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Direct concentration of municipal sewage by forward osmosis and membrane fouling behavior

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ABSTRACT

Forward osmosis (FO) draws attention due to its advantages compares to traditional pressure-driven membrane processes. In this study, a FO membrane concentrating system was built for sewage concentration to investigate membrane rejection, concentrating effect, membrane fouling behavior. Sewage could be concentrated to 1/10 original volume by FO membrane, while pollutants concentrating multiple could not reach 10. The FO membrane had excellent rejecting effect, with effluent COD, ammonia nitrogen, total nitrogen, total phosphorus concentration of 18, 2.5, 2.8, 0.4 mg/L, respectively. The FO membrane flux was mainly associated with the draw solution (DS) concentration, which increased with DS concentration but more severe membrane fouling engendered in the meantime. Scanning electronic microscope and fourier transform infrared spectroscopy analysis indicated the formation and constitution of the fouling layer, which included humic acid, protein, and polysaccharide. After concentration, fouled FO membrane was remitted by physical and chemical cleaning, with recovery of 90% and 96%.

1. Introduction

With the development of society and the boom of the population, issues caused by shortage and pollution of water resources are constructing a threat to the sustainable development (Honda et al., 2015; Iskander et al., 2017; Lee et al., 2014; Liu et al., 2017). Forward osmosis (FO) is a process that water passes through the membrane spontaneously, driven by osmotic pressure difference across semi-permeable membrane (Madhumala et al., 2017; McHugh et al., 2017; Ortega-Bravo et al., 2016). It is a natural phenomenon based on water transport towards a solution with higher osmotic potential (Cath et al., 2006), which provides advantages over traditional pressure-driven membrane technologies. As a new membrane technology, it draws attention worldwide in recent years due to its advantage of high rejecting rate, excellent effluent quality, low energy consumption and fouling potential (Akther et al., 2015; Ansari et al., 2017). In the past decades, FO membrane technology has been applied in a number of aspects, including the treatment of different waste streams like industrial wastewater, landfill leachate, etc., seawater desalination, and production of drug and food (Bell et al., 2017; Du et al., 2017; Efraty, 2016). Lutchmiah proposed the concept of sewage mining, by coupling FO with reverse osmosis (RO) to treat sewage directly, and introducing the concentrated water into the anaerobic reactor to recycle biogas (Lutchmiah et al., 2011). Other researches dealt with real wastewater by considering real seawater as draw solution (DS) in FO process (Choi et al., 2009; Valladares Linares et al., 2014). The above results indicated that dealing with real sewage by FO was feasible, and the concentrated sewage could also be further treated by other methods. FO membrane process was recognized as an emerging technology for wastewater reclamation.

Among the numbers of studies and applications, FO is regarded as a novel technology for separation and recovery of nutrients from different kinds of wastewater (Hey et al., 2017; Sun et al., 2016; Xue et al., 2016; Yu et al., 2017; Zhang et al., 2016), which is of great significance and potential for water resource and energy sustainability (Zhang et al., 2017; Zhao et al., 2015). Concentrated sewage, with significantly higher organics, can also be an alternative for the feed of traditional anaerobic digestion (Chen et al., 2014). Until now only a few reports dealing with direct real sewage concentration by FO were reported (Hey et al., 2017; Lutchmiah et al., 2011; Lutchmiah et al., 2014; Ortega-Bravo et al., 2016; Sun et al., 2016; Wang et al., 2016; Xue et al., 2016; Zhang et al., 2014). Positive results indicate sewage concentrated by FO membrane is theoretically feasible, and dealing with sewage by FO makes it possible to obtain high quality effluent as well as the concentrated sewage simultaneously (Zhao et al., 2015; Zhao et al., 2017; Zhu et al., 2017). However, still several problems remain to be solved, to make concentration by FO membrane more viable and sufficient. One is that the synthetic evaluation of real sewage concentrated

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by FO membrane is incomprehensive (e.g., endocrine disrupting chemicals (EDCs) in real sewage treated by FO membrane), as FO membrane had different concentrating multiples and effect for contaminants and different rejecting effect. It was in consideration of its complexity that all of them should be studied. The other one is to discuss membrane fouling influencing factors. For all membrane processes, fouling is a crucial shortcoming, as it aggravated membrane performance tempestuously. In FO system, DS plays a vital role. As for real sewage, there was amounts of suspended solids and solutes contained, which could cause foulants accumulation on the membrane active layer surface, quite different from simulated water (Yang et al., 2017a,b). How DS of variously ranged concentrations exactly affects membrane flux, and then membrane fouling, is in great request of investigation. Further study of cross-flow velocity is also demanded.

In this research, a FO membrane concentrating system was built for sewage concentration, in order to evaluate FO membrane performance comprehensively, including membrane rejection, concentrating effect, and membrane fouling characteristics. In addition, concentrating and rejecting effects of pollutants, ions, and EDCs in sewage by FO membrane were also studied. Changes of membrane flux, membrane fouling behavior and influencing factors by different DS concentrations and cross-flow velocity were also investigated, to deepen the understanding the cause of membrane fouling.

