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Advanced Water Treatment by Tubular Alumina Ceramic Ultrafiltration: Effect of Periodic Water-back-flushing Period

Jin Yong Park† and Song Hui Lee

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

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Abstract: The periodic water-back-flushing using permeate water was performed to minimize membrane fouling and to enhance permeate flux in tubular ceramic ultrafiltration (UF) system for Gongji stream water treatment in Chuncheon city. The filtration time (FT), which was the water-back-flushing period, 2 min with periodic 15 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) of 6.35 L. Consequently FT 2 min at back-flushing time (BT) 15 sec could be the optimal condition in advanced UF water treatment of Gongji stream. Then the average rejection rates of pollutants by our tubular ceramic UF system were 99.4% for Turbidity, 31.8% for COD_{Mn}, 22.6% for NH_3-N and 65.9% for T-P.

Keywords: *ultrafiltration, ceramic membrane, water treatment, water-back-flushing, tubular*

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 [1]. Recently researches of water treatment by using membrane separation have achieved actively. Fiksdal and Leiknes [2] could remove viruses in drinking water by MF and UF membrane filtration combined with pre-coagulation/flocculation. And Malek *et al.* [3] 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) [4,5]. And it caused concentration polarization, gel layer formation on the surface of membranes, and adsorption and pore blockage in the pores inside membranes.

Therefore, many researchers have been accomplished for solving the membrane fouling effectively to maintain high permeate flux during membrane filtration. Then, the membrane back-flushing is a general technology to minimize the membrane fouling, and to maintain a high permeate flux during membrane separation. Many papers related with membrane back-flushing have been published nowadays. Davis *et al*. [6] built up a modeling of concentration and depolarization with high frequency backpulsing. And Kuberkar *et al*. [7] could reduce the fouling resistance of pollutant layer on the membrane by back-flushing in the microfiltration of protein cell mixture (BSA, yeast). Then, we

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

published membrane fouling control effects of periodic water-back-flushing using tubular ceramic UF membranes for recycling paper wastewater and lake water treatment [8,9]. Also, we recently investigated the effect of periodic N_2-back-flushing in paper wastewater treatment using multichannels ceramic MF membranes [10]. And we found out the optimal operating condition of water-back-flushing in advanced water treatment system using tubular MF or UF membranes [11,12].

In this study we performed periodic water-back-flushing using permeate water to minimize membrane fouling and to enhance permeate flux in advanced water treatment system by tubular ceramic ultrafiltration membrane for Gongji stream water. And we tried to find optimal operating conditions by investigating effects of water-back-flushing period (FT), and to compare with the results of tubular ceramic MF or UF membranes in our previous study [11,12].

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 [1].

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

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).

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

Items	Effect of FT	
	Range	Average
TDS (mg/L)	62～72	64
Turbidity (NTU)	10.9～14.0	12.2
COD_{Mn} (mg/L)	2.69～3.51	3.15
NH_3-N (mg/L)	0.058～0.249	0.121
T-N (mg/L)	1.435～2.438	1.988
T-P (mg/L)	0.048～0.084	0.066

3. Materials and Methods

3.1. Membrane and Water Source

Tubular ceramic UF membrane (NCMT-5231) 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 63.1 cm^2, its pore size 0.05 μm, O.D. 10 mm, I.D. 8 mm, length 251 mm, and its thickness 1 mm. The source water used here was sampled at Gongji stream located in Chuncheon city, and water quality was arranged in Table 1.

