Chemical Engineering Journal 302 (2016) 128–136

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Effect of different physical conditions on fouling control in *in-situ* chemical cleaning in place (CIP) for flat sheet membranes fouled by secondary effluents

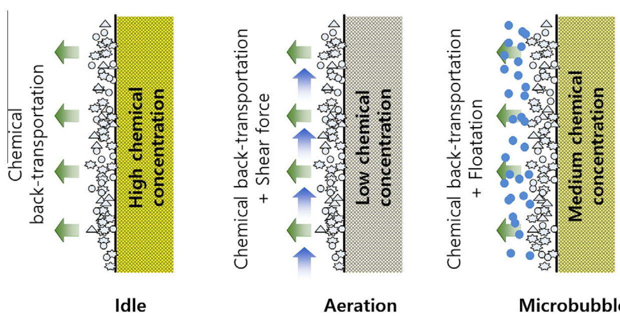
Eui-Jong Lee [a,c], Young-Hoon Kim [b], Chang-Ha Lee [c], Hyung-Soo Kim [d,*], Hyung-Sook Kim [e,1]

[a] School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue Kowloon, Hong Kong
[b] Daewoo Institute of Construction Technoloy, Jangan-gu, Suwon, Gyeonggi-do 440-210, Republic of Korea
[c] Department of Civil and Environmental Engineering, Sungkyunkwan University, 2066 Seobu-ro, Jangan-Gu, Suwon, Gyeonggi-do 440-746, Republic of Korea
[d] Graduate School of Water Resources, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do 440-746, Republic of Korea
[e] Department of Food and Nutrition, School of Human Ecology, The University of Suwon, 17 Wauan-gil, Bongdam-eup, Hwaseong-si, Gyeonggi-do 445-743, Republic of Korea

HIGHLIGHTS

- Application of *in-situ* CIP on fouled FS-membranes with secondary effluents.
- Effect of different physical conditions on the efficiency of the *in-situ* CIP method.
- Examination of detached foulants from membranes and fouled membranes through *in-situ* CIP.
- Comparisons between *in-situ* CIP with aeration and microbubble in short-term membrane filtration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 8 May 2016
Accepted 9 May 2016
Available online 9 May 2016

Keywords:
Membrane fouling
In-situ cleaning in place (CIP)
Microbubble
Flat sheet (FS) membrane
Reclamation

ABSTRACT

Although microfiltration (MF) system has been employed as pretreatment for reclamation, the MF process is prone to irreversible fouling by secondary effluents as feed. In particular, flat sheet (FS) membrane has trouble in controlling fouling due to restriction of backwashing. In this study, *in-situ* CIP (NaOCl 300, 600, 1200 mg/L) was applied to fouled membranes by secondary effluents with different physical conditions (idle, aeration, microbubble) and evaluated via examination of detached foulants (or fouled membrane) and continuous membrane process. The *in-situ* CIP with microbubble, the most effective method, showed cleaning efficiencies from 32.6% to 81.9% depending on operating conditions. Although microbubble could not induce hydraulic shear stress, it removed particulates and colloids on the membrane surface effectively. In addition, it influenced the structure of fouling layers. Moreover, *in-situ* CIP with microbubble retarded the increase of fouling resistances and controlled irreversible fouling compared to *in-situ* CIP with aeration.

1. Introduction

Secondary effluents of municipal wastewater have attracted increasing attention as an optional resources for drinking water production with increasing number of regions facing water shortage [1,2]. Various approaches to treat secondary effluents have

* Corresponding author.
E-mail addresses: sookim@skku.edu (H.-S. Kim), hyungsook@suwon.ac.kr (H.-S. Kim).
[1] Co-corresponding author.

http://dx.doi.org/10.1016/j.cej.2016.05.039
1385-8947/

been carried out [3–5] due to the fact that secondary effluents not only have abundant quantity but also have high accessibility compared to seawater. Among numerous methods, membrane techniques have been proven to be attractive advanced treatment processes that can facilitate high quality water with compact system and easy operation. In most membrane processes for reclamation, reverse osmosis (RO) or nanofiltration (NF) system combined microfiltration (MF) or ultrafiltration (UF) has been adopted, where MF (or UF) processes are used for pretreatment [6,7].

Although MF filtration can preserve RO system efficiently from particulates and colloidal matters in reclamation processes, membrane used in MF filtration has enormous potential of severe fouling. Secondary effluents are composed of particulate and colloidal matters containing natural organic matter (NOM), soluble microbial products (SMP), and extracellular polymeric substances (EPSs). Their removal by physical settling or biological decomposition can be problematic [8]. Wastewater effluent organic matter (EfOM) composed of SMP and NOM has been regarded as major organic foulants in wastewater reclamation [9,10]. EPSs not only adhere to membrane surface, but also affect the structure of cake layers [11]. Such foulant can contribute to irreversible fouling, which is not removed by physical cleaning such as backwashing and aeration [12]. Consequently, the membrane needs to be cleaned by chemicals to remove the foulants strongly attached to the surface or pores of membranes.

