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Inclining filtration and enhanced backwash for initial fouling control in microfiltration

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Abstract−It is believed that rapid membrane fouling generally occurs at early-stage of filtration. The operating parameters have great effects on membrane performance. As a result, conducting filtration with appropriate conditions in initial stage may improve membrane efficiency. Therefore, we propose the idea of improving membrane performance by controlling initial operating parameters. Two strategies are employed for this purpose: enhanced backwash and inclining filtration. During initial period of operation, backwash frequency is increased (enhanced backwash) or/and flux is increased from the sub-critical flux to the critical or the supra-critical flux (inclining filtration). To evaluate the effects of these strategies, synthetic water simulating a river is treated through microfiltration (MF) of polyvinylidene fluoride (PVDF) membrane at dead-end mode. The study results showed that initial enhanced backwash causes more fouling than normal backwash. Instead, filtration without initial backwash successfully reduces fouling. Inclining filtration is found effective in fouling reduction. Rapid fouling progress is successfully suppressed by employing filtration at low flux during initial operation.

Key words: Inclining Filtration, Enhanced Backwash, Initial Fouling, Microfiltration

INTRODUCTION

Membrane fouling leads to an increase in transmembrane pressure (TMP) at constant flow mode or flux decline at constant pressure mode. Accordingly, the economic viability of membrane filtration mainly depends on the effective fouling controls [1]. Although fouling is a complex phenomenon, it can be classified as follows: concentration polarization on membrane surface, surface fouling due to adsorption and gel-layer formation, and internal pore fouling due to pore adsorption, constriction and blocking [2,3]. Correspondingly, various fouling control methods, such as pretreatment of raw water, periodic cleaning, hydraulic control (providing surface shear force such as cross-flow circulation, vibration of membrane system, applying vigorous air bubbles, and intermittent suction operation), and optimization of operation conditions (dead-end or cross-flow mode, sub-critical flux) have been widely used [4-10]. To make specified antifouling method play its role more effectively, the feature of membrane fouling has to be investigated carefully.

According to Field [11], typical variation of flux with time is that of an initial rapid decrease followed by a long and gradual flux decline. This observation is also confirmed by other researchers [12, 13]. So, a possible suggestion could be drawn that initial fouling is more crucial in the membrane filtration process. As a result, the control of initial fouling may play an important role for improving overall membrane performance. To verify this hypothesis, two strategies are proposed in this study: enhanced backwash and inclining filtration. The enhanced backwash refers to a frequent backwash and the inclining filtration refers to a step-increase in flux. Both of them are only conducted in initial stage of operation. The sub-critical flux was chosen as the starting operation flux because many investigations demonstrated that the sub-critical flux can effectively improve membrane performance [11,14,15].

MATERIALS AND METHODS

1. Microfiltraiton (MF) System

A polyvinylidene fluoride (PVDF) membrane (Kolon, Korea) with a mean pore size of 0.1 μm, surface area of 17.3 cm^2 is used in

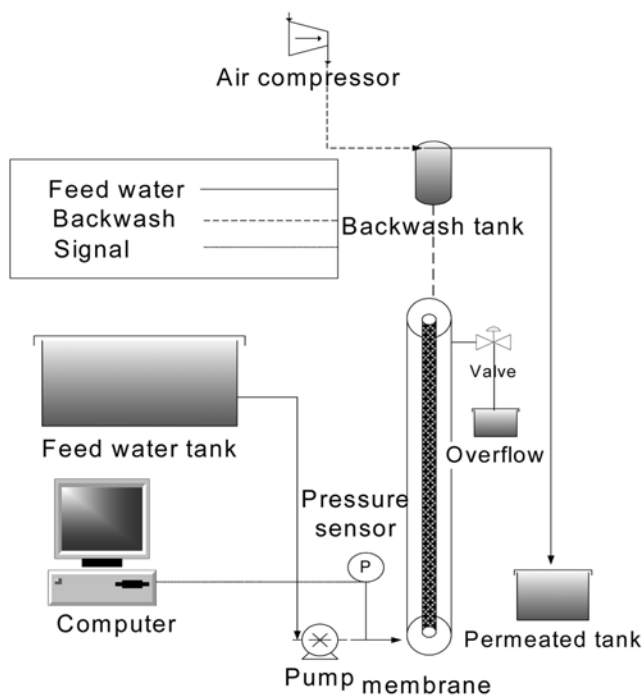

Fig. 1. Schematic of the bench-scale MF system used in this study.