2. Material and methods

2.1. FO system

The FO concentrating system (Fig. 1) was consisted of membrane module, draw solution and feed solution. A sheet FO membrane module was applied in the system, with an effective area of 56 cm^2 and runner depth of 7 mm. The FO membrane (HTI, USA) was cellulose triacetate with embedded polyester screen (CTA-ES), consisted of two layers, the active layer (cellulose triacetate) and support layer (polyester), with a total thickness of 115 μm and a pore size ranged from 0.3 to 1.0 nm. The active layer of FO membrane was faced to feed solution chamber. Both chambers of feed and draw solutions were 2 L volume and mixed by magnetic stirrers. During the entire experiment, the temperature (25 ± 1 °C) of solutions was kept constant by a thermostatic water bath. The draw solution chamber was placed on an electronic balance. Changes of draw solution quantity could be recorded by a computer connected to the balance, and then the flux was calculated by the changes of draw solution quantity in unit time. A conductivity meter and pH meter were put in both feed and draw solution chambers. The conductivity data was recorded automatically by a computer connected to conductivity meters. To keep the osmotic pressure stable during the experiment, an automatic conductivity control system was used. DS concentration was remained stable, as saturated NaCl solution was added automatically in DS when it became attenuated. The error range was kept within ± 1%.

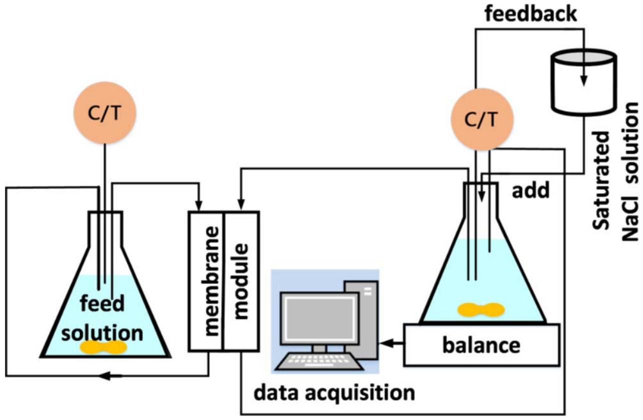

Fig. 1. Experimental setup of concentrating sewage by FO membrane.

Table 1
Water index of sewage used in the present study.

Water index	Concentration (mg/L)	Water index	Concentration (mg/L)
COD	522	Ca^{2+}	5.2
NH_4^+-N	42.3	K^+	5.7
TN	55.4	SO_4^{2-}	10.7
TP	8.5	PO_4^{3-}	6.5
		Mg^{2+}	7.1

The sewage was collected from the aeration grit chamber of a local municipal wastewater treatment plant, Beijing. It was used after primarily setting in the laboratory. Water index was shown in Table 1.

2.2. Membrane cleaning

Membranes were cleaned after sewage concentration, using both physical and chemical cleaning. In physical cleaning, online air-water washing, which lasted for 15 min, was applied. Both feed and draw solution were replaced with deionized water, and the air was pumped into the membrane module through feed inlet to be mixed with water to wash off some fouling layer. In in-situ chemical cleaning, both feed and draw solution were replaced with 1% NaClO solution, which was cycled slowly in the membrane module, getting sufficient contact with membrane surface for 30 min. After chemical cleaning, deionized water was cycled in the whole membrane module for 2–3 times to wash away NaClO residues.

2.3. Analysis methods

Chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), total phosphorus (TP) and suspended solids (SS) of the influent and effluent of the system were determined according to Standard Methods for the Examination of Water and Wastewater. Metallic cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and metallic anions (Cl^-, SO_4^{2-}, PO_4^{3-}) were tested by inductively coupled plasma (ICP Thermo IRIS) and anion chromatography (Dionex ICS2000), separately.

The permeate flux and transmembrane pressure of the FO membrane were recorded automatically. The actual flux (L/(m^2h), LMH) of the FO membrane, which indicated the permeability of the mixed liquor permeating through the membrane, was calculated by the change of volume per square meter in a certain time.

Membrane morphology was observed by scanning electronic microscope (SEM). Before observation, membrane samples used for sewage concentration were vacuum-dried and sputter-coated with a 4-nm-thick layer of Au/Pd (precision etching and coating system, 682, Gatan, USA).

Four target EDCs (BPA (Bisphenol A), E1 (Estrone), E2 (17β-estradiol) and E3 (Estriol)) contained in sewage were detected by liquid chromatography tandem mass spectrometry (LC–MSMS) (Gorga et al., 2013).

The elemental composition and functional groups of the membrane surface were measured by fourier transform infrared spectrometer (FTIR, Thermo Scientific, USA) (Wang et al., 2015). To prepare samples, membranes were vacuum-dried at room temperature (23 ± 1 °C).

3. Results and discussion

3.1. Rejecting effect of pollutants by FO membrane

3.1.1. Rejecting effect of normal pollutants

FO membrane had an excellent rejecting effect for normal pollutants, in terms of COD, NH_4^+-N, TN and TP (Fig. 2). The removal rate of