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Water extraction from mixed liquor of an aerobic bioreactor by forward osmosis: Membrane fouling and biomass characteristics assessment

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ABSTRACT

This study investigated membrane fouling and biomass characteristics during water extraction from mixed liquor of an aerobic bioreactor by a submerged forward osmosis (FO) system. As the sludge concentration in the reactor increased from 0 to 20 g/L, fouling of the FO membrane increased but was much less severe than that of a reference microfiltration membrane. The results also indicate that aeration can be used to effectively control membrane fouling. By increasing the draw solute concentration, as expected, the initial water flux was increased. However, there appears to be a critical water flux above which severe membrane fouling was encountered. A short-term osmotic membrane bioreactor experiment showed build-up of salinity in the bioreactor due to the reverse draw solute transport and inorganic salts rejection by the FO membrane. Salinity build-up in the bioreactor reduced the permeate flux and sludge production, and at the same time, altered the biomass characteristics, leading to more soluble microbial products and less extracellular polymeric substances in the microbial mass. Additionally, the inhibitory effects of the increased salinity on biomass and the high rejection capacity of FO led to the build-up of ammonia and ortho-phosphate in the bioreactor.

1. Introduction

Membrane bioreactor (MBR), which integrates the physical membrane filtration process with conventional activated sludge (CAS) treatment, is a promising technology for wastewater treatment and reuse. In comparison to CAS, MBRs can offer an improved effluent quality and a lower sludge production [1,2]. However, conventional MBRs do not sufficiently remove many trace organic chemicals (TrOCs), particularly those that are hydrophilic and resistant to biodegradation [3]. The molecular dimensions of these TrOCs are much smaller than the pores of either microfiltration (MF) or loose ultrafiltration (UF) membranes that are currently used in conventional MBRs [4]. Because TrOCs are readily permeable through these membranes, their residence time in the bioreactor is similar to the hydraulic retention time (HRT), which is usually very short (i.e. 3–24 h) for conventional MBRs [1]. As a result, a post treatment process, such as nanofiltration, reverse osmosis, and/or activated carbon, may be required to further remove TrOCs prior to water reuse applications [4,5].

Efforts to enhance the removal of TrOCs by MBRs have led to the development of a novel process known as osmotic membrane bioreactor (OMBR), which is an integration of forward osmosis (FO) with the CAS treatment [6]. In the OMBR system, water transfers from the mixed liquor, across the semi-permeable FO membrane, to the draw solution using osmotic pressure as the driving force. The high rejection capacity of the FO membrane can effectively retain small and/or biologically recalcitrant TrOCs and thus prolong their residence time in the bioreactor for further biodegradation [7].

The osmotically driven nature allows the FO membrane to have a lower fouling propensity compared to the hydraulic pressure driven MF and UF membranes. Thus, the OMBR system can potentially be used as a low fouling alternative to conventional MBRs [6]. However, the fouling behavior of the FO membrane during OMBR treatment is still poorly understood. Lay et al. [8] and Qiu and Ting [9] reported a low degree of membrane fouling during OMBR operation. On the other hand, severe fouling of the FO membrane was observed by Zhang et al. [10] and Holloway et al. [11]. Unlike MF/UF membranes that can be hydraulically backwashed, FO membranes can only be chemically cleaned or osmotically backwashed. As a result, it is necessary to better understand the fouling behavior of the FO membrane and develop efficient and cost-effective control strategies of fouling, such as air scouring, for OMBR application, especially under demanding conditions (e.g. high water flux and sludge concentration).

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Aeration is an important operating parameter for submerged MBRs, which provides oxygen for biomass, prevents sludge settlement, and scours the membrane surface. The hydrodynamic shear force induced by aeration can control the deposition of suspended solids on the membrane surface [12]. It is noteworthy that aeration can account for up to 70% of the overall energy consumption of a submerged MBR system [2]. In addition, excessive aeration is counterproductive as a high hydrodynamic shear force can result in floc breakage and exacerbate pore blocking [13]. Thus, a specific aeration demand (SAD_m) of approximately 15 to 30 m^3/m^2 h is typically used for conventional MBRs using submerged hollow fiber and plate-and-frame membranes, respectively [2]. Despite the potential of OMBR, it is surprising to note the dearth of information regarding the effects of aeration on membrane fouling and biological performance of OMBR in the literature. Recent studies by Zhang et al. [14] and Qiu and Ting [15] are probably the only two exceptions. Zhang et al. [14] observed a thick biofilm on the FO membrane surface and attributed it to the low aeration rate used in their study. It is noteworthy that both Zhang et al. [14] and Qiu and Ting [15] did not attempt to investigate influence of aeration and other operating conditions (e.g. draw solute concentration) on membrane fouling.