3.2. Experimental Procedures

In this study we performed periodic water-back-flushing using permeate water to minimize membrane fouling in tubular ceramic UF system for water treatment of stream source. And crossflow ultrafiltration with water-back-flushing system used here was shown Fig. 1 [12]. The feed tank was filled with 15 L of source water, and it flowed to the inside of the tubular ceramic UF membrane. The permeate flow and the concentrate flow were recycled to the feed tank to maintain the concentration of the feeding water almost constant during operation. The source water in the feed

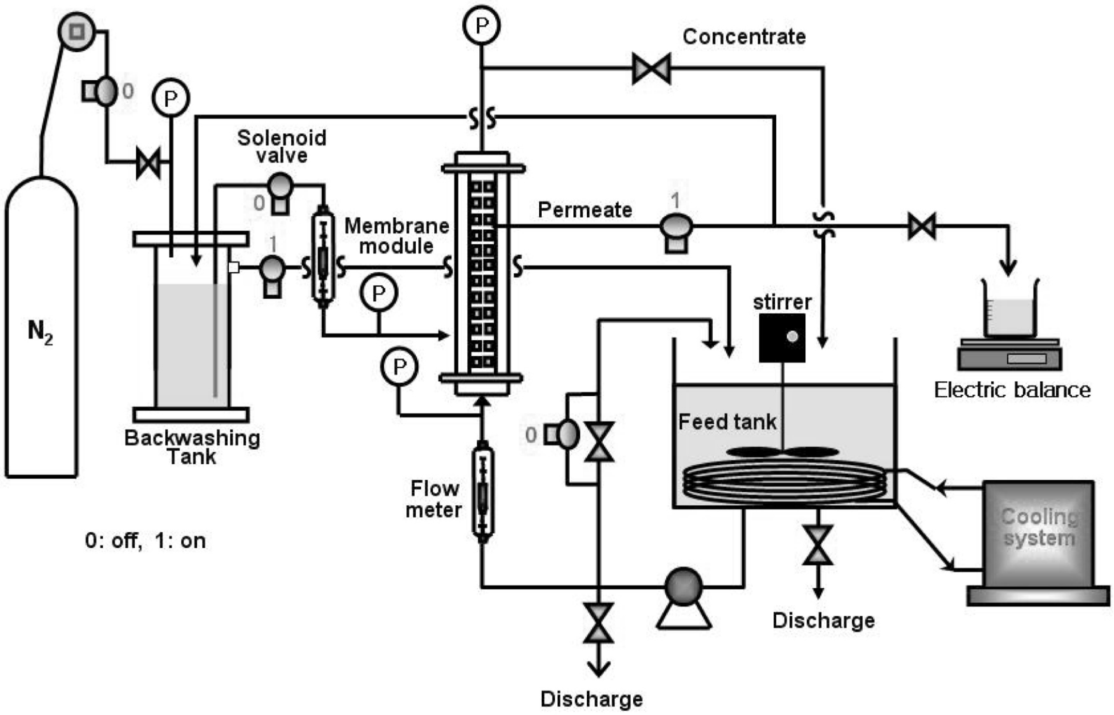

Fig. 1. Apparatus of ultrafiltration with periodic water-back-flushing system [12].

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 the back-flushing water tank using solenoid valves.

Back-flushing time (BT) was fixed at 15 sec and filtration time (FT) was changed as 2, 4, 6, 8 and 10 min to see effect of back-flushing period. TMP was fixed at 1.77 bar, water-back-flushing pressure at 1.98 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 resistance of membrane fouling (R_f) using equation (1) and (2). And we could acquired total permeate volume (V_T) by integrating J from starting time to 3 hour [10]. 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 [14,15].

4. Results and Discussions

4.1. Effect of Water-back-flushing Period (FT, filtration time)

The fouling was investigated according to water-back-flushing period and time in Gongji stream water treatment using tubular ceramic UF membrane. The result of FT effect was given in Fig. 2 at fixed 15 sec back-flushing time. As shown in Fig. 2, the lowest value of R_f was represented at FT 2 min and BT 15 sec. 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. Then, the values of R_f at no back-flushing (NBF) condition were the lower than those at FT 8 min until 45 min of ultrafiltration, which could be compared with the lowest values of R_f at NBF before 60 min in our previous study [12] using the same ceramic UF membrane. It means that the effect of water-back-flushing at FT 8 min was not clearly shown until membrane fouling increased severely after 60 min's ultrafiltration.

