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A study on enhancing physical cleaning effectiveness in microfiltration membrane system

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ABSTRACT

Fouling control is generally taken by selective pre-treatments, proper membrane operation conditions, and various membrane cleaning methods. The compactness and growth of cake layer on the membrane surface should be timely controlled by mechanical force or hydraulic action. In this work, the sequence of physical cleaning method was strategically introduced by changing cross-flow velocity (CFV), backwash intensity, and backwash waste discharge method from membrane housing. Intensive backwash flush was automatically applied when delta TMP obtained after backwash events was more than 2%. It provided higher pressure on the permeate side of the membrane compared to the normal backwashing, resulting in the reduction of sharp increase of TMP during several operation modes. In addition, the variation of CFV from 0 to 16 m/d based on the membrane fouling index caused turbulence on the membrane fiber, resulting in the discharge of particles accumulated on the membrane surface from membrane module. Finally, flushing mode followed by filtration was more effective in maintaining the TMP stable rather than discharging mode. Flushing effect could induce another shear force to the suspended solids in the bulk and remove cleaning wastes effectively from membrane housing. Large particulates and colloidal matters could be controlled by the proper sequence of physical cleaning based on the TMP monitoring. Furthermore, the strategic physical cleaning could sufficiently reduce not only TMP increase but also the damage of membrane, which is resulted from the more frequent and aggressive chemical cleanings.

Keywords: Cross-flow velocity; Flushing effect; Fouling; Intensive backwash flush; Physical cleaning

1. Introduction

Membrane fouling results in the loss of the membrane performance. Fouling control is generally taken by selective pre-treatments, proper membrane operation conditions, and various membrane cleaning methods resulting in critical loss of the membrane performance [1–4]. In a real membrane plant, chemical cleaning shows effectiveness in flux recovery but it needs production stop of individual membrane unit or

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skid, long cleaning time, complicated cleaning, rinsing and confirmation procedure, and proper treatment of chemical wastes [5,6]. Thus, referring to the cleaning methods, physical cleaning using proper hydrodynamic force and cycle can be available to control reversible fouling as well as potential irreversible fouling without stopping membrane operation. The mechanical force is generally designed or generated into the individual filtration, backwash, and drain or flush mode and it can help to dislodge or flush out the foulant from the membrane surface or pore [7]. Backwashing procedure can impact the overall operation of the membrane system such as mass balance, energy consumption, and operation cost. However, operating condition with high mechanical force such as high cross-flow, forward flushing, and gas bubbling requires large pump usage and finally increases high energy consumption [8–10].

In a study by Shon et al. [11] a periodic relaxation step and/or a periodic increased cross-flow rate at a decreased pressure could help productivity improvements, because the resistances associated with the concentration polarization and the gel layer significantly could be controlled. Chen et al. [12] investigated that the optimized physical cleaning procedure was able to increase cleaning efficiency. In this study, backwash followed by forward flush was more effective than forward flush followed by backwash, resulting in high clean water flux recovery and low wash water usage.

From the previous studies, hydrodynamic force is required to be balanced through individual membrane operation mode. During the filtration, linear velocity works as a shear which can detach the accumulated foulants on the membrane surface and sweep the deposits toward the recirculation line. In the backwash mode, backwash pressure and time are needed enough to form optimum permeate reversal in order to remove deposits from the membrane surface and colloids within the membrane pores. In addition, the backwash waste after backwashing event should be effectively discharged from the membrane housing through draining or flushing approaches.

There has not been enough research performed on the various physical and physicochemical cleaning methods for microfiltration (MF) and ultrafiltration membranes in drinking water. In the real membrane plants, most cleaning studies reported are based on trial and error at the specific site, even though vendors provide their proper cleaning methods. A more strategic and experienced approach is required to build up the various fouling control. In this study, further active efforts are tried to develop more feasible and cost-effective fouling control approaches. The experimental parameters included hydrodynamic conditions such as linear velocity during filtration, backwash intensity, and discharging methods.

