

Effect of N₂-back-flushing in multichannels ceramic microfiltration system for paper wastewater treatment

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Abstract

The ceramic microfiltration system with periodic N₂-back-flushing was operated for treating paper wastewater discharged from a company making toilet papers by recycling milk or juice cartons. Two kinds of alumina membranes with 7 channels used here for recycling paper wastewater. The optimal N₂ filtration time for HC04 membrane with 0.4 μm pore size was lower value of 4 min than 16 min for HC10 with 1.0 μm pore size at fixed back-flushing time 40 s, trans-membrane pressure 1.0 kg_f/cm² and back-flushing pressure 5.0 kg_f/cm². From the results of TMP effect at fixed filtration time and back-flushing time, the lower TMP was better on membrane fouling because high TMP could make easily membrane cake and fouling inside membrane structure. However, we could acquire the highest volume of total permeate for the reason that TMP was driving force in our filtration system to treat paper wastewater. Then the permeate water of low turbidity was acquired in our microfiltration system using multichannels ceramic membranes, and the treated water could be reused in paper process.

Keywords: Ceramic membrane; Multichannel; Back-flushing; Microfiltration; Paper wastewater

1. Introduction

Nowadays the recycling rates of industrial wastewater should be increased, and the dual water system extended to solve the shortage of water source and water pollution by dramatic economic development of developing countries. Various technologies for advanced

wastewater treatment have been developed to satisfy such a demand, and one of them was membrane separation. Recently the membrane separation has been applied to wastewater treatment for reuse.

Many researchers have published the results of wastewater treatment by membrane separation. Tchobanoglous et al. [16] treated highly the domestic wastewater by ultrafiltration (UF), and

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Cheryan and Rajagopalan [2] studied the economic efficiency of oil–water emulsion treatment by combining method of the traditional chemical treatment and membrane separation. Roorda and van der Graaf [13] investigated the characteristics of ultrafiltration for effluents of two wastewater treatment plants. As an example of applications of ceramic membranes used in this study Li et al. [9] used ceramic microfiltration (MF) membranes to separate cells from *E. coli*-containing fermentation broth. Then, Nazzal and Wiesner [10] reported the effect of pH and ionic strength in water treatment by ceramic microfiltration membranes.

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. For an example, Taylor vortex was applied to microfiltration to reduce the membrane fouling by Park et al. [11] and Choi et al. [3]. Then, the membrane back-flushing is a new 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. [4] built up a modeling of concentration and depolarization with high frequency backpulsing. Srijaroonrat et al. [15] applied the back-flushing to ultrafiltration of oil/water emulsion. And Sondhi et al. [14] researched that the membrane fouling could be minimized by backpulsing in the cross-flow filtration of chromium hydroxide suspension using ceramic membranes. And Kuberkar and Davis [8] could reduce the fouling resistance of

pollutant layer on the membrane by back-flushing in the microfiltration of protein cell mixture (BSA, yeast). Heran and Elmaleh [5] showed that highly frequent back-flushing could be effective on the microfiltration of three kinds of suspended solids through inorganic tubular membranes. Then, we published membrane fouling control effects of periodic water-back-flushing period, TMP, and flow rate using tubular carbon ceramic UF and MF membranes for recycling paper wastewater [7]. Also, we recently reported effects of periodic N₂-back-flushing in paper wastewater treatment using carbon UF and MF membranes [6].

The high chemical resistance of ceramic membranes used here made it possible to treat the paper wastewater including various chemicals and pollutants. And the ceramic membranes were washable by strong acid or steam with high pressure because of their high mechanical strength, and had a long lifetime. We tried to find the optimal conditions of 7 channels ceramic microfiltration system with periodic N₂-back-flushing for the wastewater discharged from a company making toilet papers, and to reuse in paper process.

