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Characterizing flat sheet membrane resistance fraction of chemically enhanced backflush

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HIGHLIGHTS

- The investigation of fouling control mechanism via the CEB method in FS-MBRs.
- Effect of the CEB method on the removal of the cake layer and fouling resistances.
- Evaluation of the effect of the foulant type on the efficiency of the CEB method.
- Optimization of the chemical concentration and cleaning run time for an enhanced foulant removal.

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ABSTRACT

This study attempts to demonstrate the applicability of chemically enhanced backflush (CEB) to flat sheet (FS) membranes and aims at examining the membrane resistance fraction of complex organic foulants without applying hydraulic cleaning. With sodium hypochlorite (NaOCl) applied (i.e., 100–600 mg/L) as an oxidant chemical, complex soluble microbial products (SMP) foulants were effectively removed from the membrane in 60–90 min, and the membrane resistance is governed by the CEB bulk reaction and the transport, penetration and back transport of NaOCl. An in-depth study has proved that the cake resistance associated from the SMP foulants is more sensitive to CEB runtime, whereas the fouling resistance is more sensitive to the concentration of NaOCl. Nevertheless, for the foulant which mainly compose of dissolved organic matters, the cake resistance can be effectively removed in a shorter runtime and with a lower concentration of NaOCl as compared with the SMP foulant. However, high concentration of NaOCl is still needed to remove its fouling resistance. In addition, this study demonstrates that even in the absent of hydraulic backflush CEB is still highly compatible with FS membrane and the effectiveness is comparable to that of hollow fiber membrane.

1. Introduction

Membrane bioreactor (MBR) is a promising technique to continuously produce a high-quality effluent with a good disinfection capability with a small footprint compared to the conventional activated sludge process [1]. With increasing environmental concerns and a growing global water demand, the utilization of MBR systems for wastewater treatment, water reuse and water recycling is growing rapidly [2,3]. Nevertheless, membrane fouling, one of the major challenges in MBR systems, still remains unsolved and hinders the widespread full-scale application of MBR for wastewater treatment [4,5]. When fouling occurs, trans-membrane pressure (TMP) has to be further increased to maintain the water flux, and the membrane has to be chemically cleaned or even be replaced in extreme circumstances.

Based on the strength of the foulant attached on membranes, many studies attempted to elucidate the type of fouling into reversible and irreversible, and to further categorize foulants into biosolids/organic and inorganic fouling [6]. Reversible fouling is often attributed to the loosely attached foulants, such as particulate, colloidal and dissolved organic matter on the membranes, and gradually forming a biosolid cake layer [7,8]. Irreversible fouling, on the other hand, is caused by strongly attached foulants which eventually block the membrane pores over the operation time [9]. Physical and chemical cleaning are two widely-used methods to resolve this fouling issue. Physical backwashing and several techniques, such as relaxation and aeration, have been developed to enhance the efficiency of the fouling control [10,11]. However, the performance of physical backwash is fairly

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effective on reversible fouling and was suggested not suitable for removing irreversible foulants from membranes [12]. It is also worth noting that among three predominant membrane modules, i.e., flat-sheet (FS), hollow fiber (HF), and tubular membrane, physical backwashing is not applicable for most FS or MT due to the nature of membrane modules [6].

To enhance cleaning performance in MBRs, in situ chemically-enhanced backflush (CEB) is recently studied by adding a low concentration of sodium hypochlorite (NaOCl) or sodium hydroxide (NaOH) in the course of membrane maintenance and is proved to be an effective method for simultaneous removal of reversible and irreversible foulants from membranes. The major advantage of CEB is to delay the period of recovery (intensive) cleaning which normally requires a large amount of chemicals and intensive labor [13]. Buzatu et al. have conducted pilot-scale trials on a HF-MBR with physical cleaning and CEB. It was reported that combination of physical de-clogging and CEB provided a generally higher permeability recovery than that from physical de-clogging alone, and it can be attributed to alleviated fouling resistance by hypochlorite CEB [14]. Furthermore, same research group used real municipal wastewater to assess the efficacy of CEB with sodium hypochlorite at different fluxes for HF-MBR and showed increased permeability with CEB duration [15]. Interestingly, Ramos et al. applied CEB in anaerobic membrane bioreactor treating food industry wastewater and reported 2000 ppm NaClO CEB achieved 56.8% pore resistance and 60.7% overall resistance without any negative effect on the biomass actively [16]. Wang et al. [17] optimized the CEB conditions such as chemical loads, backflushing duration and flux for fouling control of a hollow fibre (HF) membrane and Zhou et al. [18] suggests that on-line NaOH CEB could maintain membrane permeability as well as supply alkali to facilitate the operation of MBRs. In view of the recent researches, a comprehensive CEB mechanism in fouling control is yet to be established; however, is essential to the CEB application in MBR. In particular, the CEB application on flat sheet (FS) membranes is rarely discussed, due to the fact that CEB is a pressure-driven process, while flat sheet membranes are not mechanically strong enough to withstand the pressure.