2. Materials and methods

The hybrid MF pilot plant was shown in Fig. 1 and was operated for six months. Raw water from Paldang reservoir was used for the pilot testing. It was coagulated, flocculated, settled, and filtered by MF membrane. The river water showed high turbidity in rainy season and high algae number in dry season as shown in Table 1. In addition, low temperature less than 5℃ gave great resistance to the membrane performance due to water viscosity. Under the design membrane flux of 1.5 m/d, coagulant was dosed to

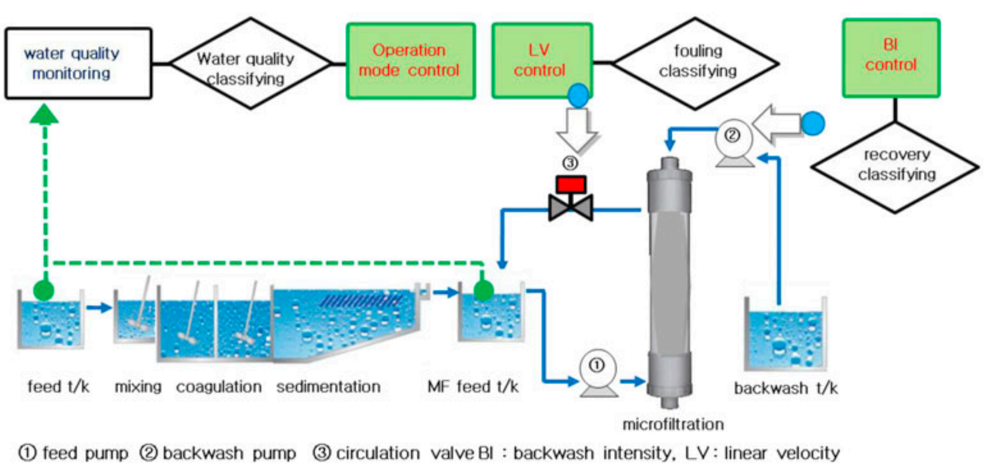

Fig. 1. The detailed process of hybrid MF pilot system.

Table 1
Characteristics of the raw water supplied from Paldang reservoir

	Temp. (℃)	pH	Turbidity (NTU)	TOC (mg/L)	UV_{254} (cm^{-1})	Chlorophyll-a (μg/L)
Max.	27.4	8.8	393	4.2	0.072	299
Min.	1.25	7.0	1.25	1.6	0.040	11
Average	17.3	8.1	22.4	2.6	0.053	45

Table 2
Experimental design of physical cleaning mode

Mode	Parameters	Operation condition
1	Backwash intensity	$Q = 1.5 \times$ flux, time = 60 s
2		$Q = 2.0 \times$ flux, time = 30 s
3	Linear velocity (LV)	Circulation rate = 0% (dead-end)
4		Circulation rate = 5% (cross-flow, fixed)
5		Circulation rate = 5–20% (cross-flow, varied)
6	Drain of backwash waste	Backwash followed by downward drain
7		Backwash followed by forward flush

produce the settled water less than 25NTU of turbidity, even at high turbidity.

The applied MF module (LG Electronics, Korea) has 0.1 μm of pore and 75 m^2 of effective membrane area. The MF was operated at 1.5 m/d of flux and 96% of flux recovery. The operation mode is described in Table 2 for identifying the effect of physical cleaning. Operation interval between backwashes is 30 min, and filtration mode was varied by both dead-end and cross-flow based on raw water quality. In this study, turbidity and chlorophyll-a as algae number indicator were main factors to control the filtration mode. During the filtration mode, particulates and organic foulants are filtered and concentrated within the membrane housing. If there is no circulation of feed water under the dead-end filtration, the concentration

