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Study of flux decline and solute diffusion on an osmotically driven membrane process potentially applied to municipal wastewater reclamation

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ABSTRACT

One major challenge in this study was to investigate the performance of an osmotically driven membrane process, such as forward osmosis (FO) in a case of using raw wastewater that was obtained from a municipal wastewater treatment plant, with a focus on the flux decline and solute diffusion. First, to determine the effect of suspended solids (SS) in wastewater, wastewater was used containing 20 SS mg/L and filtered by a 0.45 μm filter to remove the SS. The results showed that a noticeable flux decline was observed in the case of the existing SS, but flux was slightly decreased without the SS. Furthermore, a larger decline in reverse salt flux (J_s) was also obtained with the SS, thus it can be implied that cake enhanced osmotic pressure (CEOP) phenomenon occurred. In other words, the SS could accelerate membrane fouling, resulting in a flux decline and hindered reverse salt diffusion. There was also a comparison of the FO performance using wastewater and a MBR permeate. As hypothesized, it has been found that wastewater resulted in a higher flux and reverse salt flux (J_s) decline through the consecutive fouling experiments (four times), but a MBR permeate also brought about substantial flux decline, which was contrary to what was conjecture. These findings indicate that an effective method to control fouling, such as pretreatment and cleaning, may be required even if the treated water resulting from wastewater treatment is used as feed water. As the fouling was getting severe, UV_{254} rejection was gradually decreased. That phenomenon might possibly be attributed to the increased humic substances on the membrane surface, changes in the membrane characteristics, and J_s decline.

Introduction

Water scarcity is one of the most serious global challenges of our time and needs to be urgently solved, as it is exacerbated by population growth, industrialization, and climate change [1]. Membrane-based seawater desalination and wastewater reclamation is widely regarded as promising solutions for the purpose of augmenting water supply and mitigating water shortage [2]. Currently, a reverse osmosis (RO) process is the leading technology in the field of desalination and wastewater reclamation. A RO process is cost-effective and has high energy efficiency, compared with conventional thermal desalination processes such as multi-stage flash (MSD) and multi-effect distillation (MED), its demand has been rapidly increasing in the desalination market. However, a high amount of energy is still required to produce fresh water in a RO process. Despite the advances in the technology, the energy costs can be as much as 75% of the operating costs of desalination plants, or between 30 and 50% of the total production cost of water [3]. Furthermore, the long-standing problem of fouling aggravates the water productivity [4], so the use of cleaning agents is required, thereby increasing the water production cost [2].

In recent years, a FO process has gained increasing attention in the field of water treatment[5], such as wastewater reclamation, desalination and even complex and difficult liquid streams [5–7]. Unlike the pressure-driven membrane process, a FO process is operated by the osmotic gradient between the feed and draw solutions [8,9], hence it requires low or no hydraulic pressure. Thus, it has several advantages, such as low fouling propensity, easy fouling removal, and high water recovery [10–12]. However, the lack of appropriate draw solutions, which can be easily regenerated with low energy costs, has been hampering its application [7,13–15]. Fortunately, there has been a proposal for an

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osmotic dilution membrane process (ODMP) that does not require a regeneration process of the draw solution [5,16–18]. The ODMP is for seawater desalination and wastewater reclamation, using the FO and RO processes. In these hybrid processes, the impaired water and seawater or brine from a RO desalination plant are used, and seawater or brine are diluted by the impaired water through a FO process, thereby resulting in reducing the energy demand during a RO desalination. Moreover the economic feasibility of this process has been evaluated and it is confirmed to outperform existing RO process in respect to energy consumption [5,7,16–18].

In addition to energy concerns, membrane fouling is still important for reducing O&M cost in operating desalination plant using RO membrane, so much of investigation for the deep understating of the membrane fouling is conducted in respect to concentration polarization, pretreatment and membrane surface properties [19–21]. Like a RO process, for the successful operation of a FO process, despite of low fouling propensity of a FO process, membrane fouling is still important and thus an understanding of fouling behavior is needed. It has been found that a FO process is not free from fouling, and the fouling factors and mechanism are different from those of a RO process [2,8]. Lee et al. reported that a large flux decline is brought about by an accelerated cake enhanced osmotic pressure (CEOP) resulting from reverse salt diffusion from the draw solution side to the feed solution side in a FO process [2]. It was observed that in a FO process, the thick and loose fouling layer is formed on the membrane surface in the absence of hydraulic pressure while the fouling layer formed in a RO process is thin and dense, such as in the case of alginate fouling [4].

