Effects of various chemical cleaning conditions for pressured MF process

Chang-Kyu Lee, Chansoo Park, June-Seok Choi and Jong-Oh Kim

ABSTRACT

A pilot-scale pressured hollow-fiber microfiltration (MF) process as pretreatment for the reverse osmosis process was studied and operated under various conditions to assess the relative influence of backwashing, chemical enhanced backwashing (CEB), and bag filter application. The pilot plant process consisted of backwashing but without the CEB or the bag filter as the first step of the research. As the second step of the research, the impact of the backwashing on permeability recovery was assessed at different intervals followed by the influence of CEB on flowrate recovery. Results from operating the pilot-scale hollow-fiber membrane modules for more than 1 year have demonstrated that the appropriate pore size of bag filters was 25–50 μm and the optimized backwashing process was every 30 minutes with 25 mg/L of NaOCl, and CEB with an interval of 10 cycles with the use of 100 mg/L NaOCl.

Key words | backwashing, bag filter, chemical enhanced backwashing, hollow-fiber, MF, wastewater reclamation

Chang-Kyu Lee
Chansoo Park
Jong-Oh Kim (corresponding author)
Department of Civil and Environmental Engineering,
Hanyang University,
222 Wangsimni-Ro, Sungdong-Gu,
Seoul 04763,
Republic of Korea
E-mail: *jk120@hanyang.ac.kr*

Chang-Kyu Lee
Research Engineering Development Inc.,
94 Seohae-daero, Nam-gu,
Incheon 22195,
Republic of Korea

June-Seok Choi
Environmental and Plant Engineering Research Institute, Korea Institute of Civil Engineering and Building Technology,
283 Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si,
Gyeonggi-Do 10223,
Republic of Korea

INTRODUCTION

Rising water scarcity caused by increasing demand and imbalanced distribution have become more intensified in recent decades, especially in hot and arid areas under limited water sources. In addition to the scarcity problems, the effects of discharged polluted water from various industries or secondary effluent from wastewater treatment plants have drawn much attention in terms of their devastating effects on the environment due to excessive nutrient loading components such as phosphorous and nitrogen (Singh *et al.* 2004; Carey & Migliaccio 2009). The wastewater treatment, therefore, may provide an alternative potable water (Asano 2002; Asano & Cotruvo 2004; Li *et al.* 2007; Metcalf & Eddie 2013) and is required to prevent the destruction of the environment.

Among many technologies to treat the water, a process using microfiltration–reverse osmosis (MF-RO) membrane has become increasingly favored for potable and non-potable reuse of wastewater. The MF-RO system showed some competent results due to its ability to produce superior quality water. The system made removing organic and inorganic contaminants much simpler even for treating low quality sources of water such as wastewater, where the use of conventional methods is unable to remove them (Li *et al.* 2007). On top of that, MF-RO system operation can be cost-effective, requiring less land space than that of the conventional treatment processes (Pulido 2016).

The use of an MF-RO process to treat wastewater, however, possesses many problems. The organic matter becomes the major foulant of RO along with other various substances (Lee *et al.* 2006): inorganics and organics including proteins. Failure to control the fouling will cause a serious reduction in hydraulic performance and life of the membrane (Li *et al.* 2007; Hatt *et al.* 2011).

To successfully maintain RO process throughput, two types of pretreatment technique exist: conventional processes where coagulants are added to form flocs and membrane filtration techniques. Although some researchers argue that conventional pretreatment is not always inferior to the membrane filtration techniques (Isaias 2001; Galloway & Mahoney 2004; Rapenne *et al.* 2007; Quevedo *et al.* 2011), intensive research by pretreating influent using MF and ultrafiltration showed outstanding results such as achieving low silt density index values and removal ratio of bacteria and microorganism (Vial & Doussau 2002; Chua *et al.*

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2003), allowing MF to be used widely as a pretreatment process of RO since 1995 (Lazarova *et al.* 2012; Raffin *et al.* 2012). On the other hand, fouling on MF, reducing the process throughput, has now become the new drawback (Raffin *et al.* 2012). The overall pretreatment process using MF, therefore, has been intensively studied and developed to reduce the flux decrease caused by fouling.