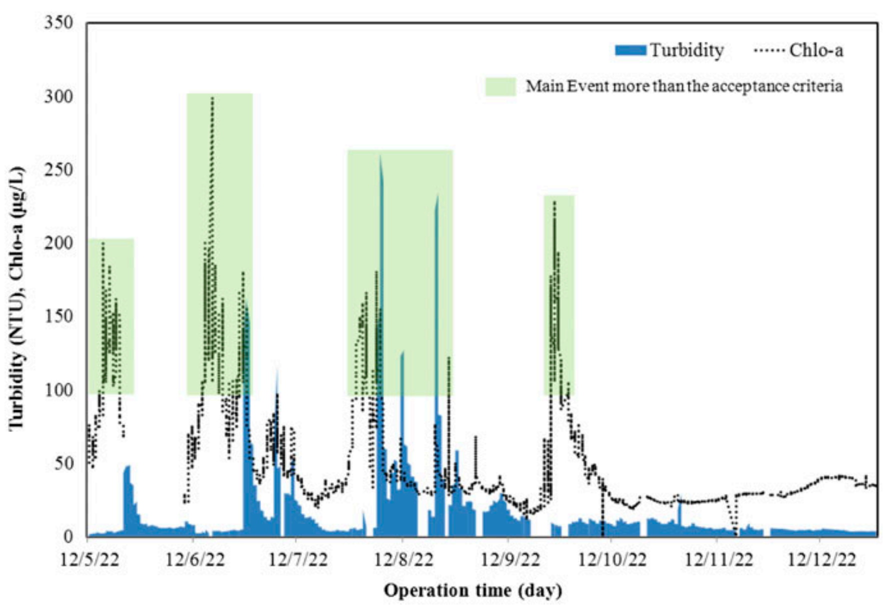

Fig. 2. Characteristics of particles and algae number in raw water.

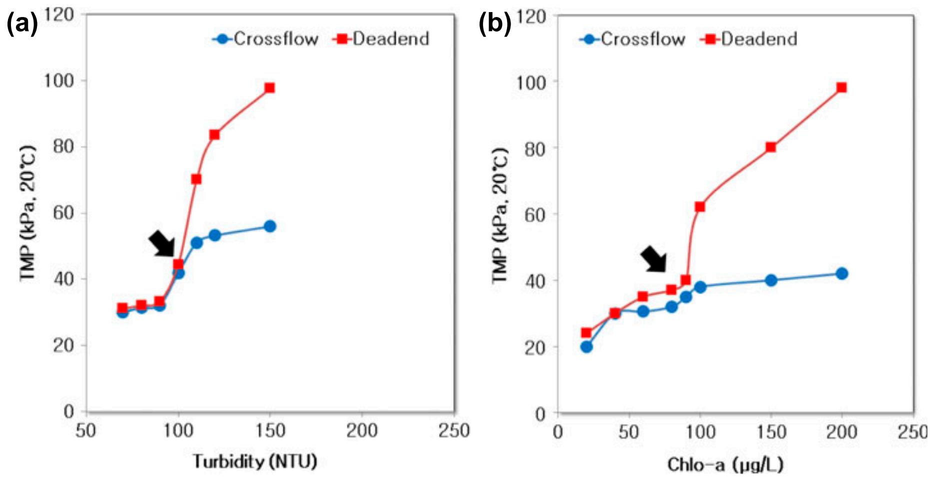

Fig. 3. Decision of operation mode based on the raw water characteristics. (a) Effect of turbidity on TMP. (b) Effect of algae on TMP.

rate in filtration cycle is greater than cross-flow filtration mode. Backwash intensity was controlled by the backwash flow and duration, however the total volume used for backwashing was same. In the cross-flow filtration mode, circulation volume vs. operation flux was varied based on TMP variation. At higher circulation volume, greater shear rate was induced to the membrane fibers. Finally, the membrane foulant (mainly suspended solids) detached from the membrane surface, pores, and inner housing during backwashing was discharged through two methods, such as draining from the bottom of membrane module and forward flushing to the upper side of membrane module. The effect of foulant removal from membrane housing was compared with TMP variation under the different discharging methods of backwash waste.

3. Results and discussion

Particles, colloidal matters, and algae act on the membrane performance as main foulants. As shown in the shaded bar of Fig. 2, peak event of turbidity and algae number happens in the raw water. These foulants can be controlled during filtration and backwash procedure if hydrodynamic actions are well applied and optimized. Especially in the dead-end mode, they can produce sharp increase of TMP, even though given proper pre-treatment.

The critical point of turbidity and chlorophyll-a concentration as an indicator of algae numbers were determined by each effect on the TMP in both dead-end and cross-flow modes through long-term operation. High turbidity and algae number caused a sharp increase of TMP due to greater accumulation on the membrane surface and needed eddies and shear in the dead-end, however minor increase of TMP was obtained in the cross-flow (Fig. 3). From this result, the acceptance criteria of turbidity and chlorophyll a are 100 NTU and 100 μg/L, respectively, which resulted in a sharp increase of TMP in dead-end. Fouling loads over the criteria caused the cake layer thick and compacted without cross flow. Thus if one parameter between turbidity and chlorophyll-a exceeds the acceptance criteria, dead-end was automatically switched into cross-flow during the operation.