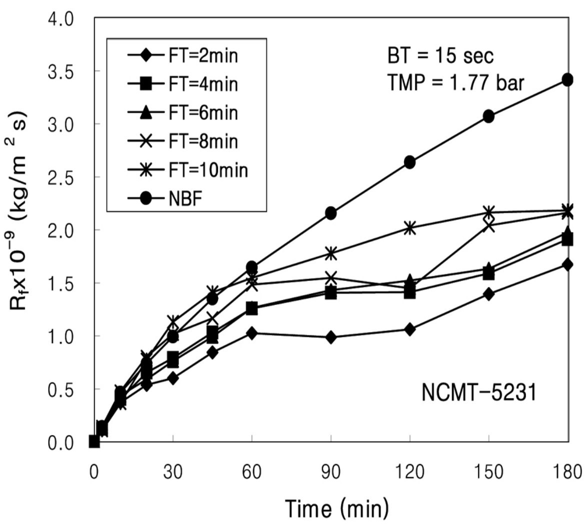

Fig. 2. Effect of water-back-flushing period (FT) on resistance of membrane fouling.

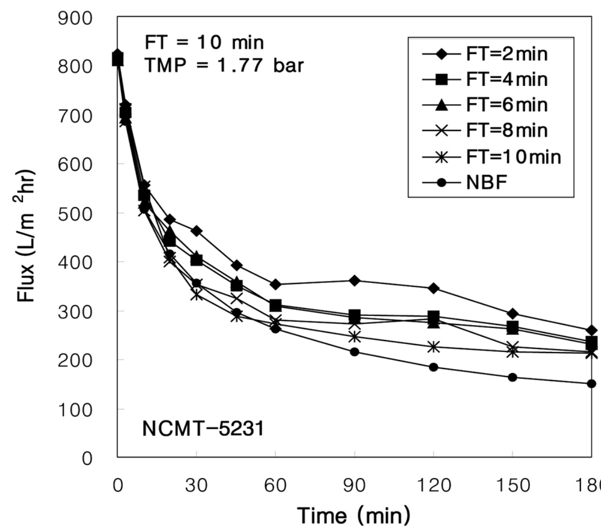

Fig. 3. Effect of water-back-flushing period (FT) on permeate flux.

Also, the highest value of the permeate flux (J) was maintained at FT 2 min from initial time, as shown in Fig. 3. Final permeate flux (J_{180}) was the highest value at FT 2 min after 180 min's ultrafiltration, but the lowest value of 4.20 × 10^{-5} m/s at NBF, as arranged in Table 2. 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 advanced water treatment UF system for Gongji stream water.

The highest value of the permeate flux on time (J) vs. the initial permeate flux (J_0) could be found at FT 2 min with fixed BT 15 sec, as shown in Fig. 4. Final J/J_0 after 180 min's filtration was 0.315 at FT 2 min, but 0.264 at FT 10 min and the lowest value of 0.187 at NBF. Then, the highest total permeate volume (V_T) of 6.45 L could be acquired at FT 2 min, as shown in Table 2. And J_{180} was the highest value of 7.22 × 10^{-5} m/s, but final resistance of membrane fouling ($R_{f,180}$) was the lowest value of 1.67 × 10^9 kg/m^2·s at FT 2 min. Then, the lowest V_T of 4.96 L was taken at NBF, and J_{180} was the lowest value of 4.20 m/s, but $R_{f,180}$ was the highest value of 3.42 × 10^9 kg/m^2 · s at NBF condition.

Finally the experimental results of R_f and V_T at frequent back-flushing of BT 15 sec and FT 2 min were much better than those at longer period of FT 10 min with the same BT 15 sec. Therefore, the optimal condition of advanced water treatment system by ceramic UF membrane for Gongji stream water was FT 2 min

Table 2. Filtration Factors in the Experiments for Effect of Back-flushing Period at BT 15 Sec