The objectives of this study are to give a deeper understanding of fouling behavior in the case of using real wastewater from a wastewater treatment plant, by focusing on the flux decline and solute diffusion. To verify the effect of the SS in wastewater, wastewater was used under conditions, with and without the SS, as feed solutions. In addition, we also examined the effect of wastewater characteristics, before and after wastewater treatment, on the performance, using wastewater and a MBR permeate.

Materials and methods

FO membrane

The membrane used in the experiments was supplied by Hydration Technologies, Inc. (Albany, OR, USA). The membrane consists of a cellulose triacetate layer with an embedded polyester mesh for mechanical support and is approximately 50 μm of the total thickness [8]. The contact angle of the membrane is 65° for the dense active layer and 66.5° for the porous support layer. The mean roughness of the dense active and porous support layer is 66 nm and 105 nm, respectively [22].

Experimental setup

The schematic diagram of the FO experimental setup is shown in Fig. 1. A FO membrane cell was a flat-and-frame design with a rectangular channel on each side of membrane, which allows the feed and draw solutions to flow, respectively. Each channel has the same dimensions of 77 mm length, 26 mm width, and 3 mm depth, thereby providing an effective area of 20.02 cm^2. The variable speed gear pumps (Cole-Parmer, USA) were used to circulate the feed and draw solutions in each channel. The flow meters (Dwyer, USA) were installed for measuring the cross-flow. The feed solution was stirred by a magnetic stirrer in order to maintain a well-mixed homogeneous solution. The temperature of the feed and draw solutions was maintained using a chiller (CPT Inc., Korea). The changes in the weight of draw solution were monitored every 1 min with a digital scale (RADWAG, Poland) that was connected to a computer for the calculation of the permeate flux.

Calculation of reverse draw solute flux

The conductivity in the feed tank was measured and converted to NaCl concentration using predetermined calibration curve for conductivity versus NaCl concentration. This system composed of closed circuit and there was no draw regeneration system to let draw solution concentration be at certain level. As time goes by,

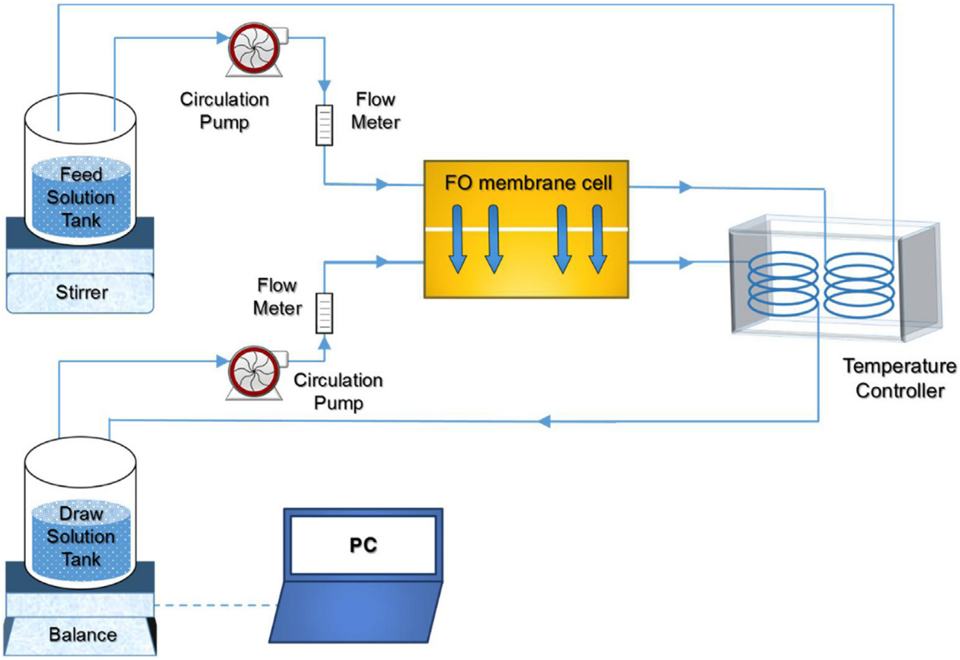

Fig. 1. Schematic diagram of the FO experimental setup.