Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/jes

JES JOURNAL OF ENVIRONMENTAL SCIENCES www.jesc.ac.cn

Fabrication and performance of PET mesh enhanced cellulose acetate membranes for forward osmosis

Guoliang Li[1,2,3], *Jun Wang*[1,2,*], *Deyin Hou*[1,2], *Yu Bai*[1,2], *Huijuan Liu*[1,2]

1. *Key Laboratory of Drinking Water Science and Technology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: glli_st@rcees.ac.cn*

2. *Beijing Key Laboratory of Industrial Wastewater Treatment and Resource Recovery, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China*

3. *University of Chinese Academy of Sciences, Beijing 100049, China*

ARTICLE INFO

Article history:
Received 7 August 2015
Revised 22 November 2015
Accepted 25 November 2015
Available online 6 February 2016

Keywords:
Forward osmosis
Cellulose acetate
Membrane
Water flux
Reverse salt flux
Internal concentration polarization

ABSTRACT

Polyethylene terephthalate mesh (PET) enhanced cellulose acetate membranes were fabricated via a phase inversion process. The membrane fabrication parameters that may affect the membrane performance were systematically evaluated including the concentration and temperature of the casting polymer solution and the temperature and time of the evaporation, coagulation and annealing processes. The water permeability and reverse salt flux were measured in forward osmosis (FO) mode for determination of the optimal membrane fabrication conditions. The optimal FO membrane shows a typical asymmetric sandwich structure with a mean thickness of about 148.2 μm. The performance of the optimal FO membrane was tested using 0.2 mol/L NaCl as the feed solution and 1.5 mol/L glucose as the draw solution. The membrane displayed a water flux of 3.47 L/(m^2·hr) and salt rejection of 95.48% in FO mode. While in pressure retarded osmosis (PRO) mode, the water flux was 4.74 L/(m^2·hr) and salt rejection 96.03%. The high ratio of water flux in FO mode to that in PRO mode indicates that the fabricated membrane has a lower degree of internal concentration polarization than comparable membranes.

Introduction

Unlike applied pressure driven membrane processes such as nanofiltration (NF) and reverse osmosis (RO), which require intensive energy consumption, the forward osmosis (FO) process utilizes the osmotic pressure gradient as the driving force, and therefore is an energy-saving membrane separation technology. In a FO process, water transports across a selectively permeable membrane spontaneously from a region of higher water chemical potential (feed solution) to a region of lower water chemical potential (draw solution) (Qin et al., 2012). This results in the concentration of the feed solution and dilution of the draw solution (Cath et al., 2006). It is traditionally believed that the FO process has the advantages of no or low pressure operation, higher water flux and recovery rate, less fouling propensity and easy cleaning (Chung et al., 2012; Duong and Chung, 2014). FO has received increased attention in the past decade in both academic research and industrial development (Shaffer et al., 2015). Although there are still considerable numbers of studies focusing on membrane preparation (Setiawan et al., 2011), characterization (Gao et al., 2013), and antifouling modifications (Wang et al., 2014),

* *Corresponding author*. E-mail: junwang@rcees.ac.cn (Jun Wang).

http://dx.doi.org/10.1016/j.jes.2015.11.025
1001-0742/

nowadays increasing numbers of studies are beginning to be carried out on pilot scale and/or industrial level application (Altaee and Hilal, 2015; Hancock et al., 2013). As an environmentally friendly separation process, it has been widely studied in potential applications including wastewater treatment (Achilli et al., 2009; Zhao et al., 2015) and water purification (Cath et al., 2005; Duong and Chung, 2014), seawater desalination (Altaee et al., 2014; McCutcheon et al., 2006), food processing (Jiao et al., 2004; Petrotos and Lazarides, 2001), pharmaceutical applications (LaVan et al., 2003; Su and Lin, 2004), and power generation (Jia et al., 2014; Yip et al., 2011). The Modern Water Inc. (UK) has constructed seawater desalination plants based on the FO process, and Hydration Technology Innovation (HTI) has successfully developed a commercial product (SeaPack) for emergency water supply.