Effect of FT	2 min	4 min	6 min	8 min	10 min	NBF*
$J_0 \times 10^5$ (m/s)	22.87	22.66	22.55	22.60	22.55	22.51
$R_m \times 10^{-9}$ (kg/m^2 · s)	0.69	0.69	0.69	0.69	0.69	0.68
$R_{f,180} \times 10^{-9}$ (kg/m^2 · s)	**1.67**	1.91	1.98	2.16	2.18	3.42
$J_{180} \times 10^5$ (m/s)	**7.22**	6.56	6.40	6.00	5.95	4.20
$R_b \times 10^{-9}$ (kg/m^2 · s)	0.08	0.09	0.09	0.09	0.09	0.10
V_T (L)	**6.35**	5.93	5.99	5.63	5.35	4.96

*No back-flushing

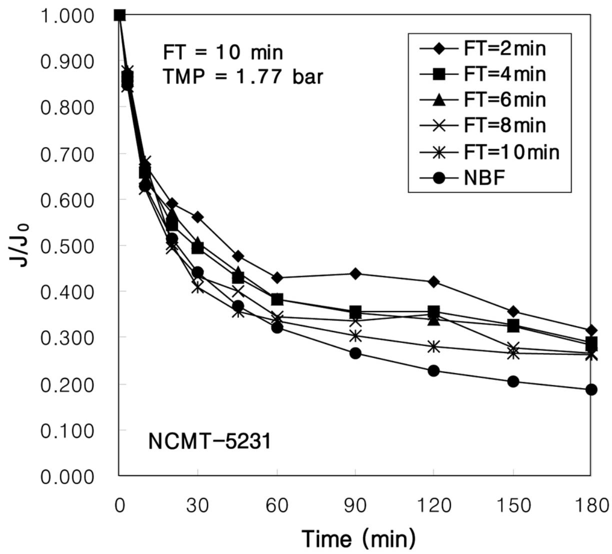

Fig. 4. Effect of water-back-flushing period (FT) on dimensionless permeate flux.

and BT 15 sec in the experimental range of this study. This result was exactly the same with our previous study [12] of FT effect experiment using the same ceramic UF membrane.

4.2. Water Quality and Rejection Rate of Pollutants

As 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 3. Where the average rejection rate of turbidity was very high as 99.4%, which was almost perfectly removal of suspended particles in water by ultrafiltration membrane. But it of TDS was very low as 0.96%, and it means that UF membrane used here was not enough to reject dissolved materials in water. And the average rejection rates were 31.8% for COD_{Mn}, 22.6% for NH_3-N, 16.9% for T-N and 65.9% for T-P. As shown in Table 3, the average rejection rate of turbidity, COD_{Mn}, T-N, and T-P in this ceramic ultrafiltration water treatment with periodic water-back-flushing were much higher than those of our previous results of ceramic microfiltration membrane [11] except of NH_3-N.

Table 3. Average Rejection Rate of Tubular Ceramic Ultrafiltration and Microfiltration System

Pollutants	Average rejection rater (%)	
	Ultrafiltration (0.05 μm)	Microfiltration (0.1 μm)[11]
TDS	0.96	1.42
Turbidity	99.4	94.7
COD_{Mn}	31.8	14.0
NH_3-N	22.6	40.0
T-N	16.9	4.93
T-P	65.9	38.6

5. Conclusion

In this study, periodic water-back-flushing using permeate water was performed to minimize membrane fouling and to enhance permeate flux in tubular ceramic UF system for Gongji stream water treatment. And the optimal condition of FT (filtration time, or water-back-flushing period) was discussed in the viewpoints of permeate flux J, resistance of membrane fouling R_f and total permeate volume V_T. As a result of FT effect, FT 2 min with periodic 15 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 6.35 L of V_T. Consequently the optimal condition of FT for Gongji stream water treatment by our ceramic UF membrane was FT 10 min at BT 15 sec in the experimental range of this study. Then, the average rejection rate of turbidity was very high as 99.4%, but it of TDS was very low as 0.96%. And the average rejection rates were 31.8% for COD_{Mn}, 22.6% for NH_3-N, 16.9% for T-N and 65.9% for T-P. Those of turbidity, COD_{Mn}, T-N, and T-P in this ceramic ultrafiltration water treatment were much higher than those of our previous results of ceramic microfiltration membrane [11] except of NH_3-N.

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