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Table 1. Characteristics of raw water

Parameters	pH	Turbidity (NTU)	UV-254 (cm^{-1})	DOC (mg/L)	Temperature (°C)	Zeta potential (mV)
Raw water	7.14	11.8	0.114	2.85	25	−29
Filtrate	7.13	0.20	0.064	1.91	25	−17

this study. A single hollow fiber housed in a plastic tube with 6 mm inner diameter with the upper part sealed with epoxy resin formed a dead-end module. Fig. 1 shows the schematic of the bench-scale MF system. The TMP was recorded by pressure gauge every 10 sec, then collected by data acquisition system (Agilent 34970A). The MF system was controlled by programmable logic controller (PLC) automatically. Membrane was regularly backwashed at constant pressure of 2 bars. The pressure was maintained by an air compressor. Backwash duration was 10 s. Two different backwash frequencies were used: 5 min (enhanced backwash) and 30 min (normal backwash).

2. Raw Water Preparation and Analysis

Synthetic water is used as raw water. The synthetic water contains the following ingredients: 2.5 mg/L of Georgia kaolinite (GK), 2.5 mg/L of alumina, 5.0 mg/L of Aldrich humic acid (AHA), 0.5 mM of $NaHCO_3$, and 0.2 mM of $CaCl_2$. The synthetic water represents a typical river in Korea, which is the major drinking water source. After GK and alumina are dispersed in distilled water, the suspension is placed in an ultrasound bath for 20 min. Then, AHA, $NaHCO_3$, and $CaCl_2$ are added and mixed for an hour. A magnetic stirrer is used to supply a homogeneous solution for an experiment. Synthetic water is daily prepared. Table 1 summarizes characteristics of raw water. Turbidity, UV-254, DOC, pH and zeta potential (ZP) are analyzed for raw water and filtrate. Two kinds of turbidimeter are used for turbidity measurements. A laser turbidimeter (Dr. mini DMT 110) is used to measure low turbidity values less than 1 NTU. Turbidity values greater than 1 NTU are measured by the Hach turbidimeter. Shimadzu UV-2101 is used for UV-254 measurements and Shimadzu TOC-5000A for DOC measurements. Nicomp 380/ZLS is used for ZP measurement. Experiments are conducted at atmosphere temperature.

Table 2. Operation strategies for initial fouling control

Operation conditions	Initial flux (LMH)	Subsequent flux (LMH)	Initial backwash frequency (min)	Initial duration (min)
Inclining filtration	37.5[1)]	75[2)]	30	30
	37.5	75	30	60
	37.5	75	30	90
	37.5	150[3)]	30	30
	37.5	150	30	60
	37.5	150	30	90
Enhanced backwash	75	75	90[4)]	90
	75	75	30	90
	75	75	5	90
	150	150	90	90
	150	150	30	90
	150	150	5	90

Notes: [1)]sub-critical flux; [2)]critical flux; [3)]supra-critical flux; [4)]backwash was not provided for 90 min

3. Experimental Methods

Considering that extensive fouling occurs at initial stage of operation, two strategies of initial fouling control are evaluated. The first strategy involves the enhanced backwash. The backwash frequency of 30 minutes is shortened to 5 minutes for the enhanced backwash. It is hypothesized that the enhanced backwash would alleviate rapid fouling progress. The second strategy involves the inclining filtration, in which variable fluxes are applied. Filtration starts at low flux, and then the flux is increased to the target value. In this study, flux is increased from the sub-critical to the critical flux. The inclining filtration is also expected to lessen rapid fouling progress. Table 2 summarizes two strategies of initial fouling control. Experiments are conducted at least three times under each condition.