MATERIALS AND METHODS

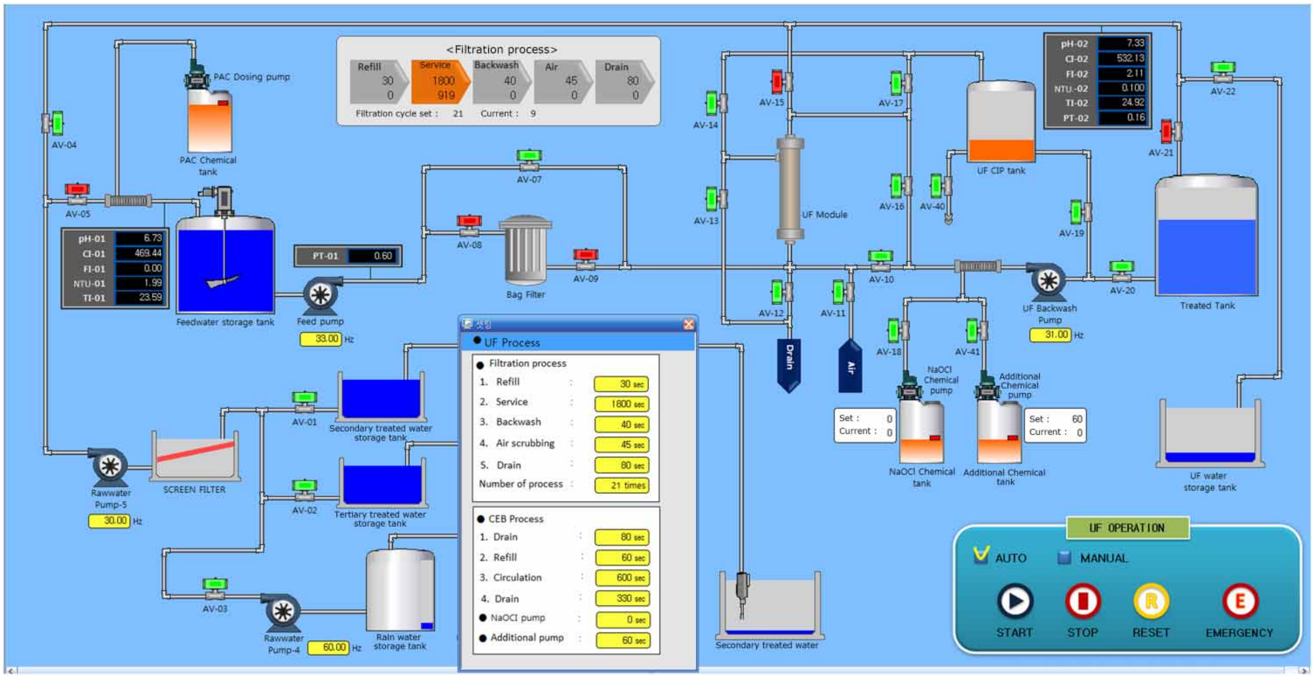
Water reclamation pilot plant overview

The operational raw data consisting of transmembrane pressure (TMP), pH, electric conductivity, temperature, and flux data were automatically logged every second and were monitored for operation and maintenance purposes. The human–machine interface (HMI) in Figure 1 shows the complete configuration of the pilot plant with implementation of an alarm system in case of an operational emergency. The pilot-scale hollow-fiber MF pretreating membrane used was provided by Econity Inc. (Yongin, Korea), and was installed in a wastewater treatment plant located in Paju City, Korea. The detailed specifications of the MF membrane are given in Table 1. The source water used in this study was the wastewater discharged from the wastewater treatment plant, and the quality of feed source water was determined by taking samples every other week and analyzing afterwards (Table 2). The automated plant was operated under various test conditions which were modified by an operator regularly visiting the plant once or twice a week. The pilot plant was designed to treat 50–75 m^3/d. The operation lasted a total of 410 days with an intermittent pause to modify experiment conditions. Bag filters used in this study were commercial grade and domestically bought.

Methods

Bag filters were used ahead of the MF process to remove extremely large particles to prevent MF membranes from being damaged. To study the effects of bag filters on turbidity removal, bag filters with a pore size of 5, 10, 20, 50, and 100 μm were used. Multiple cycles of backwashing with a high concentration of NaOCl will show enhancement in flux recovery.

Backwashing intervals and NaOCl concentration were optimized to the point where the backwashing intervals and NaOCl concentration were considered effective to prevent excessive backwashing cycles and chemicals added. The data to investigate the effects under various backwash intervals and NaOCl concentration were collected by changing backwashing intervals to 20, 30, and 45 minutes and NaOCl concentration to 10, 20, and 25 mg/L.



