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Effect of membrane type and material on performance of a submerged membrane bioreactor

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Abstract

This study evaluated the impact of membrane type and material on filtration performance in a submerged membrane bioreactor (MBR) for municipal wastewater treatment. Three types of microfiltration membranes with similar pore size of 0.1 μm but different materials and types, phase-inversed polytetrafluoroethylene (PTFE), track-etched polycarbonate (PCTE) and track-etched polyester (PETE), were used. Changes in permeability with time for the PCTE and PTFE membranes appeared similarly, whereas the PETE membrane exhibited the most rapid flux decline. Lower TOC in the permeate compared to the supernatant was probably due to a combination of biodegradation by the biofilm (cake layer) developed on the membrane surface and further filtration by cake layer and narrowed pores. The faster permeability decline and higher TOC removal rate of the PETE membrane were attributed to an initial permeate flux higher than an average design flux, which led to a faster rate of fouling and thicker cake layer. Therefore, an MBR should not be operated at a flux higher than the average design flux for a specific type of membrane. A gradual increment of biomass concentration did not significantly affect membrane permeability of each membrane investigated. Dissolved organic carbon fractionation results showed that the composition of each fraction between the supernatant and permeates did not change significantly with time, suggesting that membrane hydrophobicity was not a dominant factor affecting MBR fouling in this study. The organic foulants desorbed from the PCTE membrane contained approximately 60% of hydrophobic fraction, which was probably attributable to the extracellular polymeric substances proteins released from the biomass attached to the membrane. While the total filtration resistance of the PTFE membrane was influenced by a higher surface roughness, those of the PETE and PCTE membranes, which had a similar and lower roughness, were affected by the initial operating flux.

Keywords: Initial flux; Membrane hydrophobicity; Membrane permeability; Submerged membrane bioreactor; Surface roughness; Track-etched membrane

1. Introduction

Membrane bioreactor (MBR) process combines biological wastewater treatment with a membrane process to treat wastewater biologically and to separate biomass physically from the mixed liquor in a single step. The MBR system is increasingly adopted to treat municipal and industrial wastewaters because of complete solids–liquid separation, production of high-quality effluent, capability of handling wide fluctuations in influent quality and small footprint (Visvanathan et al., 2000). In addition, due to more stringent discharge regulations, steady decrease of the membrane cost and water reuse initiatives, MBR applications are expected to be adopted widely. However, the decrease of permeate flux with operating time due to membrane fouling is one of major deterrents to more installations of the MBR process for wastewater treatment.

To date, numerous studies were carried out to investigate the causes, characteristics and mechanisms of MBR fouling, and to develop more efficient methods for membrane fouling mitigation. Many researches on membrane fouling have focused on the effect of biomass characteristics, such as mixed liquor suspended solids (MLSS),

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particle size distribution and extracellular polymeric substances (EPS) (Nagaoka et al., 1996; Zhang et al., 1997; Rosenberger et al., 2005). In addition, MBR fouling affected by operating conditions, including hydraulic retention time (HRT), solids retention time (SRT) and permeate flux, has been extensively studied (Chang et al., 2002; Ren et al., 2005; Ng et al., 2006). Recent studies concentrated on more effective and economical methods to control membrane fouling in the MBR (Yang et al., 2006) through: (1) modification of membrane module and reactor design such as optimization of the membrane packing density and the location of aerator, (2) permeate flux control and adoption of intermittent suction mode to reduce cake formation on membrane surface, and (3) the removal of the foulants using back-washing and chemical cleaning.

Membrane fouling in an MBR is affected by interactions between membrane and mixed liquor in the bioreactor; hence membrane characteristics, such as membrane material, pore size and hydrophobicity, are important factors on membrane fouling. In particular, results of fouling experiments using polymeric and/or ceramic membranes revealed that there was a close relationship between membrane material and fouling in an MBR (Judd et al., 2004; Yamato et al., 2006). However, there is still little information available with regard to the impact of membrane material on MBR fouling, and thus further in-depth investigation is required. In addition, the impact of membrane type (i.e., phase-inversed versus track-etched) on MBR fouling has not been reported yet.

