Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Membrane scaling and flux decline during fertiliser-drawn forward osmosis desalination of brackish groundwater

Sherub Phuntsho [a], *Fezeh Lotfi* [a], *Seungkwan Hong* [b], *Devin L. Shaffer* [c], *Menachem Elimelech* [c], *Ho Kyong Shon* [b,*]

[a] *Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology, Sydney (UTS), Broadway, NSW 2007, Australia*

[b] *School of Civil, Environmental & Architectural Engineering, Korea University, 1, 5-ka, Anam-Dong, Sungbuk-Gu, Seoul 136-713, Republic of Korea*

[c] *Department of Chemical and Environmental Engineering, Yale University, P.O. Box 208286, New Haven, CT 06520-8286, USA*

ARTICLE INFO

Article history:
Received 11 January 2014
Received in revised form
27 February 2014
Accepted 16 March 2014
Available online 27 March 2014

Keywords:
Forward osmosis
Membrane scaling
Inorganic fouling
Desalination
Brackish groundwater

ABSTRACT

Fertiliser-drawn forward osmosis (FDFO) desalination has been recently studied as one feasible application of forward osmosis (FO) for irrigation. In this study, the potential of membrane scaling in the FDFO process has been investigated during the desalination of brackish groundwater (BGW). While most fertilisers containing monovalent ions did not result in any scaling when used as an FO draw solution (DS), diammonium phosphate (DAP or $(NH_4)_2HPO_4$) resulted in significant scaling, which contributed to severe flux decline. Membrane autopsy using scanning electron microscopy (SEM), energy-dispersive x-ray spectroscopy (EDS), and x-ray diffraction (XRD) analysis indicated that the reverse diffusion of DAP from the DS to the feed solution was primarily responsible for scale formation during the FDFO process. Physical cleaning of the membrane with deionised water at varying crossflow velocities was employed to evaluate the reversibility of membrane scaling and the extent of flux recovery. For the membrane scaled using DAP as DS, 80–90% of the original flux was recovered when the crossflow velocity for physical cleaning was the same as the crossflow velocity during FDFO desalination. However, when a higher crossflow velocity or Reynolds number was used, the flux was recovered almost completely, irrespective of the DS concentration used. This study underscores the importance of selecting a suitable fertiliser for FDFO desalination of brackish groundwater to avoid membrane scaling and severe flux decline.

* *Corresponding author.*
E-mail addresses: shonhokyong@yahoo.co.kr, Hokyong.Shon-1@uts.edu.au (H.K. Shon).

http://dx.doi.org/10.1016/j.watres.2014.03.034

1. Introduction

Growing water scarcity issues have been driving interest in the use of membrane processes, such as reverse osmosis (RO) and nanofiltration (NF), for seawater and brackish groundwater desalination and for wastewater reclamation to produce alternative water sources (Baker, 2010; Geise et al., 2010; Mi and Elimelech, 2010a; Elimelech and Phillip, 2011). However, inorganic scaling and organic fouling pose a significant challenge for the efficient operation of these pressure-based membrane processes. Scaling not only increases energy consumption, but it also increases the operation and maintenance costs and significantly shortens membrane life. Scaling occurs when the concentrations of some of the sparingly soluble salts in the feed solution reach supersaturation due to high product water recovery, and the salts crystallise directly on the membrane surface or crystallise in the bulk solution and deposit on the membrane (Mi and Elimelech, 2010a; Antony et al., 2011). Scaling in membrane processes occurs by surface crystallisation, bulk crystallisation, or both mechanisms, depending on the operating conditions (Gilron and Hasson, 1987; Hasson et al., 2001; Liu and Mi, 2012).

The most common scaling salts during desalination of seawater or brackish water by RO/NF are calcium sulphate, barium sulphate, and calcium carbonate. However, phosphate scaling is a major issue when RO is applied for wastewater treatment (Zach-Maor et al., 2008; Chesters, 2009; Antony et al., 2011). The presence of phosphate ions can cause serious scaling problems for RO membranes, and effective anti-scaling agents have not been identified to prevent all types of phosphate scaling (Chesters, 2009; Antony et al., 2011).