2. Theory

The resistance-in-series filtration equation shown in Eq. (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. [1] investigated the resistance of membrane, cake of bacterial cell, adsorption, and concentration polarization of solution by using Eq. (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. Eq. (1) could be simplified to Eq. (2).

$$J = \Delta P / R_m \tag{2}$$

Now R_m could be calculated from the experimental data of permeate flux for pure water using Eq. (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 Eq. (1).

3. Experiments

3.1. Ceramic membranes

The optimal conditions were investigated using 7 channels ceramic membrane HC10 (average pore size: 1.0 μm) and HC04 (0.4 μm) made in Dongseo Inc., Korea. They were prepared by alumina coating on alumina supporting membrane. Table 1 showed the characteristics and specifications of tubular alumina membrane

Table 1

Specifications of the tubular ceramic membranes used in this study

Material (model #)	Alumina (HC10)	Alumina (HC04)
Average pore size (μm)	1.0	0.4
Company	Dongseo Inc. (Korea)	
No. of channel	7	
Outer diameter (mm)	20	
Inner diameter of a channel (mm)	4	
Length (mm)	245	
Surface area (cm^2)	216	

used in this research. The tubular membrane was used here for making a crossflow to reduce the membrane fouling.

3.2. Wastewater source

We used here the wastewater discharged from a company making toilet papers by recycling milk or juice cartons. The wastewater source of this research was the wastewater discharged from a company making toilet papers by recycling milk or juice cartons. The water quality of the paper wastewater was shown in Table 2. The quality was varied a lot depending on the condition of wastewater treatment plant

Table 2

The quality of paper wastewater used in this study

Module	Experimental conditions		Turbidity (NTU)	COD (mg/L)	TDS (mg/L)
HC10	Effect of filtration time	Range	18.1–31.5	293.3–489.5	115–120
		Average	26.7	405.3	117
	Effect of TMP	Range	25.4–35.9	208.3–489.5	108–117
		Average	29.4	329.9	113
HC04	Effect of filtration time	Range	3.38–5.12	162.5–195.5	174–177
		Average	4.06	181.1	175
	Effect of TMP	Range	7.94–9.62	296.8–491.8	156–172
		Average	8.78	349.3	165

in the paper company. However, a set of experiments to see one of effects on the membrane fouling was done using the paper wastewater sampled at the same time.

3.3. Experimental procedures

The ceramic membrane module and microfiltration system with periodic N_2 -back-flushing as shown in Fig. 1 was designed and made by us in our laboratory for this study. The feed tank was filled with 5 L of paper wastewater, 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 wastewater almost constant during operation. The back-flushing nitrogen gas flowed periodically to the outside of the tubular membrane.

To see the effect of N_2 -back-flushing, back-flushing time (BT) was fixed at 40 s and filtration time (FT) was varied as 4, 8, 16 and 32 min.

Then the N_2 -back-flushing pressure was fixed at $5.0 \text{ kg}_f/\text{cm}^2$, TMP at $1.0 \text{ kg}_f/\text{cm}^2$ and the feed flow rate at $2.0 \text{ L}/\text{min}$. To see effect of TMP we fixed FT at 16 min and BT at 40 s. And then the permeate volume was measured by mass cylinder during 3 h operation. Then for water quality of the feeding wastewater and the permeated water, we measured TDS (total dissolved solid) by conductivity meter (ATI Orion, Model 162), Turbidity by turbidimeter (HF Scientific Inc., DRT-15CE), and COD (chemical oxygen demand) by chromium method.