RESULTS AND DISCUSSION

1. Determination of the Critical Flux

The critical flux is determined by using the "flux-steps" method that is consistent with the protocols suggested in literature [16-18]. Fig. 2 shows the result of the flux-steps method. It can be seen that the TMP profile of synthetic water started to deviate from TMP profile of distilled water at flux of 75 $Lm^{-2}h^{-1}$. This indicates that fouling occurs at this point, so this value is considered as the critical flux.

2. Enhanced Backwash

To examine the effect of backwash, different backwash conditions are evaluated, such as normal backwash (every 30 min), enhanced backwash (every 5 min), and no backwash during initial operation of 1.5 h. The results are shown in Figs. 3 (critical flux) and Fig. 4 (supra-critical flux).

According to Fig. 3, the most serious fouling occurs at the mode of enhanced backwash and the least fouling occurs at the mode of

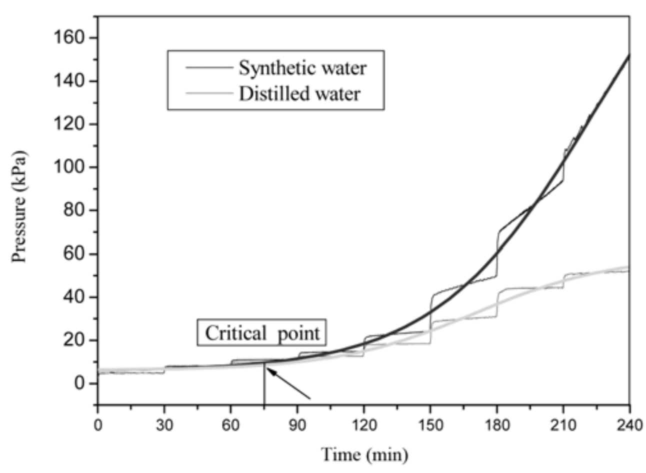

Fig. 2. Critical flux determination by the flux-steps method.

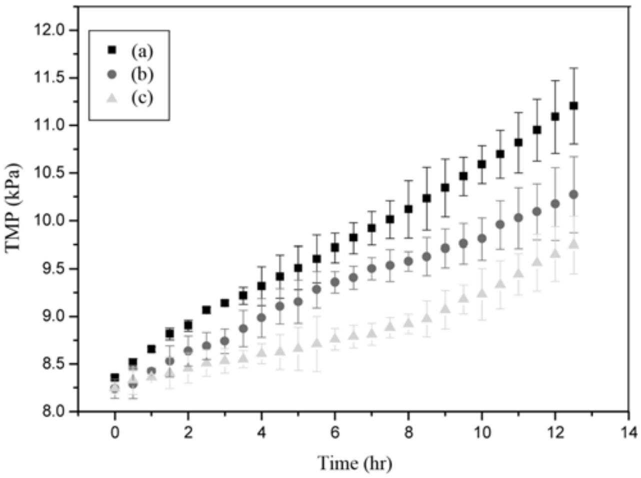

Fig. 3. TMP increase as a function of time at constant critical flux with different backwash conditions: (a) enhanced backwash; (b) normal backwash; (c) no backwash.

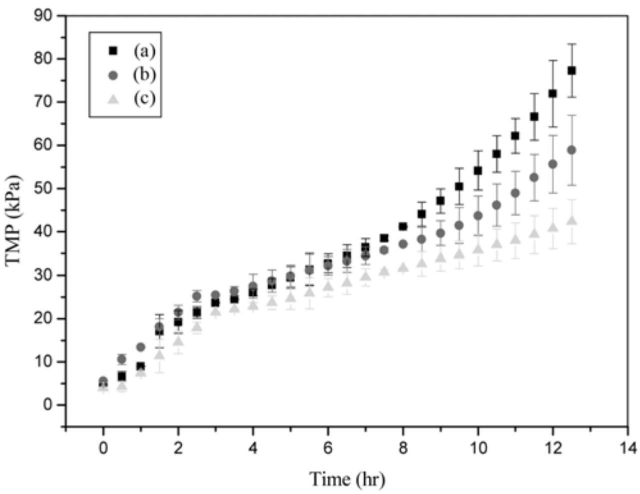

Fig. 4. TMP increase as a function of time at constant supra-critical flux with different backwash conditions: (a) enhanced backwash; (b) normal backwash; (c) no backwash.