Backwash intensity effect on cyclic TMP recovery between backwashes was investigated. Flow rate of

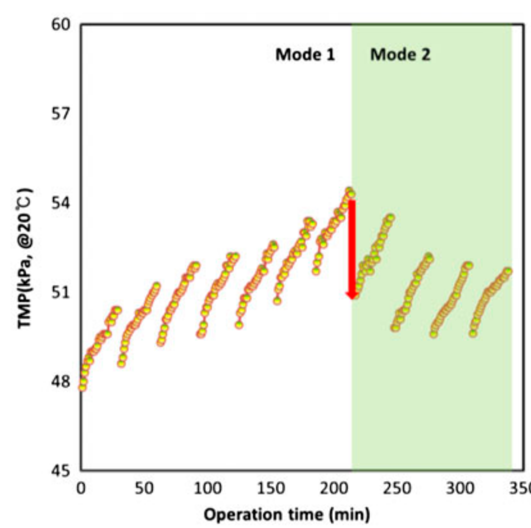

Fig. 4. Effect of IBF on TMP recovery.

general backwash is generally decided based on the design flux and calculated by 1.2–1.5 times of membrane flux. In this study, backwash intensity was varied by mode 1(recommend by membrane vendor) and mode 2. Mode 2 was applied when the cyclic TMP increase between normal backwash events is more than 2%. Intensive backwash flush (IBF) introduction could effectively dislodge reversible foulants from the membrane surface and result in high recovery of initial TMP right after IBF (Fig. 4). It provided higher pressure (backward force and shear force) on the permeate side of the membrane compared to the normal backwashing, causing the porosity of the cake layer to be increased and the pores to be cleaned (Fig. 5). In addition, water usage in mode 2 can reduce by 30% compared with that of mode 1.

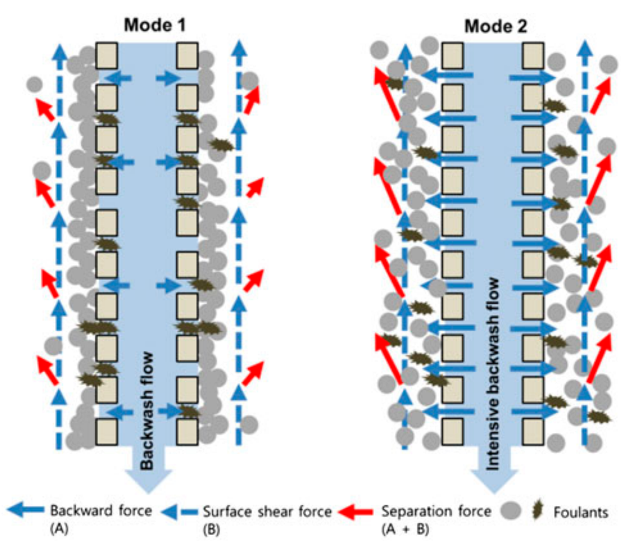

Fig. 5. Hydraulic mechanism of IBF on foulant.

Variation of linear velocity in membrane module was applied with changing the circulation volume in this fouling control study. TMP variation was compared between dead-end and cross-flow mode as shown in Fig. 6. Without circulation, 100% of feed water was filtered. There was minor TMP difference between both modes if water quality was good and operation period was short. However, particle loads via time span provided significant difference of TMP between dead-end and cross-flow filtration modes. It showed that linear velocity from circulation flow could effectively flush out the accumulated foulants on the membrane surface and. In addition, under the condition of high particle loads to the membrane, cross-flow filtration mode gave dilution effect to the accumulated foulants within the membrane housing.