4. Results and discussion

4.1. Effect of filtration time

The effect of N_2 filtration time on membrane fouling resistance R_f for HC10 (pore size $1.0 \mu\text{m}$) was shown in Fig. 2, in which the lowest values of R_f could be maintained at FT=16min and BT=40 s during 3 h operation. Also, the highest value of the permeate flux on time (J) vs. the

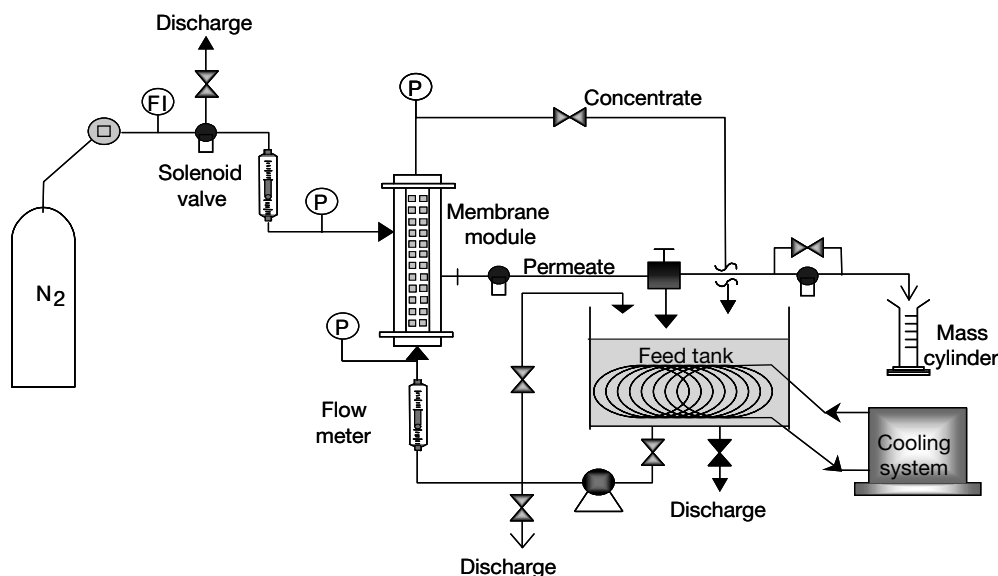


Fig. 1. Apparatus of filtration with periodic N_2 -back-flushing system.

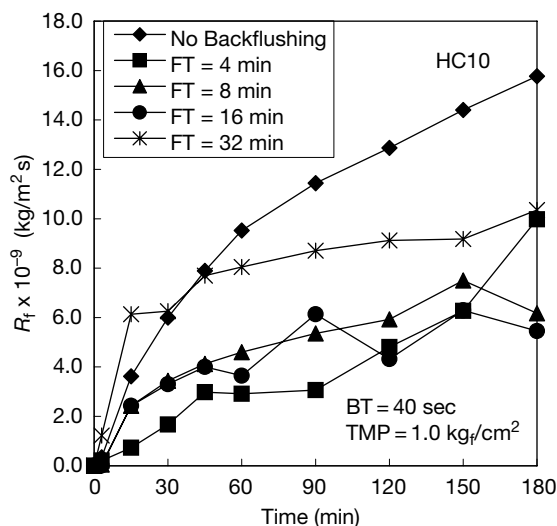


Fig. 2. Effect of N_2 filtration time on resistance of membrane fouling for HC10 membrane at $BT = 40$ s and $TMP = 1.0$ kg_f/cm^2 .

initial permeate flux (J_0) could be found at $FT = 6$ min and $BT = 40$ s as shown in Fig. 3. It means $FT = 16$ min was the most effective filtration time at $BT = 40$ s to reduce membrane

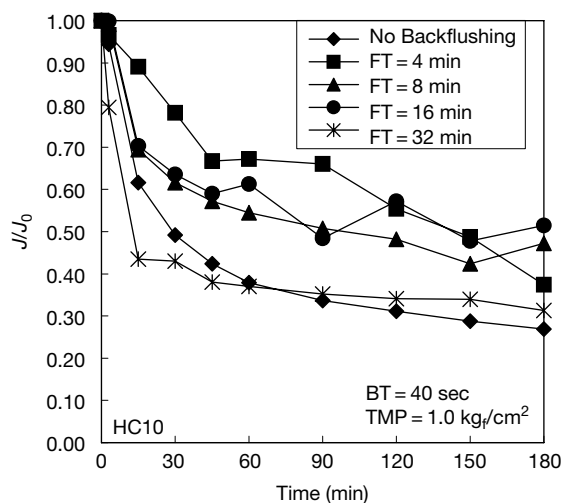


Fig. 3. Effect of N_2 filtration time on dimensionless permeate flux for HC10 membrane at $BT = 40$ s and $TMP = 1.0$ kg_f/cm^2 .