<Filtration process>

Refill	Service	Backwash	Air	Drain
30	1800	40	45	80
0	919	0	0	0

Filtration cycle set : 21 Current : 9

pH-01	6.73
CI-01	469.44
FI-01	0.00
NTU-01	1.99
TI-01	23.59

PT-01 0.60

pH-02	7.33
CI-02	532.13
FI-02	2.11
NTU-02	0.100
TI-02	24.92
PT-02	0.16

Feed pump 33.00 Hz

UF Backwash Pump 31.00 Hz

Rawwater Pump-5 30.00 Hz

Rawwater Pump-4 60.00 Hz

NaOCl Chemical pump Set : 0 Current : 0

Additional Chemical pump Set : 60 Current : 0

● UF Process

● Filtration process

1. Refill : 30 sec
2. Service : 1800 sec
3. Backwash : 40 sec
4. Air scrubbing : 45 sec
5. Drain : 80 sec

Number of process : 21 times

● CEB Process

1. Drain : 80 sec
2. Refill : 60 sec
3. Circulation : 600 sec
4. Drain : 330 sec

● NaOCl pump : 0 sec

● Additional pump : 60 sec

Figure 1 | HMI screen display of the process.

Table 1 | Domestic pressured hollow-fiber MF membrane specification

Membrane	Material	Membrane area	Type of filtration	Allowable pressure	Pore size
Domestic MF	PVDF	69 m^2	Outside to inside	3 bar (max)	0.1 micron

Table 2 | Feed water average quality analysis

Turbidity (NTU)	TOC (mg/L)	COD (mg/L)	T-N (mg/L)	T-P (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
2.15	4.75	8.83	9.21	0.069	0.000	0.005	0.018	0.028	0.008

TOC: total organic carbon; COD: chemical oxygen demand; T-N: total nitrogen; T-P: total phosphorus.

Chemical enhanced backwashing (CEB) is performed after certain cycles of operation with a high concentration of NaOCl. The effect on flux recovery is higher than that of regular backwashing. An optimized number of CEB can reduce the number of regular backwashing to be performed, which can be economically beneficial due to the reduction in the total amount of chemicals added. Thus, to study the effect of CEB, the concentration of NaOCl and CEB intervals were modified over 5 months of operation. Refill, service time, backwashing, air scrubbing, and drain periods are set to 50 seconds, 30 minutes, 40 seconds, 45 seconds, and 80 seconds, respectively. CEB was performed after a specified number of backwashing processes. One cycle of the CEB process consists of refill, circulation, and drain processes, and the duration of each process was set to 60 seconds, 10 minutes, and 30 seconds, respectively (Table 3). The CEB test details of five test sets are listed in Table 3. The flowrate data were logged every 10 minutes. At the start-up period of the pilot plant, the MF membrane was operated without bag filters or CEB, but only with a backwashing of 15 mg/L NaOCl. After 2 months of operation, the permeate flux declined noticeably and instantly from the beginning of each service period. To reduce the instant and rapid flux decline, bag filters and CEB systems were installed in series.

RESULTS AND DISCUSSION

Bag filter

The feed water quality – wastewater plant effluent – has necessitated the use of bag filters to prevent intensive MF membrane fouling. For the first 8 hours of operation, bag filters with a pore size of 5 μm were used, which happened to be too small for the turbidity matter in the influent to go through the filter, resulting in the bag filter pores being completely blocked, and the flowrate dropped close to zero (Figure 2). The bag filters were switched to 50 μm bag filters. The results showed a constant flowrate decline down to 1.5 m^3/day after 183 hours of operation. The next operation of 151 hours, operated with 25 μm pore-sized bags, showed a more intensive flowrate decline as expected. The operation continued with 10 μm bag filters for 51 hours, which showed similar results as the experiment using 5 μm bag filters; flowrate dropped immediately due to plugging of pores by turbidity matter. The work was continued with the use of 100 μm pore size bag filters. The operation showed no significant flowrate drop for over 317 hours; however, it appeared that the bag filters of 100 μm pore size were not effective in the removal of turbidity at all. The usage of bag filters of 50 μm pore size required the bag filters to be