The high rejection capacity of the FO membrane and the reverse draw solute transport leads to the build-up of salinity in the bioreactor during OMBR operation [8]. Feeding with highly saline wastewater has been reported to adversely affect sludge characteristics and thus worsen membrane fouling in conventional MBRs [16]. Zhang et al. [17] have also showed impacts of sludge characteristics on the flux behavior of OMBR by comparing twenty kinds of activated sludge from different biological treatment processes. However, little is known about the effect of salinity build-up on sludge characteristics and subsequently membrane fouling as well as process performance during OMBR treatment.

This study aimed to investigate the fouling behavior and biomass characteristics during water extraction from activated sludge by an aerated submerged FO membrane. Fouling behaviors of aerated submerged MF and FO membranes as a function of sludge concentration were compared to provide a systematic understanding of the role of aeration in fouling control. We also examined the performance of the aerated submerged FO membrane under different operating conditions to optimize the OMBR system. Additionally, a short-term OMBR experiment was performed to evaluate the build-up of salinity in the bioreactor and its associated effects on biomass characteristics, membrane fouling, and process treatment performance.

2. Materials and methods

2.1. Activated sludge

Activated sludge was collected from the Wollongong Wastewater Treatment Plant (Wollongong, Australia). The activated sludge obtained was thickened by centrifugation at 2167 g for 2 min (Allegra X-12R, Beckman Coulter, USA). The thickened sludge was stored at 4 °C and used for all experiments in this study.

2.2. Membranes

A cellulose-based FO membrane supplied by Hydration Technology Innovations (Albany, USA) was used. The membrane consisted of a cellulose triacetate active layer reinforced by a polyester mesh for mechanical support [18]. The FO membrane was mounted on a submersible plate-and-frame module made of Acrylic glass with an effective membrane surface area of 300 cm^2. Once mounted, the membrane sealed the draw solution flow channel with length, width and height of 20, 15, and 0.4 cm, respectively. The other side of the membrane was directly exposed to the feed solution. This membrane was asymmetric and could be operated in both FO mode (i.e. the membrane active layer in contact with the feed solution) and pressure retarded osmosis (PRO) mode (i.e. the membrane support layer in contact with the feed solution).

A submersible hollow fiber MF membrane module (SADF0790M mini module, Mitsubishi Rayon Engineering, Japan) was also used for a comparison with FO for water extraction from the bioreactor mixed liquor. This MF membrane was made of polyvinylidene fluoride with a nominal pore size of 0.4 μm and an effective membrane surface area of 740 cm^2.

2.3. Experimental systems

The FO and MF modules were integrated interchangeably with a 10 L rectangular glass reactor to form the submerged FO and MF filtration systems (Fig. 1). The effective cross-sectional area of the reactor was 224 cm^2. An air pump (Heilea, model ACO 012, China) was used to aerate the reactor via a coarse bubble diffuser (Aqua One, Australia) located at the bottom of the tank to prevent sludge settlement and scour the membrane. The aeration rate could be controlled within the range of 0–6 L/min by a valve mounted on the rotameter (Cole-Parmer, Vernon Hills, USA).

In addition to the membrane module and the reactor, the FO filtration system was equipped with a draw solution delivery and control equipment. A gear pump (Micropump, Vancouver, USA) was used to circulate the draw solution (NaCl) from a draw solution reservoir to the membrane module. The draw solution reservoir was placed on a digital balance (Mettler-Toledo, Hightstown, USA) connected to a computer. The balance readings indicated the amount of water extracted per unit time through the membrane, and this was used to calculate the FO membrane flux. The draw solution flow rate was monitored by a rotameter (Cole-Parmer, Vernon Hills, USA). The draw solution concentration was controlled using a conductivity probe (Cole-Parmer, Vernon Hills, USA), a conductivity controller (Cole-Parmer, Vernon Hills, USA), and a Masterflex peristaltic pump (Cole-Parmer, Vernon Hills, USA). Further details of this concentration control unit are available elsewhere [19]. Briefly, as the draw solution conductivity (i.e. concentration) decreases below the lower set point, the

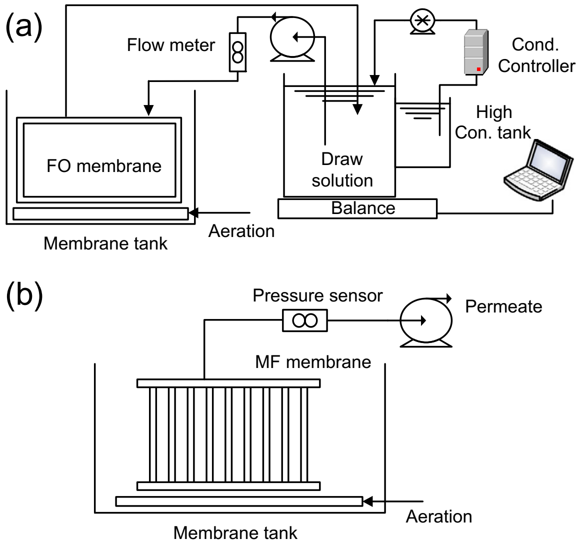

Fig. 1. Schematic diagram of a lab-scale submerged (a) FO and (b) MF filtration system.