Table 3
Effect of N_2 filtration time (FT) on total permeate volume (V_T) at $BT = 40$ s during 3 h filtration

FT (min)	No back-flushing	4	8	16	32	
$V_T \times 10^3$ (m ³)	HC10 (1.0 μ m)	1.56	2.10	2.09	2.22	1.84
	HC04 (0.4 μ m)	2.53	4.14	3.48	3.03	2.94

fouling and to maintain high permeate flux during filtration in our system. Then the highest total permeate volume (V_T) of 2.22 L could be acquired at $FT = 16$ min and $BT = 40$ s as shown in Table 3, and it should be the optimal N_2 -back-flushing condition for HC10 in our N_2 -back-flushing system.

Then HC04 (pore size 0.4 μ m) membrane showed the lowest value of R_p and the highest value of J/J_0 at $FT = 4$ min and $BT = 40$ s as shown Figs. 4 and 5. Also we acquired the highest V_T of 4.14 L at $FT = 4$ min and $BT = 40$ s as shown in Table 3, and it could be the optimal

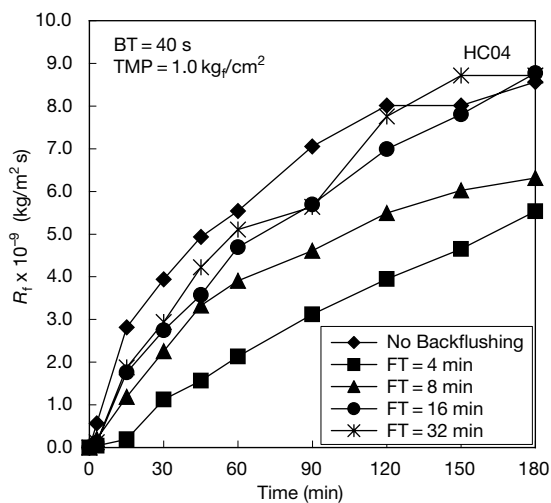


Fig. 4. Effect of N_2 filtration time on resistance of membrane fouling for HC04 membrane at $BT = 40$ s and $TMP = 1.0$ kg_f/cm^2 .

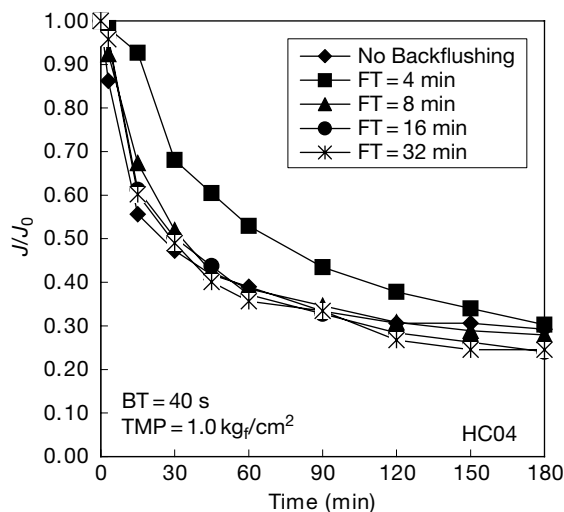


Fig. 5. Effect of N_2 filtration time on dimensionless permeate flux for HC04 membrane at BT = 40 s and TMP = 1.0 kgf/cm².

N_2 -back-flushing period for HC04 in our system. The optimal FT of 4 min for HC04 should be much lower than the optimal FT of 16 min for HC10 membrane. It means that HC04 with smaller pore size than HC10 should need frequent N_2 -back-flushing to reduce membrane fouling and to maintain high flux.

