Available online at www.sciencedirect.com

ScienceDirect

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

Gravity-driven membrane filtration as pretreatment for seawater reverse osmosis: Linking biofouling layer morphology with flux stabilization

Ebrahim Akhondi [a], *Bing Wu* [a,*], *Shuyang Sun* [b,c], *Brigit Marxer* [d], *Weikang Lim* [a], *Jun Gu* [e], *Linbo Liu* [e], *Michael Burkhardt* [d], *Diane McDougald* [b,c], *Wouter Pronk* [f], *Anthony G. Fane* [a,g]

[a] Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, CleanTech One #06-08, Singapore 637141, Singapore

[b] Singapore Centre on Environmental Life Sciences Engineering, Nanyang Technological University, 60 Nanyang Drive, Singapore 637551, Singapore

[c] Centre for Marine Bio-Innovation, The University of New South Wales, Sydney, NSW 2052, Australia

[d] Institute of Environmental and Process Engineering, HSR University of Applied Sciences Rapperswil, Oberseestrasse 10, 8640 Rapperswil, Switzerland

[e] School of Electrical & Electronic Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

[f] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Ueberlandstrasse 133, 8600 Duebendorf, Switzerland

[g] School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

ARTICLE INFO

Article history:
Received 17 September 2014
Received in revised form
27 November 2014
Accepted 1 December 2014
Available online 9 December 2014

Keywords:
Biofouling layer porosity
Confocal laser scanning microscopy
Fouling resistance
Microbial community structure
Optical coherence tomography
Predation

ABSTRACT

In this study gravity-driven membrane (GDM) ultrafiltration is investigated for the pretreatment of seawater before reverse osmosis (RO). The impacts of temperature (21 ± 1 and 29 ± 1 °C) and hydrostatic pressure (40 and 100 mbar) on dynamic flux development and biofouling layer structure were studied. The data suggested pore constriction fouling was predominant at the early stage of filtration, during which the hydrostatic pressure and temperature had negligible effects on permeate flux. With extended filtration time, cake layer fouling played a major role, during which higher hydrostatic pressure and temperature improved permeate flux. The permeate flux stabilized in a range of 3.6 L/m^2 h (21 ± 1 °C, 40 mbar) to 7.3 L/m^2 h (29 ± 1 °C, 100 mbar) after slight fluctuations and remained constant for the duration of the experiments (almost 3 months). An increase in biofouling layer thickness and a variable biofouling layer structure were observed over time by optical coherence tomography and confocal laser scanning microscopy. The presence of eukaryotic organisms in the biofouling layer was observed by light microscopy and the microbial community structure of the biofouling layer was analyzed by sequences of 16S rRNA genes. The magnitude of permeate flux was associated with the combined effect of the biofouling layer thickness and structure. Changes in the biofouling layer structure were attributed to

* *Corresponding author*. Tel.: +65 9195 0394; fax: +65 6791 0756.
E-mail address: wubing@ntu.edu.sg (B. Wu).
http://dx.doi.org/10.1016/j.watres.2014.12.001

(1) the movement and predation behaviour of the eukaryotic organisms which increased the heterogeneous nature of the biofouling layer; (2) the bacterial debris generated by eukaryotic predation activity which reduced porosity; (3) significant shifts of the dominant bacterial species over time that may have influenced the biofouling layer structure. As expected, most of the particles and colloids in the feed seawater were removed by the GDM process, which led to a lower RO fouling potential. However, the dissolved organic carbon in the permeate was not be reduced, possibly because some microbial species (e.g. algae) could convert CO_2 into organic substances. To further improve the removal efficiency of the organic carbon, combining carrier biofilm processes with a submerged GDM filtration system is proposed.

1. Introduction

Reverse osmosis (RO) has been widely implemented for seawater desalination. Due to the presence of particulate, colloidal, dissolved organic and inorganic matters, and biofilm-forming microorganisms in the feed seawater, the RO membranes potentially suffer particulate fouling, scaling, organic fouling, and biofouling (Bae et al., 2011; Sutzkover-Gutman and Hasson, 2010). To improve process efficiency and lessen RO membrane fouling, the seawater feed needs to be pretreated before the RO process. Conventional pretreatment processes such as coagulation, dissolved air flotation, and media filtration have been shown to mitigate RO membrane fouling (Bonnelye et al., 2004; Voutchkov, 2010). Recently, membrane-based pretreatment processes, e.g., microfiltration (MF) (Bae et al., 2011), ultrafiltration (UF) (Huang et al., 2011), and nanofiltration (NF) have been increasingly considered to replace the conventional pretreatment processes as they are chemical-free (except membrane cleaning chemicals), space saving and result in superior permeate quality (Pearce, 2008).

The benefits of UF/MF membrane pretreatment processes are, however, lessened by their high energy demand (Knops et al., 2007), which is mainly due to membrane fouling control strategies (such as cross-flow, backwashing, and air scouring etc.) (Akhondi et al., 2014). Elimelech and Phillip (2011) emphasized that the energy demand for the pretreatment of raw seawater accounts for the majority of the total energy used for intake, pretreatment, posttreatment, and brine discharge stages. Moreover, Voutchkov (2010) stated that when pretreating seawater by UF membranes during an algal bloom, the seawater filtrate could increase biofouling on RO membranes if the driving pressure was great enough to rupture the algal cells (a limiting pressure of >0.4 bar was suggested). Thus, there is an incentive to develop low-energy membrane-based RO pretreatment processes delivering beach-well quality permeate. Such pretreatment could potentially contribute more to the overall process energy efficiency than the remaining incremental opportunities for the RO process.

Gravity-driven membrane (GDM) filtration, initially developed by researchers from the Swiss Federal Institute of Aquatic Science and Technology (Eawag), has been used to treat a broad range of surface waters with differing levels of natural organic matter (NOM) and inorganic components, as well as diluted wastewaters (Derlon et al., 2013, 2012; Peter-Varbanets et al., 2012, 2010, 2011). In a dead-end filtration mode, GDM filtration uses gravity to move the water across the membrane. Results have shown that a stable flux (2–20 L/m^2 h, depending on NOM concentration, temperature, oxygen content, and the microbial community in the fouling layer) can be achieved without the need for backwashing or flushing when the hydrostatic pressure is approximately 40–60 mbar. Flux stabilization is attributed to the formation of a porous, heterogeneous cake (i.e., biofouling layer) on the UF membrane, which is the result of deposition of non-biodegradable substances and microorganisms, combined with bacterial activity and predation by eukaryotic organisms (e.g., heterotrophic protists) (Derlon et al., 2013, 2012; Peter-Varbanets et al., 2011).

Due to increased interest in low energy and chemical-free processes for pretreatment of seawater for RO, GDM filtration is potentially attractive. Compared to the energy consumption for the conventional UF/MF processes for RO pretreatment (0.1–0.3 kWh/m^3 treated water) (Pearce, 2008), GDM filtration requires negligible energy input for the generation of the head, i.e. approximately 0.01 kWh/m^3 treated water. Chemical use for membrane cleaning is also negligibly small.

The aim of this study is to evaluate GDM filtration as an RO pretreatment process. Flux and membrane fouling was investigated during dead-end, low-pressure ultrafiltration of seawater. The influences of temperature and the hydrostatic driving force on system performance were investigated. In addition, the dynamic biofouling layer morphology, structural changes, and microbial community composition of the biofouling layer were monitored and the permeate quality was examined.

2. Materials and methods

2.1. Seawater

Raw seawater was collected from West Coast Park beach, Singapore, from September to December 2013 and screened