The objective of this work was to investigate the effect of membrane type and material on MBR performance for municipal wastewater treatment. Three different polymeric microfiltration (MF) membranes were used in this study: polytetrafluoroethylene (PTFE) membrane (Sumitomo Electric, Japan), polycarbonate (PCTE) membrane (GE-Osmonics, USA) and polyester (PETE) membrane (GE-Osmonics, USA).

2. Materials and methods

2.1. Membrane characteristics and experimental setup

As the focus of this work was to investigate the impact of membrane type and material on MBR performance, membrane modules with a similar pore size of 0.1 μm were used. Three types of membranes were investigated: PTFE (porous phase-inversed), PCTE and PETE (both track-etched) membranes. Each flat-sheet membrane module is A4 in size with membranes attached on both sides, which resulted in a total membrane surface area of 0.1 m^2. Properties of the membranes used are listed in Table 1. Pure water permeability (PWP) values were determined by filtering deionized water using clean membrane modules in the MBR and the results showed that the PWP values of the PCTE and PTFE membranes were higher by 30% and 43%, respectively, compared to that of the PETE membrane. The PTFE membrane is less hydrophobic (HPO) and rougher compared to the other two membranes.

Table 1
Properties of the MF membranes used in this work

Item	PETE[a]	PCTE[a]	PTFE[a]
Manufacturer	GE-Osmonics	GE-Osmonics	Sumitomo electric
Pore structure	Cylindrical	Cylindrical	Non-cylindrical
Pore size (μm)	0.1	0.1	0.1
Contact angle (°)[b]	66.0 ± 4.4	66.2 ± 2.8	49.1 ± 5.4
Mean roughness (nm)[c]	8.3 ± 1.5	11.6 ± 0.1	131.5 ± 31.9
Pure water permeability ($l\,m^{-2}\,h^{-1}\,kPa^{-1}$)[d]	20.5 ± 2.9	26.7 ± 3.0	29.5 ± 7.5

[a] PETE = polyester; PCTE = polycarbonate; PTFE = polytetrafluoroethylene.
[b] Data are expressed as mean ± standard deviation ($n = 5$).
[c] Surface roughness was measured in triplicate (mean ± standard deviation).
[d] The filtration test was performed using deionized water at 29 °C.

Three flat-plate membrane modules, each with different types of membranes mentioned earlier, were immersed in a single bioreactor, which was divided into three compartments with a similar volume of 8.1 l each (overall effective volume of the bioreactor: 24.3 l). An air diffuser, controlled using a flow regulator, was installed under each membrane module to provide similar aeration and hydrodynamic conditions.

2.2. Feed wastewater and operating conditions

Wastewater collected from a local municipal wastewater treatment plant was used as the feed water. Raw wastewater was prefiltered using a fine screen (mesh size: 1.0 mm) to remove large particles before being fed to the MBR. The influent wastewater quality parameters throughout the operation were $379 \pm 172\,mg\,l^{-1}$ for chemical oxygen demand (COD), $52.7 \pm 5.9\,mg\,l^{-1}$ for total nitrogen (TN), $244 \pm 100\,mg\,l^{-1}$ for suspended solids (SS), and $175 \pm 52\,mg\,l^{-1}$ for volatile suspended solids (VSS).

Seed-activated sludge was collected from the same wastewater treatment plant at a MLSS concentration of approximately $1600\,mg\,l^{-1}$. Initial permeate flux was set to approximately $9.1\,l\,m^{-2}\,h^{-1}$. Intermittent suction with a cycle of 3-min run and 2-min pause was carried out for permeate production. HRT and SRT were controlled at 8 h and 15 d, respectively. A pH controller and $NaHCO_3$ solution of 0.25 M were used to maintain the mixed liquor pH at 7.0.

In order to restore permeate flux, each membrane module was cleaned physically and chemically on day 43 and day 82 of the experimental run. Physical cleaning was carried out by wiping the membrane surfaces with a soft sponge followed by rinsing with tap water. Then, the membranes were chemically cleaned by immersing the modules in 1% (w/v) HCl for 0.5 h and in 0.5% (w/v) NaClO for 2 h in series. During the membrane cleaning on day 82, PWP values of the fouled and cleaned membranes were measured using deionized water.