Cross-flow mode (Mode 4) was shifted from dead-end mode by 5% of circulation rate when critical point of turbidity or chlorophyll-a were monitored in the raw water. Mode 5 was designed to run using 10–20% of circulation rate (8–16 m/d of linear velocity) if initial TMP difference between two continuative backwashing events was recorded more than 2% even after IBF application. The higher

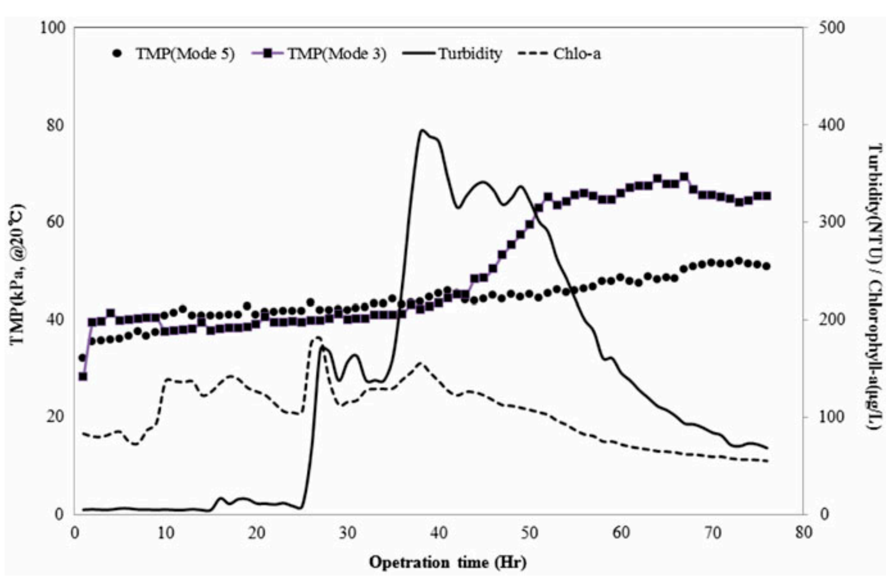

Fig. 6. Comparison of TMP between dead-end and cross-flow modes.

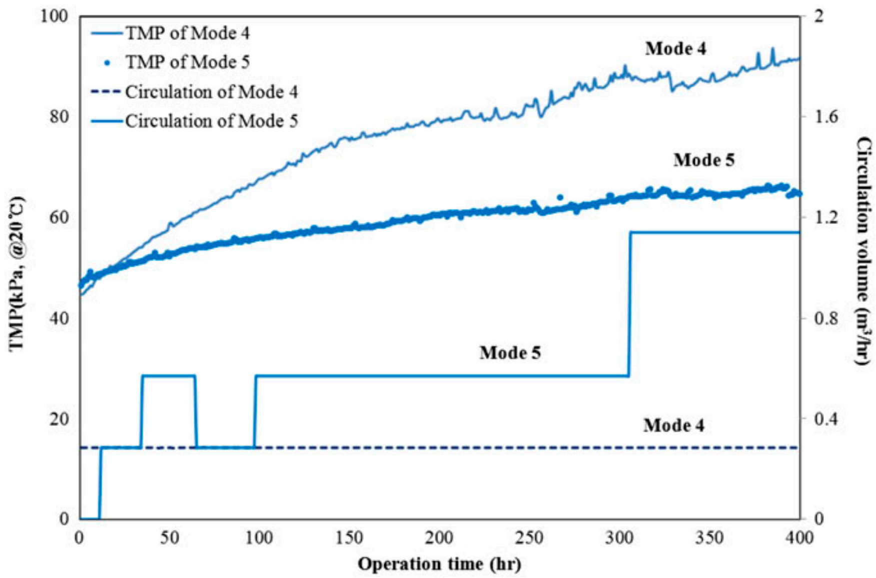

Fig. 7. Effect of linear velocity variation on TMP.

circulation rate and the greater shear rate, thus TMP in the Mode 5 was more stable than Mode 4 (Fig. 7). Thus irregular variation of feed and circulation flow could reduce severe fouling phenomena during a continuous filtration process, especially preventing the reversible foulants from the strong and thick attached irreversible foulants as reported by Yazhen et al. [13]. The more rapid flow on the feed side caused turbulence and the particles accumulated on the membrane surface could be effectively discharged into circulation or discharge line. However, energy consumption should be considered under the higher cross-flow velocity (CFV).