Table 3 | Process cycle and CEB test conditions

Time of 1 process cycle (sec)		CEB (sec)		Condition number	CEB interval (cycles)	NaOCl (mg/L)	Service time (sec)
Refill	50	Refill	60	1	42	100	1,800
Service	1,800	Circulation	600	2	21	100	1,800
Backwash	40	Drain	80	3	21	200	1,800
Air scrub	45			4	15	200	1,800
Drain	80			5	10	100	1,800

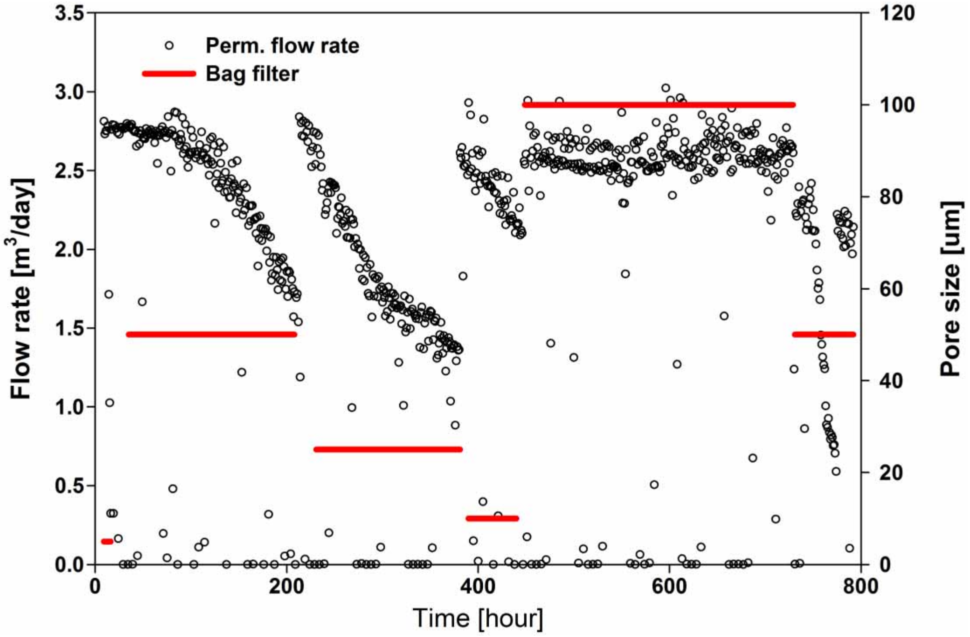


Figure 2 | Operation with the usage of different pore size of bag filters.

changed to a new one every day. The tests with 10 and 25 µm bag filters may have not operated long enough to represent any significant relationship in removing turbidity matter, although the operation with 50 µm bag filters showed appropriate turbidity matter removal efficiency. The final 50 µm bag filter was tested with an injection of polyaluminum chloride coagulant (PAC) in the influent wastewater. The results showed a rapid drop of flowrate which may have been caused by the flocs blocking the entire pores of the bag filter. Considering flowrate reduction and turbidity matter removal efficiency, bag filters of 50 µm pore size were used throughout the experiment afterwards.

Conductivity of permeate and feed side along the bag filter experiment were measured as shown in Figure 3. The graph shows that bag filters and MF membrane have no significance on removing ions.

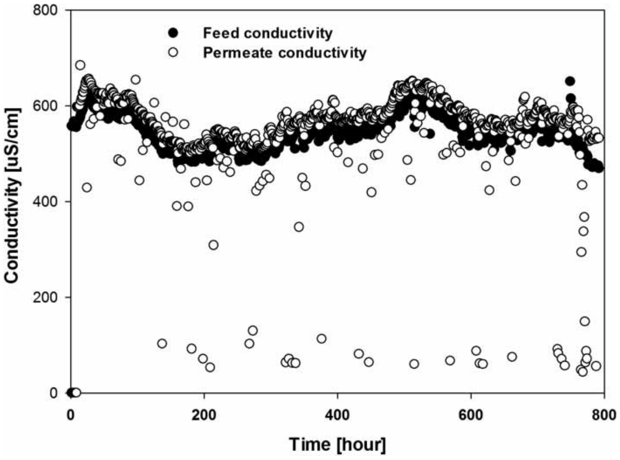


Figure 3 | Conductivity trend of feed and permeate of same time period.

Backwash intervals and NaOCl concentration

Fouling on the membrane can be reduced by introducing a backwashing process or implanting CEB. Extensive CEB requires many chemicals; therefore, optimization of backwashing, where the need for CEB is minimized, becomes as much of an important factor as the optimization of the CEB process for economic reasons.