Forward osmosis (FO) is an emerging osmotic membrane process that has been studied for a wide variety of applications, including desalination and wastewater treatment, food processing, and power generation from salinity gradients (Cath et al., 2006; McGinnis and Elimelech, 2007; Charcosset, 2009). FO utilises the osmotic pressure gradient between a concentrated draw solution (DS) and a feed solution (FS) as a driving force to pull water molecules from the FS through a semi-permeable membrane (Cath et al., 2006). For desalination applications, the diluted DS is then further processed to separate potable water and reconcentrate the draw solution. Many of the promising applications of FO focus on the low fouling propensity of the process and the associated benefits for treating feed waters with high fouling potential (Zhao et al., 2012). Although the FO process can experience membrane scaling and fouling, the absence of hydraulic pressure in FO operation is advantageous in terms of fouling rate and cleaning efficiency. In fact, several studies have demonstrated that inorganic scaling and organic fouling are almost fully reversible by adopting simple physical cleaning/rinsing without the need for chemical cleaning reagents (Lee et al., 2010; Mi and Elimelech, 2010b,a). In some cases, the FO process has been observed to have less fouling potential or a reduced fouling rate compared to the RO process (Holloway et al., 2007; Cornelissen et al., 2008; Achilli et al., 2009; Zhang et al., 2012).

One of the practical applications of FO technology is for irrigation, in which the diluted fertiliser DS that contains desalinated water can be used directly for fertigation instead of requiring a separation process to reconcentrate the draw solution. Termed fertiliser-drawn forward osmosis (FDFO) desalination (Phuntsho et al., 2011b, 2012a; Phuntsho, 2012), this process can use commercially-available soluble fertilisers as draw solutions to generate very high osmotic pressures. The FDFO process has been recently investigated for desalination of both seawater (Phuntsho et al., 2011b; Phuntsho et al. 2012a) and brackish groundwater (Phuntsho et al., 2013a). Fertilisers are composed of compounds that contain major essential elements for plants, such N, P, K, Ca, Mg, and S. However, when such compounds are used as DS in FO, especially for desalination of BGW containing scaling precursor ions, ionic species of these essential fertiliser elements could adversely affect the process through membrane scaling. Ca^{2+}, Mg^{2+} and PO_4^{3-}/HPO_4^{2-} ions are all scaling precursors that accelerate membrane scaling and fouling, thereby undermining the efficiency of RO desalination plants (Hatziantoniou and Howell, 2002; Li and Elimelech, 2004; Lee and Elimelech, 2006). In RO, these scaling precursors have been shown to interact with ions in the feed solution to promote membrane scaling, resulting in flux decline and ultimately undermining the process efficiency.

Fouling in FO is influenced by the feed water quality, similar to pressure-based membrane processes such as RO and NF. However, unlike RO/NF processes, scaling and fouling in the FO process could be influenced by reverse draw solute flux from the DS to the FS. Reverse diffusion of draw solutes has been cited as one of the major challenges of the FO process because it not only results in economic losses from the cost to replenish the DS, but it also could complicate FS concentrate management and enhance membrane fouling potential. Reverse draw solute flux into the feed solution has been observed to influence colloidal and organic fouling (Lee et al., 2010; Boo et al., 2012). It also exacerbates cake-enhanced osmotic pressure on the membrane surface in contact with the feed solution, thereby reducing the effective driving force for permeation and causing flux decline (Lee et al., 2010). When the DS contains divalent ions, such as Mg^{2+} or Ca^{2+}, the reverse diffusion of these ions could result in interaction with dissolved organic matter present in the FS through a bridging effect, significantly affecting foulant cake formation and flux decline (Hatziantoniou and Howell, 2002; Lee and Elimelech, 2006).

The effects of fertiliser draw solutions on membrane inorganic scaling during the FDFO process has not been studied. Higher feed recovery rates can be achieved in FDFO when high fertiliser DS concentrations are used, and hence, scaling may become a significant issue due to both feed solution super-saturation and reverse diffusion of fertiliser salts. The objective of this study was to investigate flux decline due to inorganic scaling of FO membranes during the desalination of brackish groundwater by the FDFO process. The major factors affecting membrane fouling during the FDFO process were evaluated, including FS and DS properties. The study also investigated the effects of physical cleaning on membrane flux recovery.