It is very important that the particulates remained in the membrane housing after individual backwash is removed thoroughly from the module. Both downward draining and forward flushing after every backwash were applied in order to evaluate discharging effect of the foulants remained in the membrane housing. Flushing mode followed by filtration was more effective in maintaining the TMP stable than discharging mode (Fig. 8). Flushing effect could induce another shear force to the suspended solids in the bulk and remove them effectively from the membrane housing. Especially it was found that flushing could lift out the accumulated solids at the bottom of membrane module. However, downward draining caused accumulation phenomena of suspended solids within the bottom membrane fibers via time, resulting in TMP increase (Fig. 9). In addition, it produced less backwash effluents, resulting in high recovery. In

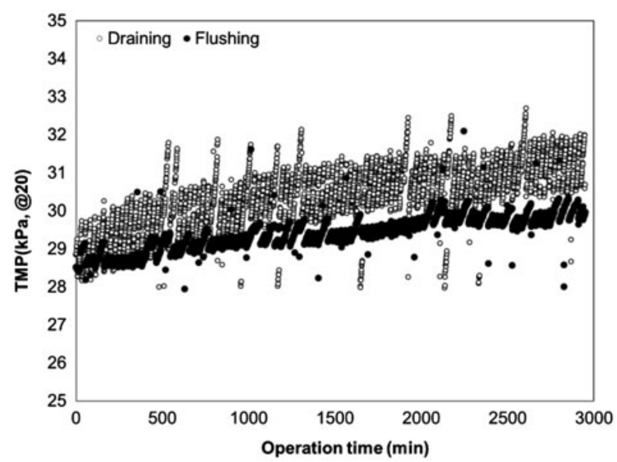

Fig. 8. Comparison between draining (mode 6) and flushing (mode 7).

this work, large particulates and colloidal matters could be controlled by the proper sequence of physical cleaning based on the TMP monitoring. Especially, it was convinced that the compactness and growth of cake layer on the membrane surface should be timely controlled by mechanical force or hydraulic action. Thus the strategy in physical cleaning could sufficiently reduce not only TMP increase but also the damage of membrane fibers resulted from the more frequent and aggressive chemical cleanings.

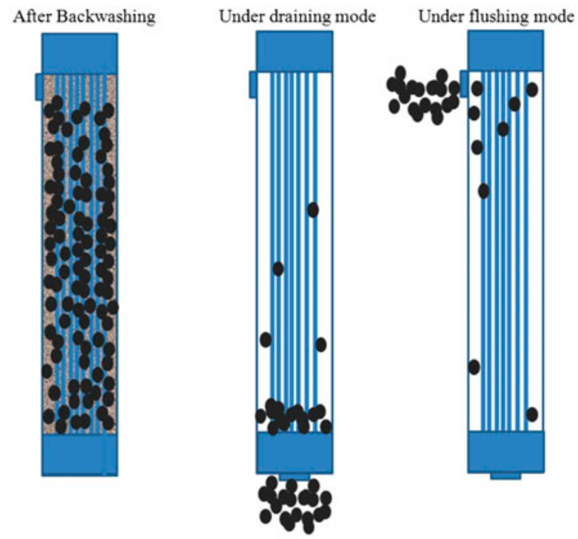

Fig. 9. Discharging suspended solids between draining and flushing.

4. Conclusions

In this study, the sequence of physical cleaning method was strategically introduced by changing CFV, backwash intensity, and backwash waste drain method in order to investigate the hydrodynamic effect on the membrane fouling. If the applied membrane can be operated with dual modes (dead-end and cross-flow), it is better to combine based on the raw water characteristics or fouling index. It was found that turbidity and algae numbers were main foulants, resulting in sharp increase of TMP and the acceptance criteria of turbidity and chlorophyll-a as an indicator of chlorophyll-a are 100 NTU and 100 μg/L, respectively, for automatically switching into cross-flow from dead-end during filtration. IBF applied automatically when TMP recovery between continuative backwash events was less than 98%. IBF introduction could reduce sharp increase of TMP during several operation modes and result in the delay of chemical cleaning time. In addition, CFV was diversified from 0 to 16 m/d through the valve control at circulation line of membrane module based on the membrane fouling index. The more rapid flow on the feed side caused turbulence on the membrane fibers and the particles accumulated on the membrane surface could be effectively discharged into circulation or discharge line. However, energy consumption was greater under higher CFV. Flushing mode followed by filtration was more effective in maintaining TMP stable than discharging mode. Flushing effect can induce another shear force to the suspended solids in the bulk and remove them effectively from the membrane housing. In addition, it produced higher recovery and less backwash waste.

Acknowledgments

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