adopted as 6, 10, 15 and 20 sec to see the effect of BT. The lowest value of membrane fouling resistance could be found at BT = 20 sec and FT = 10 min, in which membrane fouling could decrease to 55.2% of R_f in NBF condition, as plotted in Fig. 4.

Also, we have got the highest dimensionless permeate flux (J/J_o) value at BT = 20 sec, as shown in Fig. 5. It means that the longest BT should reduce the membrane fouling effectively during operation. As arranged in Table 3, the most V_T of 6.660 L could be

Table 3. Filtration Factors in the Experiments for Effect of Back-flushing Time at FT = 10 min

Experimental conditions		Filtration factors			
FT (min)	BT (sec)	V_T (L)	$R_{f,180}$ × 10^{-9} (kg/m^2 · s)	Jo × 10^5 (m/s)	J_{180} × 10^5 (m/s)
10	NBF	4.964	2.572	29.89	5.58
	6	5.712	1.689	27.08	7.54
	10	5.993	1.475	30.02	8.55
	15	6.421	1.415	31.71	8.95
	20	**6.660**	**1.151**	31.20	**10.28**

obtained at BT = 20 sec and FT = 10 min.

Finally, the experimental results of R_f and V_T at short and frequent back-flushing of BT = 6 sec and FT = 2 min were very similar with those at longer back-flushing and longer period of BT = 20 sec and FT = 10 min. However the short and frequent back-flushing of BT = 6 sec and FT = 2 min seems to be optimal condition when considered a high turbid water source above 10 NTU. But FT = 10 min and BT = 20 sec was superior to reduce operating costs because of lower back-flushing frequency.

4.3. Water Quality and Rejection Rate of Pollutants

As the results of water quality analysis for feed and treated water, average rejection rate of TDS, Turbidity, COD_{Mn}, NH_3-N, T-N and T-P were arranged in Table 4. Where the rejection rate of Turbidity was very high as 99.36~99.40%, but that of TDS was very low as 1.7~6.0%. And the rejection rates were 32.0~34.5% for COD_{Mn}, 48~52% for NH_3-N, 15.96~28.68% for T-N and 82~89% for T-P. Then the average quality of treated water was Turbidity = 0.07 NTU, COD_{Mn} = 1.86 mg/L and NH_3-N = 0.007 mg/L, which were satisfied with Korean drinking water standard, TDS = 30 mg/L, T-N = 1.035 mg/L and T-P = 0.003 mg/L.

5. Conclusion

In this study, periodic water-back-flushing using permeate water performed to minimize membrane fouling

Table 4. Treated Water Quality and Average Rejection Rate of Tubular Ceramic MF System

Items	Effect of FT		Effect of BT	
	Treated water	Average rejection rate	Treated water	Average rejection rate
TDS (mg/L)	31	1.7 %	29	5.9 %
Turbidity (NTU)	0.07	99.40 %	0.08	99.36 %
COD_{Mn} (mg/L)	1.95	34.5 %	1.69	32.0 %
NH_3-N (mg/L)	0.006	52 %	0.008	48 %
T-N (mg/L)	1.012	28.68 %	1.081	15.96 %
T-P (mg/L)	0.004	82 %	0.002	89 %

and to enhance permeate flux in tubular ceramic MF system for water treatment of high turbid source. And the optimal conditions were discussed in the viewpoints of permeate flux J, resistance of membrane fouling R_f and total permeate volume V_T. As a result, FT = 2 min with periodic 6 sec water-back-flushing showed the highest value of permeate flux and J/J_o, and the lowest value of R_f, and we acquired the highest V_T of 6.805 L. Also, in the results of BT effect at fixed FT = 10 min, BT = 20 sec showed the lowest value of R_f and the highest value of permeate flux and J/J_o, and we could be obtained the highest V_T of 6.660 L. Consequently, FT = 2 min and BT = 6 sec could be the optimal condition in water treatment of high turbid source above 10 NTU. However FT = 10 min and BT = 20 sec was superior to reduce operating costs because of lower back-flushing frequency. Then, the average quality of water treated by our tubular ceramic MF system was Turbidity = 0.07 NTU, COD_{Mn} = 1.86 mg/L and NH_3-N = 0.007 mg/L, which were satisfied with Korean drinking water standard, TDS = 30 mg/L, T-N = 1.035 mg/L and T-P = 0.003 mg/L.

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