no backwash. This is contrary to our expectation that frequent initial backwash would be in favor of fouling control. No backwash in initial time successfully improved membrane performance. The possibilities for this phenomenon could be related to the change of the physico-chemical interactions between membrane and foulants. The membrane surface is being covered by more foulants at the no backwash condition than the normal and the enhanced backwash conditions, leading to a change in surface properties. This may shift the fouling mechanisms from pore blocking to cake formation. After the initial stage, all the backwashing frequencies are adjusted to normal backwashing condition (every 30 min). However, the cake layer formed during the initial stage at no backwashing condition cannot be effectively removed under current backwashing conditions (2 bars, every 30 min, last for 10 seconds). This is probably because the cake can strongly stick on the membrane surface due to the high hydrophobicity of PVDF. But the hydraulic backwash still can keep the cake layer under certain critical thickness. To some extent, the cake layer certainly causes an increase of the membrane total resistance. But from the long-term point of view, the cake layer may act as a barrier to prevent small particles from penetrating and attach on membrane inner pores and form irreversible fouling.

More rapid fouling occurs at the supra-critical flux than at critical flux, as expected as shown in Fig. 4. But the effect of backwash on membrane performance is similar. Filtration without initial backwash performs better than the normal and the enhanced backwashing conditions in term of TMP increase.

3. Inclining Filtration

The operation of the MF system is then changed from constant filtration to inclining filtration. The filtration starts at the sub-critical flux, and then increases to the critical flux and the supra-critical flux.

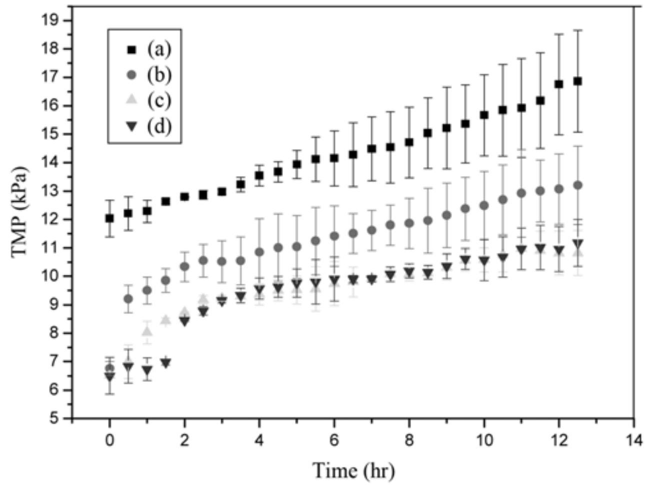

Fig. 5. Comparison of TMP increase in constant filtration with that in inclining filtration at the critical flux: (a) constant filtration (75 LMH); (b) inclining filtration (37.5 LMH for 30 min); (c) inclining filtration (37.5 LMH for 60 min); (d) inclining filtration (37.5 LMH for 90 min).

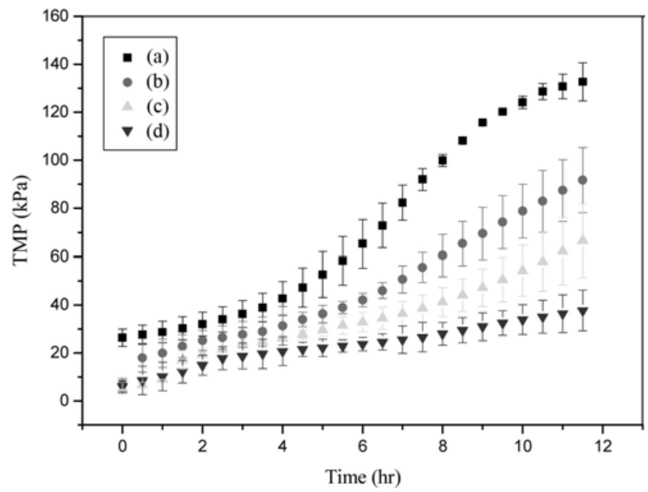

Fig. 6. Comparison of TMP increase in constant flux filtration with that in inclining filtration at the supra-critical flux: (a) constant filtration (150 LMH); (b) inclining filtration (37.5 LMH for 30 min); (c) inclining filtration (37.5 LMH for 60 min); (d) inclining filtration (37.5 LMH for 90 min).