Previous experiments showed that the backwash intervals set to between 30 and 60 minutes can reduce the need for frequent CEB (Wang *et al.* 2008; Raffin *et al.* 2012). In this study, the backwash was performed every 45 minutes for approximately 1,000 operation hours with an initial concentration of 15 mg/L of NaOCl. Due to the apparent increase of flux, the backwashing interval was changed to 30 minutes with the same NaOCl concentration, which then was operated for 900 hours.

The graph in Figure 4 shows a continuous TMP increase and constant flux decline even after changing service conditions. The interval was reduced to 20 minutes with an increased NaOCl concentration of 20 mg/L. In spite of

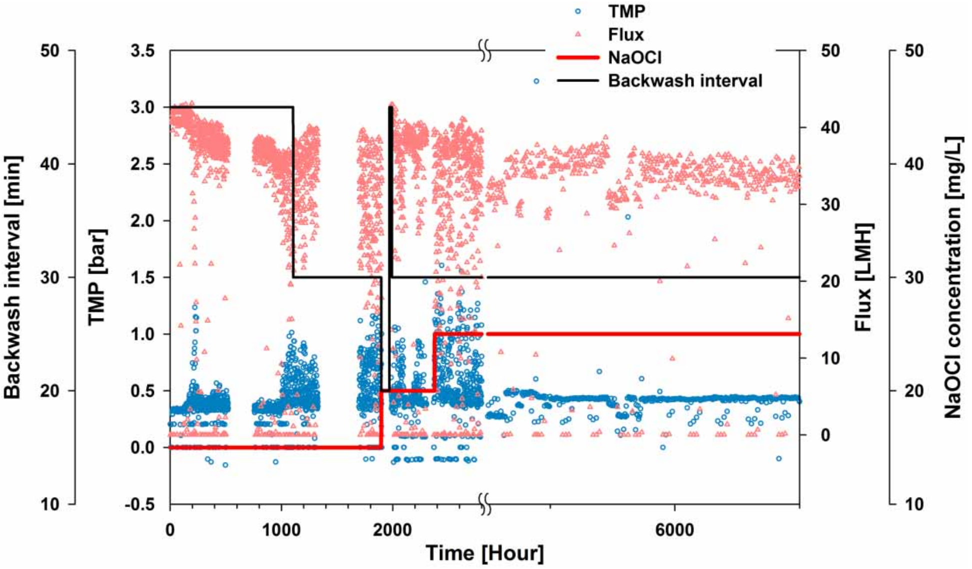


Figure 4 | Optimization of backwashing intervals and NaOCl concentration changes.

reducing backwash interval from 45 to 20 minutes, the effect on flux recovery was only apparent up to a certain point. Hence, NaOCl concentration was increased from 15 to 20 mg/L with a backwash interval of 45 minutes for a brief moment and changed back to 30 minutes until the increase of chemical concentration started to show its effects. The modification showed a gradual enhancement in flux. The NaOCl concentration was finally raised to 25 mg/L while the flux stabilized 3,000 hours after the operation first started, until the end of the operation.

Effects of CEB

Effective CEB can be represented as a high recovery rate of flux. However, NaOCl concentrations are much higher than that of backwashing NaOCl concentrations. Optimizing the CEB process will not only enhance the operation process but also reduce the operation cost. Figure 5 represents approximately 5 months of operation in terms of flowrate. The specific operation conditions are shown in Table 3. Data logging error, additional construction of facility,

