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Short-term fouling propensity and flux behavior in an osmotic membrane bioreactor for wastewater treatment

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HIGHLIGHTS

- Short-term FO membrane fouling in OMBR was insignificant.
- Both MLSS and osmotic pressure had no severe effect on membrane fouling.
- Membrane fouling was affected by elevation of salinity.
- Hydrophobic proteins were the main cause of membrane fouling.
- Some proteins were identified as the major membrane foulant.

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ABSTRACT

The short-term fouling behavior of forward osmosis (FO) membrane in an osmotic membrane bioreactor (OMBR) was investigated, using NaCl or $MgCl_2$ as the draw solutions. The effect of membrane orientation, mixed liquor suspended solids (MLSS) concentration and draw solution (DS) osmotic pressure on water flux and membrane fouling behaviors was examined, along with the effects of simulated elevated salinity on sludge properties and on membrane fouling. Water flux and membrane fouling were not significantly affected by both MLSS concentration (4.91–12.60 g/L) and osmotic pressure (3.0–15.0 MPa), but were severely affected by elevated salinity, due to changes in activated sludge properties, in particular the increase in extracellular polymeric substances (EPS) and sludge hydrophobicity. $MgCl_2$ as the DS showed more significant influence on activated sludge properties and membrane fouling than NaCl but gave rise to lower salt accumulation. Analyses of the membrane foulants showed that small sludge floc/particles and EPS (in particular, proteins) were enriched in the fouling layer. UPLC–MS/MS analyses of the proteins showed that hydrophobic proteins were the main cause of membrane fouling.

1. Introduction

Membrane bioreactor (MBR) technology, first reported in wastewater treatment application about 40 years ago, is now actively employed in municipal and industrial wastewater treatment [1–6]. MBR has gained popularity due to some distinctive advantages compared to conventional wastewater treatment systems, such as reduced footprint, low production of excess sludge [2], high quality effluent and high sludge concentration [1]. Unfortunately its widespread application is seriously hampered by the higher energy demand resulting from the more intensive aeration and/or mixing needed to control membrane fouling [4,7,8].

Recently there has been increasing interest in a novel MBR which integrates forward osmosis (FO) and the biological process for wastewater treatment in a process combination commonly known as osmotic membrane bioreactor (OMBR) [9–15]. In an OMBR system, a high rejection semipermeable membrane (i.e. FO membrane) is used instead of a microporous membrane in the traditional MBR. Water is transported from the mixed liquor into a draw solution (DS) under a driving force of osmotic pressure. Compared to the traditional MBR, OMBR offers some unprecedented advantages: (i) Osmotic pressure is used as the driving force instead of hydraulic pressure, and hence offers a high potential to reduce energy consumption as well as increase theoretical water flux [9,15]. Although the downstream treatment needed to regenerate the DS and to obtain the product water would increase capital and operation costs, this may be mitigated by recent developments in novel DS [11,12]. (ii) Higher rejection of the FO membranes for a wide range of contaminants and mineral salts results in high quality product water as well as the potential to reduce membrane fouling in downstream reverse osmosis (RO) units [12,16]. (iii) The dense and tight surface structure of FO membranes and the milder foulant compaction effects in FO processes may result in much lower fouling propensities of the membranes [10,17]. For these reasons, OMBR is considered a

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promising alternative in wastewater treatment and reclamation [9,18], especially in the removal of emerging organic pollutants [19,20].

Although the fouling potential of FO membranes in OMBRs is expected to be much lower [14], fouling nonetheless occurs [10,21]. Moreover, due to the different filtration/permeation mechanisms and distinctive surface structure of FO membranes, fouling on FO membranes in OMBRs is likely to differ from pressure-driven membrane in the traditional MBRs. Additionally, as a novel MBR process, OMBR suffers from some inherent drawbacks, such as reverse DS transport [22–27] and salt accumulation in the bioreactor [10,28]. The elevated salinity and salt accumulation may cause unpredictable changes in the activities and properties of the activated sludge, which would further impact membrane fouling [28,29]. Furthermore, the interactions of the inorganic ions (especially divalent cations) and the organic foulants, as well as the scaling of low soluble salts (e.g. gypsum [24], calcium carbonate and calcium phosphate [30]) under relative high ionic strengths give rise to more complex fouling phenomena on FO membranes [30–32]. Additionally, critical flux phenomena have also been observed for FO membranes, where significant flux reduction occurred when the water flux level exceeded some threshold value [31,33]. The existence of critical flux in osmotically driven FO processes highlights the importance of optimizing osmotic pressures in reducing membrane fouling.

Currently, most studies on FO membrane fouling have been conducted using model foulants (e.g. bovine serum albumin, alginate and humic acid) and with high DS concentrations. Studies on FO membrane fouling behavior with activated sludge under typical OMBR operation conditions are relatively scarce. Additionally, different fouling mechanisms have been reported. For instance, in a study by Lay and co-workers, a thin gel-like secondary layer was detected on the membrane surface, and further investigation found extracellular polymeric substances (EPS) on the used membrane surface, with small numbers of scattered bacterial cells but no mature biofilm formation [10]. Zhang and co-workers showed that biofilm formation together with inorganic scaling could be an important factor governing membrane fouling in OMBR [30]. Models have also been developed to describe membrane fouling behavior on various activated sludge processes [21]. Results showed that initial flux and bound protein were the key factors controlling membrane fouling in OMBR. Since membrane fouling is highly dependent on operational conditions and sludge properties [2,3], systematic studies are needed to better understand the fouling propensities and mechanisms of FO membranes in activated sludge under typical OMBR operating conditions.