Fig. 5 gives the results for operating conditions consisting of (a) constant filtration (75 LMH), (b) inclining filtration (from 37.5 LMH to 75 LMH, initial time last for 30 min), (c) inclining filtration (from 37.5 LMH to 75 LMH, initial time last for 60 min), and (d) inclining filtration (from 37.5 LMH to 75 LMH, initial time last for 90 min). Fig. 6 shows the results for operating conditions consisting of (a) constant filtration (150 LMH), (b) inclining filtration (from 37.5 LMH to 150 LMH, initial time last for 30 min); (c) inclining filtration (from 37.5 LMH to 150 LMH, initial time last for 60 min); and (d) inclining filtration (from 37.5 LMH to 150 LMH, initial time last for 90 min).

According to Figs. 5 and 6, constant filtration results in higher TMP increase rate than inclining filtration. From Fig. 5 it can be seen that extending the duration of the sub-critical flux from 30 min to 60 min is beneficial for strengthening this effectiveness. However, further extending to 90 min only brings a slight improvement. The advantage of inclining filtration is more obvious when the MF system is operated at the conditions shown in Fig. 6. In comparison, the duration of initial stage also affects the results. The longer the duration of the initial stage, the lower the TMP increase rate.

The possibilities for this phenomenon may be due to fact that the different initial hydraulic conditions (flux and pressure) cause different fouling mechanisms. Fig. 7 illustrates a difference in fouling behaviors by constant filtration and inclining filtration. More particles may quickly penetrate into membrane pores due to high initial flux in constant filtration, which results in irreversible fouling being accelerated. On the other hand, the inclining filtration starts at low initial flux, which leads to relatively fewer particles penetrating into membrane pores. In addition, high initial flux means high initial TMP, which can compress the foulants deposited on the membrane surface and form denser cake layer. The cake more firmly sticks on the membrane surface. In our case a hydraulic backwash is not sufficient to effectively remove it. A visible brown cake layer still exists after backwash giving evidence. Therefore, this sort of cake can be considered as irreversible fouling, which deteriorates membrane performance.

4. Long-term Evaluation

To confirm the effects of initial fouling control, two long-term experiments consisting of (a) constant filtration (75 LMH) with normal backwash; (b) inclining filtration (from 37 LMH to 75 LMH) without initial backwash for 1.5 h are conducted. Fig. 8 clearly shows the advantage of the strategy of initial fouling control. The TMP increase rate of condition B is much lower than that of condition A.

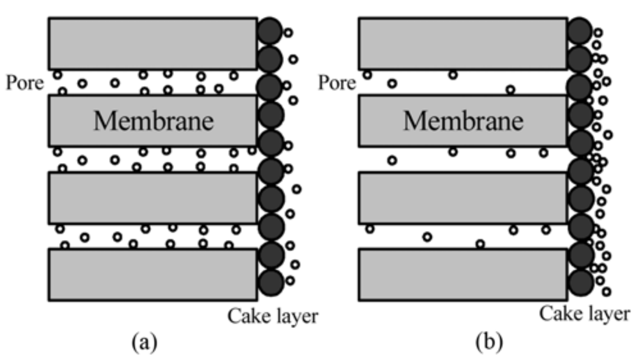

Fig. 7. Illustration of different fouling behaviors: (a) constant filtration; (b) inclining filtration.