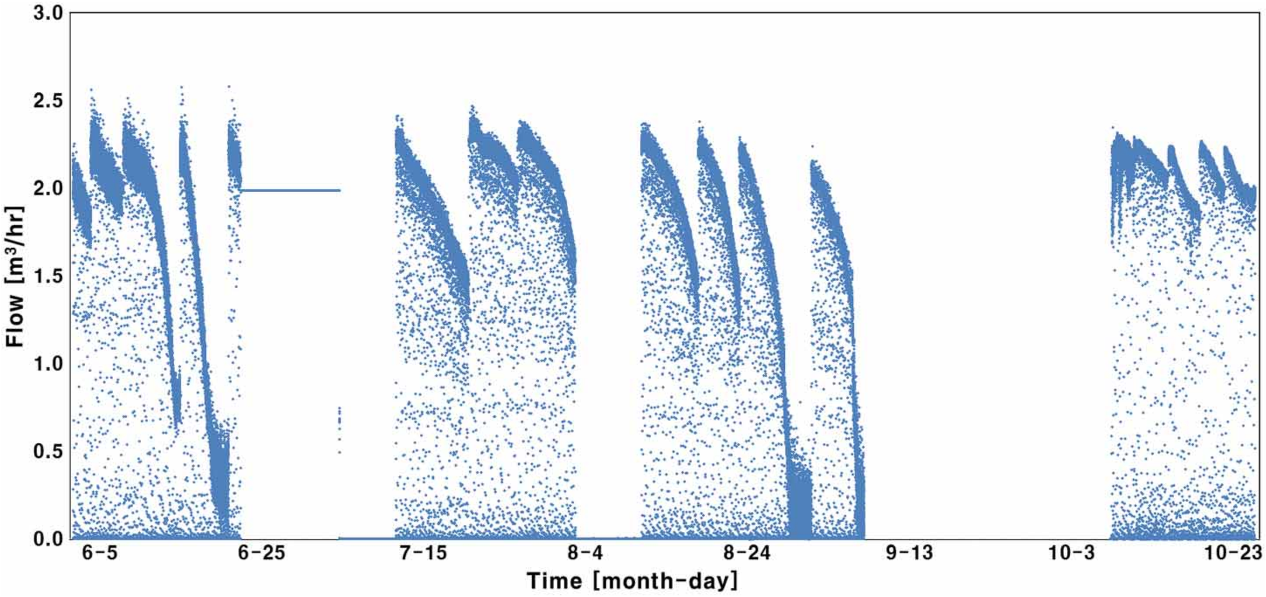


Figure 5 | The effects of flowrate decline by different CEB conditions.

clean-in-place, and bag filter replacement have caused blank data on the figure.

The flowrate decline varied for each experiment condition. For instance, the flowrate dropped to 0.7 m^3/hr on 7 June while the CEB process using NaOCl 100 mg/L was implemented after every 42 backwashing cycles. With the same NaOCl concentration and change of CEB interval from 42 to 21 cycles, 4.17% flowrate decrease was observed from the beginning of the experiment until 21 July. As shown in Figure 6(a), the initial flowrate of 2.2 m^3/h dropped to 2.1 m^3/h. This may seem insignificant, but a high TMP value of more than 0.4 bar and evident difference