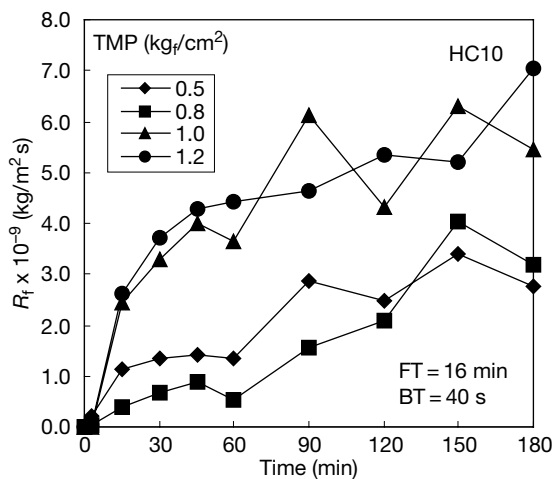


Fig. 6. Effect of trans-membrane pressure on resistance of membrane fouling for HC10 membrane at FT = 16 min and BT = 40 s.

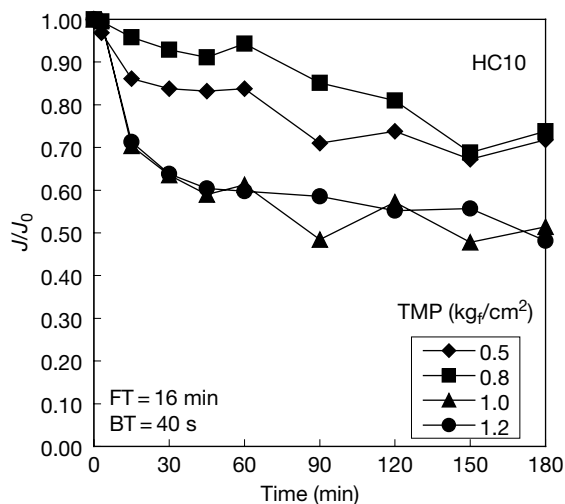


Fig. 7. Effect of trans-membrane pressure on dimensionless permeate flux for HC10 membrane at FT = 16 min and BT = 40 s.

4.2. Effect of trans-membrane pressure

At the fixed FT = 16 min and BT = 40 s, we tried to find an optimal trans-membrane pressure (TMP) for HC10 membrane. The lowest value

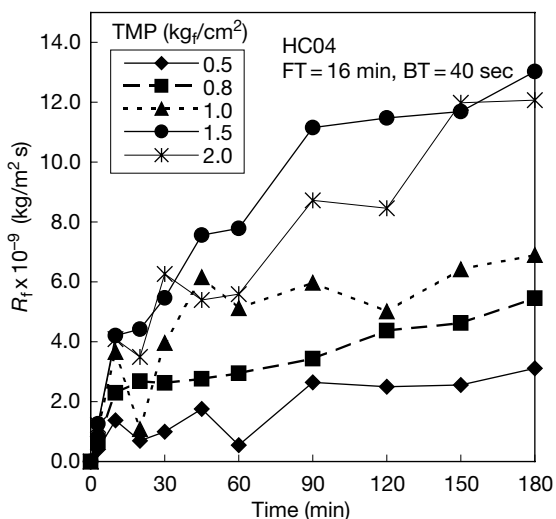


Fig. 8. Effect of trans-membrane pressure on resistance of membrane fouling for HC04 membrane at FT = 16 min and BT = 40 s.