This study attempts to demonstrate CEB to remove two types of foulants, soluble microbial products (SMP) and dissolved organic matters from FS membrane through the characterization of membrane resistance fraction. The aim of this study is to investigate the fouling control mechanism of FS membrane via the CEB technique. By optimizing the chemical concentration and runtime, the foulant removal efficiency of FS membrane is compared with HF membrane. This novel cleaning approach not only improves the performance of the FS MBR, but also retains the integrity of membrane structure and provides useful operational conditions for its full-scale application.

2. Materials and methods

2.1. Membrane specifications and foulant composition

The specifications of the membranes used in this study were summarized in Table 1 and were applied to evaluate the fouling control capability of CEB. The HF membrane module is about 25 mm in diameter and 100 mm in length. The inner and outer diameters of the fibres are 0.8 mm and 1.2 mm, respectively. The HF membrane, which is widely-used in water treatments [19], is made of polyvinylidene fluoride (PVDF) and the FS membrane is made of polytetrafluoroethylene (PTFE) with advantages of high permeability and durability. The FS membrane was directly used in an acrylic module setup in this study.

Table 1
Characteristics of the membranes used.

Classification	HF type	FS type
Material	PVDF	PTFE
Manufacturer	Asahi Kasei	Dupont
Pore size (μm)	0.12	0.22
Membrane area (m^2)	0.0057	0.0033
Pure water flux (LMH/bar)	2546	5250

Complex foulants formed by SMP (WW-A) are composed of lysis sludge particles, colloids with extracellular polymeric substances (EPS) and solutes which can cause severe membrane fouling [20]. The pH of the MBR sludge was maintained at 10 for 3 h by adding NaOH, to mimic an extreme foulant condition. Another type of foulant, dissolved organic foulant was prepared from pretreated municipal wastewater (WW-B) using a 0.45 μm filter. All solutions of foulant were diluted to about 35 mg/L COD with de-ionized water.

2.2. CEB operation and membrane permeability measurement

A schematic diagram of the lab-scale experimental set up is illustrated in Fig. 1. Nitrogen gas was injected into a pressure vessel which equipped with a magnetic stirrer to prevent the settling of foulants. A digital pressure gauge was used to adjust the pressure throughout the experiment. The FS membrane was mounted on a custom-made acrylic module: The flow was in a downward direction with permeate collected at the bottom. The HF membrane was operated according to an established method, as previously described in a recent study [21]. The volumes of WW-A and WW-B flowing through the membranes were set at 160 and 400 mL, respectively, to achieve the same theoretical initial membrane permeability in both experiments. For the FS membrane CEB, 100, 300 and 600 mg/L of NaOCl (i.e., 200 mL in total volume) were applied to permeate side and a shear force was introduced on the surface of the fouled membrane for 1 min at the end of the CEB. On the other hand, the CEB of the HF membrane was operated as a backwash: 200 mL of chemical CEB was applied at a flux of 40 L/m^2/h, and then an idle time was allowed for the diffusion of NaOCl. The amount of permeate was recorded with time and was utilized for the calculation of membrane resistance.

2.3. Membrane resistance fraction

The general equation of Darcy's law which expresses the flux in terms of pressure change, viscosity and resistance was applied and the total membrane resistance can be obtained according to Eq. (1):

$$J = \frac{\Delta P}{\eta \times R_t} \tag{1}$$

where ΔP is the trans-membrane pressure (Pa), η is the absolute viscosity (Pa s) and R_t is the total resistance of filtration (m^{-1}). R_t is the summation of three distinct resistances as shown in Eq. (2):

$$R_t = R_m + R_c + R_f \tag{2}$$

where R_m is the pure membrane resistance, R_c is the cake resistance and R_f is the fouling resistance.

When de-ionized water is used as the feed solution, R_c and R_f are equal to zero and Eq. (1) can be simplified to Eq. (3) and therefore, R_m can be calculated.

$$J = \frac{\Delta P}{\eta \times R_m} \tag{3}$$

R_c, as the reversible cake layer foulant, can be removed by scrubbing the membranes with a soft sponge. Similarly, R_f is the remaining irreversible foulant obtained after scrubbing. To prevent