Despite the recent advancements in FO, there remain several challenges to overcome for successful widespread use of FO processes. Almost all the FO membranes suffer from severe internal concentration polarization (ICP). This is an important factor that hinders the application of FO, and is believed to be the main reason why the FO process has a much lower water flux than expected (McCutcheon et al., 2006). Early FO studies showed that ICP may be capable of reducing water flux by more than 80% (Mehta and Loeb, 1979). ICP is closely related with the thickness and porosity of the supporting layer (Gao et al., 2014). A thin membrane with a high porosity support layer has less potential for severe ICP. However, a thinner support layer results in weaker membrane mechanical strength. What's more, the traditionally believed advantages of FO may confront some more real-life problems. For example, Shaffer et al. (2015) draw the conclusion that FO cannot reduce the minimum energy required for desalination, regardless of the type of draw solution used. This is almost the reverse of the conclusions of most studies on the FO process, which reported that FO consumes less energy than the pressure-driven membrane processes (Venketeswari et al., 2014; Xie et al., 2012). Fabrication of an ideal membrane with high performance is still the main direction for FO development.

In recent years, numerous efforts have been made toward developing high-performance FO membranes with considerably higher water permeability than that of commercial FO membranes, by tuning the support layer structure and active layer characteristics (Liu et al., 2013; Wang et al., 2015; Zhao et al., 2014). Several materials have been used to fabricate FO membranes including cellulose triacetate (CTA), polyamide and biomimetic materials (Shibuya et al., 2015). Sairam et al. (2011) prepared a membrane containing a thin layer of cellulose acetate (CA) cast on a nylon fabric via a phase inversion process, using $MgSO_4$ as the draw solution for desalination. Kim et al. (2013) fabricated a polyamide FO membrane with a newly synthesized acetylated methylcellulose (AMC) membrane as the support layer, and the membrane performed better than a polyamide RO membrane. Wang et al. (2010) prepared a CA FO membrane and showed that the second skin layer can significantly mitigate the adverse effects of ICP.

CA is a reasonably low cost and readily available material that has been successfully used in NF and RO membranes (Haddada et al., 2004; Idris et al., 2002). It also appears to be a good candidate for the fabrication of FO membranes with respect to the high water permeability. However, high reverse solute flux and a weak mechanical strength limit its application potential (Li et al., 2013). Polyethylene terephthalate mesh (PET) mesh can be a good candidate for strengthening the membrane mechanical properties. In this work, various CA membranes were fabricated via a phase inversion process and the optimized fabrication parameters were obtained. The effects of some fabrication parameters on the FO membrane performance were investigated. The performance of the membrane was tested using NaCl as the feed solution and glucose as the draw solution.

1. Experimental

1.1. Materials and chemicals

CA with an acylation degree of 39.2% was purchased from Sinopharm Chemical Reagent Co., Ltd. A mixture of N-methyl-2-pyrrolidone (NMP) and acetone was used as the solvent. Analytical grade sodium chloride, glucose, acetone and NMP were obtained from Sinopharm. Deionized (DI) water was used both in the coagulation process and for the membrane performance test.

1.2. Polymer solution preparation and CA membrane fabrication

The CA powder was dried overnight at 90°C in a vacuum oven to remove moisture. After cooling to room temperature, a certain amount of the dried polymer was added to a flask containing a premixed solvent of acetone (to obtain a constant concentration of 10 wt.% in the solution) and NMP. The flask sealed with cling film was subjected to continuous stirring on a rotator (IKA RV10 digital) at the speed of 20 rpm until a homogenous solution was obtained. The solution was then stored at room temperature for 1 day to deaerate.

The fabrication involved in this work was conducted via a phase inversion process that has been reported in earlier works (Hou et al., 2009). Specifically, the polymer solution was spread evenly on the surface of a clean horizontal glass plate using a casting knife at a gate height of 200 μm. Then a tailored PET mesh (150-mesh) was placed on the surface of casting solution from the top carefully to avoid trapping any bubbles. The PET mesh was then embedded in the solution automatically due to capillarity. After evaporation for a few seconds, the whole composite was immediately immersed into a coagulation bath containing DI water at various temperatures to initiate phase separation. The resultant membrane was peeled off gently from the glass plate and was rinsed with flowing tap water overnight to remove the residual solvent. A hot water annealing process was then carried out at different temperatures for the purpose of structure adjustment of the membrane. The fabricated membranes were stored in DI water prior to use.

1.3. Study of membrane morphology and strength

The fabricated CA membrane was prone to deform and become brittle upon drying at room temperature. To mitigate the morphological transformation, the membranes were first