Table 4

Effect of trans-membrane pressure (TMP) on V_T at FT = 16 min and BT = 40 s during 3 h filtration

TMP (kg _f /cm ²)		0.5	0.8	1.0	1.2	1.5	2.0
$V_T \times 10^3$ (m ³)	HC10 (1.0 μm)	1.21	1.73	2.22	2.53	–	–
	HC04 (0.4 μm)	1.68	2.36	2.69	–	3.02	4.52

of membrane fouling resistance could be found at TMP = 0.5 kg_f/cm² as shown in Fig. 6. Then we got the highest J/J_0 values at TMP = 1.0 kg_f/cm² as shown in Fig. 7. Therefore the low TMP conditions could reduce the membrane fouling, but could not maintain high flux during filtration because TMP was a driving force in our membrane system. However, the highest $V_T = 2.53$ L value could be obtained at TMP = 1.2 kg_f/cm² during 3 h as shown in Table 4, and it should be the best TMP in our experimental conditions.

The effect of TMP on membrane fouling resistance for HC04 membrane was shown in Fig. 8. We could keep the lowest value of R_f at

TMP = 0.5 kg_f/cm² which was the lowest condition in our experiments. Also the highest value of J/J_0 could be taken at the same TMP = 0.5 kg_f/cm² as shown in Fig. 9. It means the lower TMP should reduce the membrane fouling during filtration of paper wastewater, and could maintain high permeate flux compared to initial flux. However, TMP was driving force in our filtration system, and the largest value V_T of 4.52 L could be obtained at the highest TMP condition of 2.0 kg_f/cm² as shown in Table 4.

The average rejection rates were above 90% for turbidity, and above 25% for COD_{Cr}, and below 1% for TDS because microfiltration membranes were used here. And the permeate water treated in our system could be reused in paper plant because its turbidity was low under 5 NTU.

5. Conclusions

For HC10 membrane with 7 channels, FT = 16 min at fixed BT = 40 s and TMP = 1.0 kg_f/cm² could be the optimal N₂-back-flushing period in our microfiltration system for recycling wastewater discharged from a plant making toilet papers. However, FT = 4 min at fixed BT = 40 s and TMP = 1.0 kg_f/cm² should be the best condition for HC04 membrane with 7 channels. Therefore, membrane fouling in HC04 membrane should progress easily than HC10 because HC04 had smaller pore size than HC10. And HC04 needed more frequent N₂-back-flushing than HC10 to maintain high flux and largest total permeate volume. From the results of TMP effect on

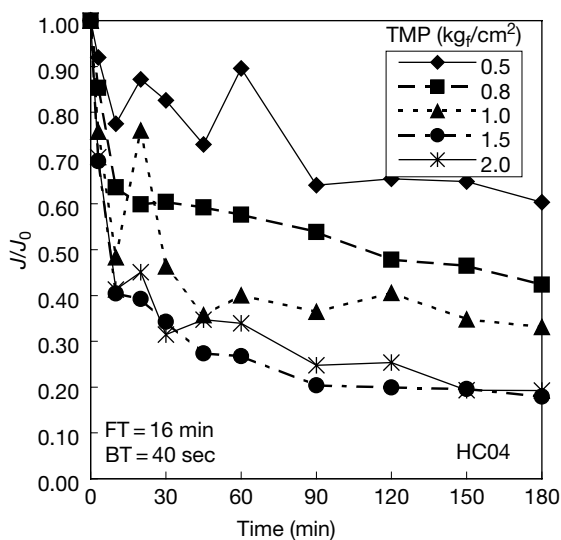


Fig. 9. Effect of trans-membrane pressure on dimensionless permeate flux for HC04 membrane at FT = 16 min and BT = 40 s.

resistance of membrane fouling (R_f) and permeate flux vs. initial flux (J/J_0), the lower TMP was better on membrane fouling because high TMP accumulated easily membrane cake on membrane surface and made fouling inside membrane structure. However, we could acquire the highest volume of total permeate at highest TMP for the reason that TMP was driving force in our filtration system to treat paper wastewater. Then the permeate water with low turbidity below 5 NTU was acquired in our microfiltration system using two kinds of alumina ceramic membranes with 7 channels. And this wastewater treated in our system could be reused in paper process.

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