Ex-situ cleaning in place (CIP) for recovering initial permeability of membranes requires a large amount of chemicals and intensive labor [13]. To decrease frequency of *ex-situ* CIP in membrane process for wastewater treatment, *in-situ* chemically enhanced backflush (CEB) integrating backwashing and CIP has been introduced recently [14]. Generally, CEB is carried out by adding a low concentration of chemical to backwashing water in a membrane container without removing membranes from the container. Hence, this technique can control both reversible and irreversible fouling simultaneously. It can overcome the limit of conventional physical and chemical cleaning methods. Several studies using hollow fiber (HF) membranes have reported on the applicability of the CEB method for fouling control [15–18]. Wang et al. [19] have attempted to optimize the CEB conditions. On the other hand, different from HF membranes, most flat sheet (FS) membranes are not allowed to apply CEB due to structural vulnerability of FS membranes in pressurized backwashing. Hence, in the case of FS membranes, *in-situ* CIP by adding a low concentration of chemical inside the membrane module without pressure (not backwashing) is employed to control fouling effectively [12,20].

Maintenance chemical cleaning such as CEB and *in-situ* CIP can be a proper option to control membrane fouling in MF or UF pretreatment processes for wastewater reclamation because the membrane system can suffer from irreversible fouling formed by particulates and colloids. Nevertheless, few studies have been carried out in membrane fouled with secondary effluents to control membrane fouling with maintenance chemical cleaning. Therefore, we examined the applicability of *in-situ* CIP in this study to remove foulants of membranes for reclamation. To the best of our knowledge, this study is the first attempt to remove membrane foulants by *in-situ* CIP in FS membrane fouled by EfOM. In addition, *in-situ* CIP was implemented under different physical conditions (i.e., relaxation without aeration, general (coarse bubble) aeration, microbubble) to offset the limit of *in-situ* CIP resulting from cleaning chemical diffusion without pressure. In *in-situ* CIP, NaOCl at different concentrations (300, 600, 1200 mg/L) was used and cleaning efficiencies were measured with an interval of 30 min. To investigate the properties of *in-situ* CIP, foulants detached from membrane and fouled membranes were analyzed.

2. Materials and methods

2.1. Setup of membrane filtration system and microbubble generator

As shown in Fig. 1(a), treated water was produced by decreasing the pressure inside the membrane modules by peristaltic pump until transmembrane pressure (TMP) reached 40 kPa. The fouled membrane at the end of operation was used to investigate propensities of fouling control. Polytetrafluoroethylene (PTFE) membrane with pore size of 0.45 μm and surface area of 0.3 m^2 was submerged in acrylic container of 30 L. The membrane process was operated with an interval of 9 min filtration and 1 min relaxation at high flux of 40 $L/m^2/h$ without aeration for fouling control. Drainage or circulation was not carried out before physicochemical membrane cleaning was applied. Secondary effluent of conventional wastewater treatment plant was used. Raw water was flowed into the membrane tank along the surface of acrylic wall to minimize shaking water in the tank. The raw water was composed mostly of particulates and colloidal matter not settled so that suspended solid concentration was considerably low (Table 1).

To create microbubble consistently for cleaning, additional device needed to be installed as shown in Fig. 1(b). After an amount of air was dissolved in water in the mixing chamber through a pump, microbubbles were made when water containing air came out at normal pressure. While the mixing chamber was at pressure of 40 kPa and air was flowing at a rate of 4 L/min, a microbubble with diameter size ranging from 10 μm to 200 μm (average of 44.8 μm), was supplied through diffuser hole.

2.2. Procedure of in-situ CIP with flat sheet membrane

At the end of membrane operation, fouled membrane was moved into another tank filled with deionized water for *in-situ* CIP (CIP hereafter). To inject NaOCl solution of designated concentrations inside the membrane module, the tube with funnel was connected to the permeate hole of membrane module. NaOCl solution (1 L) spontaneously flowed inside each membrane module without any pressure. This situation was kept for from 30 min to 120 min for NaOCl diffusing through the membrane.

2.3. Evaluation of cleaning efficiency after in-situ CIP

At the end of membrane operation, fouled membrane was moved into another tank filled with distilled water to measure membrane resistance. R_m was obtained from transporting deionized water through the pristine membrane. R_f was calculated by filtration of fouled membrane using deionized water.

$$J = \frac{\Delta P}{\eta \times R_t} \quad (1)$$

where J was the filtrate flux through the membrane ($m\ s^{-1}$), ΔP was the trans-membrane pressure (Pa), η was the absolute viscosity (Pa s), and R_t was the total resistance of filtration (m^{-1}). R_t was composed of R_m and R_f, the resistance caused by inherent properties and foulants within membranes.

Cleaning efficiencies were calculated using the following equation.

$$\text{Cleaning efficiency } (\%) = \frac{R_f - R_{f'}}{R_f} \times 100(\%) \quad (2)$$

where R_f was the resistance caused by foulants when transmembrane pressure reached 40 kPa, and $R_{f'}$ was the resistance caused by remained foulants after CIP.