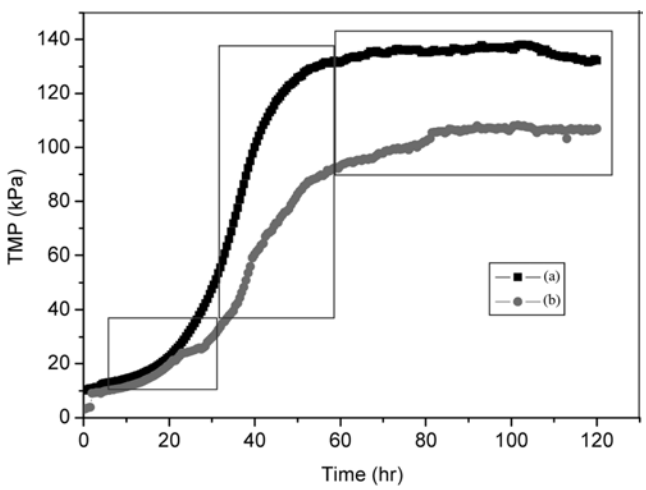

Fig. 8. Long-term evaluation of inclining filtration without initial backwash: (a) constant filtration (75 LMH) with normal backwash; (b) inclining filtration without initial backwash for 1.5 h.

CONCLUSIONS

This study evaluates the effects of initial fouling controls (enhanced backwash and inclining filtration). For this purpose, synthetic water simulating a river is treated by the MF system employing a PVDF membrane at dead-end mode. The results demonstrate that the initial enhanced backwash mode leads to more serious fouling than the normal backwash mode. Instead, filtration without initial backwash successfully reduces fouling. Inclining filtration is found effective for fouling reduction. Beneficial effects of initial fouling control are confirmed in long-term experiments.

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REFERENCES

1. P. Le-Clech, V. Chen and T. A. G. Fane, *J. Membr. Sci.*, **284**, 17 (2006).
2. S. G. J. Heijman, M. Vantieghem, S. Raktoe, J. Q. J. C. Verberk and J. C. van Dijk, *J. Membr. Sci.*, **287**, 119 (2007).
3. A. W. Zularisam, A. F. Ismail and R. Salim, *Desalination*, **194**, 211 (2006).
4. J. D. Lee, S. H. Lee, M. H. Jo, P. K. Park and J. W. Kwak, *Environ. Sci. Technol.*, **34**, 3780 (2000).
5. A. T. Pikkarainen, S. J. Judd, J. Jokela and L. Gillberg, *Water Res.*, **38**, 455 (2004).
6. K. Katsoufidou, S. G. Yiantsios and A. J. Karabelas, *J. Membr. Sci.*, **266**, 40 (2005).
7. P. J. Smith, S. Vigneswaran, H. H. Ngo, R. B. Aim and H. Nguyen, *J. Membr. Sci.*, **278**, 381 (2006).
8. N. M. Mostefa, O. Akoum, M. Nedjihoui, L. Ding and M. Y. Jaffrin, *Desalination*, **206**, 494 (2007).

9. Z. F. Cui and K. I. T. Wright, *J. Membr. Sci.*, **117**, 109 (1996).
10. L. Defrance and M. Y. Jaffrin, *J. Membr. Sci.*, **152**, 203 (1999).
11. R. W. Field, D. Wu, J. A. Howell and B. B. Gupta, *J. Membr. Sci.*, **100**, 259 (1995).
12. C. C. Ho and A. L. Zydney, *J. Colloid Interf. Sci.*, **232**, 389 (2000).
13. E. Iritani, Y. Mukai, Y. Tanaka and T. Murase, *J. Membr. Sci.*, **103**, 181 (1995).
14. P. Bacchin, P. Aimar and R. W. Field, *J. Membr. Sci.*, **281**, 42 (2006).
15. K. Y. J. Choi and B. A. Dempsey, *J. AWWA*, **97**(7), 134 (2005).
16. R. Chan, V. Chen and M. P. Bucknall, *Desalination*, **146**(1-3), 83 (2002).
17. I. H. Huisman, E. Vellenga, G. Trägårdh and C. Trägårdh, *J. Membr. Sci.*, **156**, 153 (1999).
18. B. O. Cho and A. G. Fane, *J. Membr. Sci.*, **209**, 391 (2002).