The aim of the current work is to systematically investigate short-term water flux and membrane fouling behavior of FO membrane in an OMBR operated with synthetic wastewater. NaCl or $MgCl_2$ was used as the DS for comparison. The effect of membrane orientation, mixed liquor suspended solids (MLSS) concentration, and DS osmotic pressure on water flux and membrane fouling behaviors was investigated. In order to investigate the effect of elevated salinity on activated sludge properties, as well as on the water flux and membrane fouling behavior, activated sludge was cultured under different NaCl or $MgCl_2$ concentrations before being subjected to the short-term fouling test. Finally, the membrane foulants were analyzed to uncover the potential fouling mechanism. This study provides useful information for the determination of appropriate parameters in OMBR operations as well as better understanding of membrane fouling mechanisms in OMBR.

2. Materials and methods

2.1. Description of OMBR system

A schematic of the laboratory-scale OMBR system is shown in Fig. 1. The bioreactor (200 mm length × 125 mm width × 250 mm height) has an effective volume of 4.85 L and housed a flat-sheet membrane module (cellulose triacetate FO membrane; from Hydration Technologies Inc., Albany, OR) with an effective membrane area of 2 × 0.018 m^2. The OMBR was continuously aerated at a flow rate of 150 L/h to supply oxygen to the activated sludge as well as to create enough hydrodynamic shear force to control membrane fouling.

The bioreactor was operated with a feed wastewater delivered from a feed tank placed on a digital scale (Kern, Balingen, Germany). The liquid level in the bioreactor was maintained by an overflow trough with its bottom connected to the bioreactor. Water flux was calculated from the weight change of the influent recorded by the digital scale. Salt accumulation in the bioreactor was determined by monitoring the conductivity of the mixed liquor with a conductivity meter (Thermo, Pittsburgh, PA).

A peristaltic pump (Cole-Parmer, Barrington, IL) was used to recirculate the DS at 0.2 L/min. Constant DS concentration was set and maintained by a conductivity controller (Thermo, Pittsburgh, PA) linked to a concentrated DS reservoir. The temperature of DS was maintained at 23.2 ± 0.5 °C with a water bath (Polyscience, Niles, Illinois).

2.2. Feed and DS

Activated sludge was collected from Ulu Pandan MBR plant in Singapore. Before use, the activated sludge was cultivated with synthetic wastewater (COD 400 mg/L, NH_4^+–N 40 mg/L, PO_4^{3-}–P 8 mg/L,

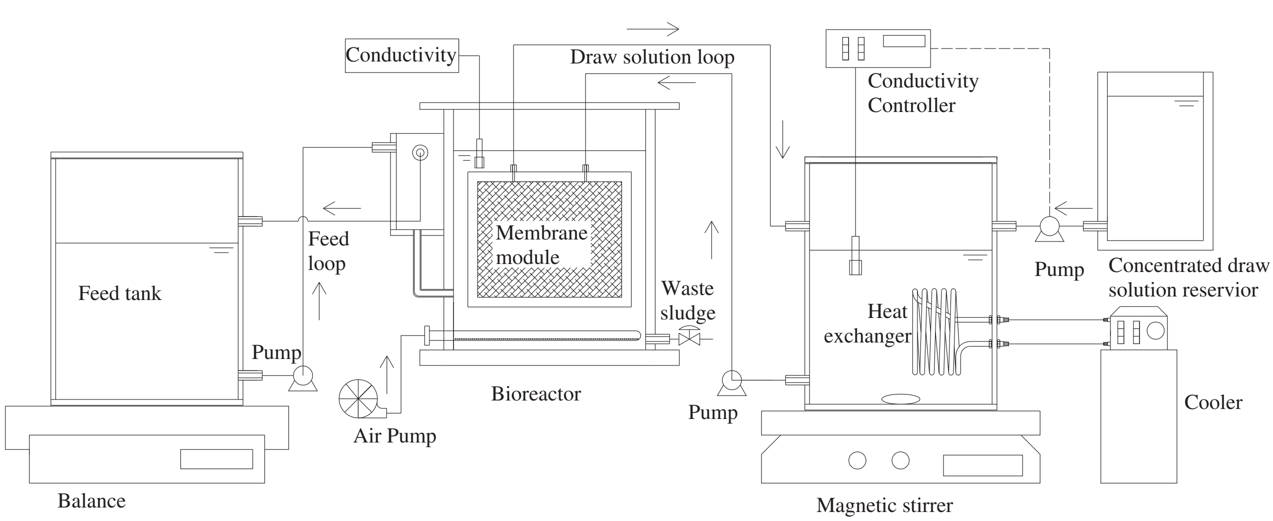

Fig. 1. Schematic of the OMBR system.