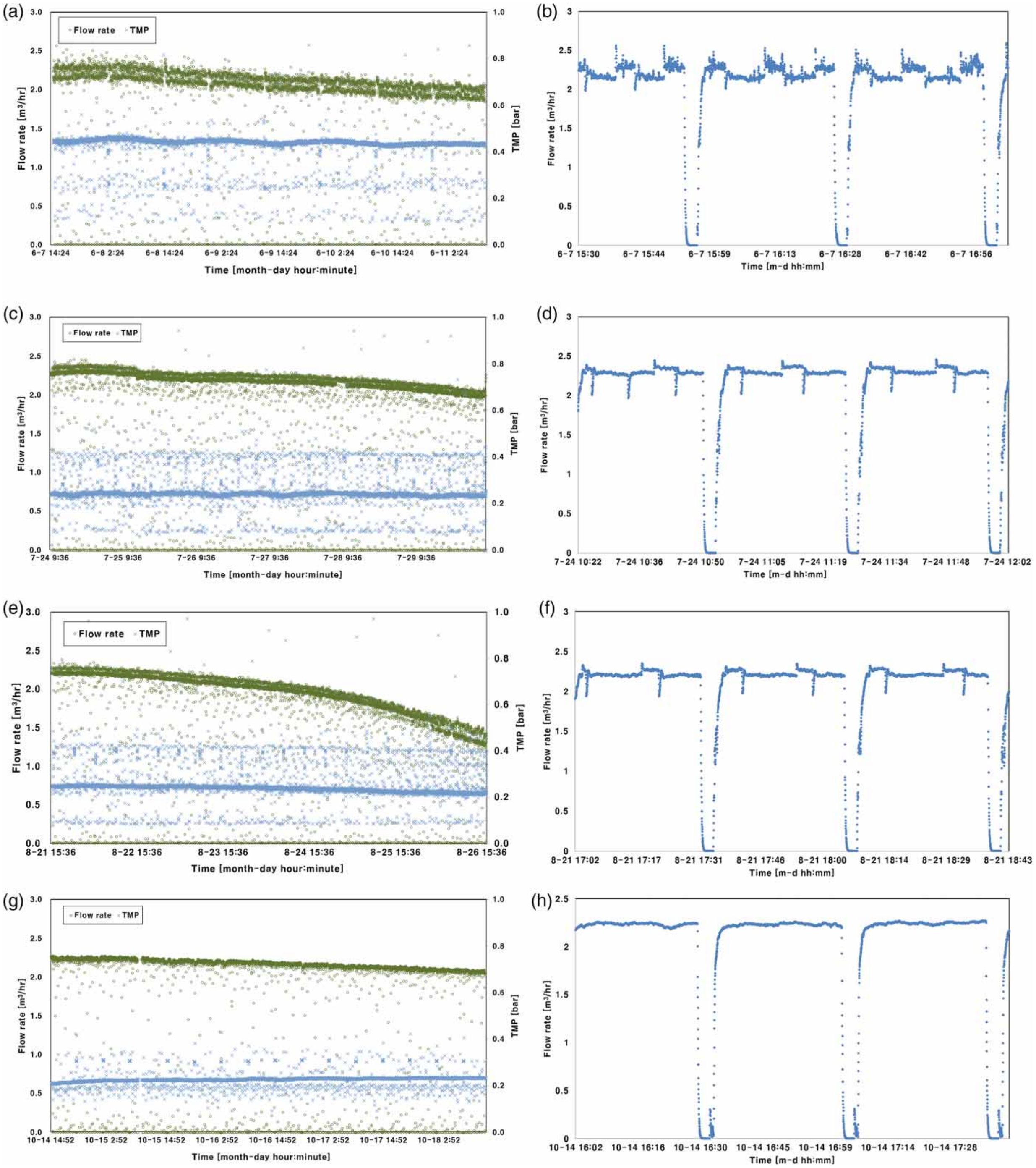


Figure 6 | Operational flowrate and TMP data of 5 days and three cycles: (a) 5 days' operation from 7 June, (b) three cycle data from 7 June, (c) 5 days' operation from 24 July, (d) three cycle data from 24 July, (e) 5 days' operation from 21 August, (f) three cycle data from 21 August, (g) 5 days' operation from 14 October, and (h) three cycle data from 14 October.

between maximum and minimum flowrate of each cycles (Figure 6(b)) may prove that the CEB operation has not yet been optimized.

The test continued by doubling the NaOCl concentration to 200 mg/L with the same interval conditions. The flowrate recovery was apparent and the flux fluctuated less as shown in both 5-day long operational data and cycle data (Figure 6(c)–6(d)). The CEB interval was then reduced to 15 cycles with an NaOCl concentration of 200 mg/L. Figure 6(e) shows that the overall flowrate of the whole operation period has declined. However, this result was caused by a reduction in flow since the bag filters were clogged at that time. This has been proven by steady TMP values as well as Figure 6(f), where TMP values stabilized around 0.2 bar and the cycle data show no sign of flowrate decrease. The flowrate when the CEB intervals were reduced to 10 cycles (Figure 6(g) and 6(h)), even though NaOCl concentration was reduced to 100 mg/L, showed continuous stable data. The cycle data of Figure 6(h) show a clean linear flowrate line with the TMP value of 0.2 bar.

The study concluded that CEB interval optimization may have been finalized. This study also shows that CEB intervals are a more important factor than NaOCl concentration. However, more tests with various NaOCl concentrations are required for accurate results.

CONCLUSIONS

In municipal wastewater reuse process, bag filters may be used to maintain performance and protect the MF membrane process. The appropriate pore size of bag filters found in this study was 25–50 μm. However, the tests with the use of 10 and 25 μm bag filters may have not operated long enough to represent a significant relationship in removing turbidity matter. The rapid flowrate drop at the final stage of bagfilter operation may have been caused by PAC blocking the entire pores of bag filters. The flowrate of the backwashing optimization operation stabilized when backwashing was performed every 30 minutes with 25 mg/L of NaOCl. Comparing the effects of CEB and the backwashing process, the CEB process showed higher efficiency of flowrate recovery than backwashing with low NaOCl solution. The effective CEB interval was 10 cycles with an NaOCl concentration of 100 mg/L. Overall, the results from more than 1 year of study of pilot-scale hollow-fiber membrane modules have demonstrated the trends in permeability and its recovery by chemical cleaning in a wastewater reuse system.

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