Available online at www.sciencedirect.com

ScienceDirect

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

Spatial and temporal evolution of organic foulant layers on reverse osmosis membranes in wastewater reuse applications

Elizabeth L. Farias, Kerry J. Howe, Bruce M. Thomson*

Department of Civil Engineering, MSC01 1070, 1, University of New Mexico, Albuquerque, NM 87131, USA

ARTICLE INFO

Article history:
Received 21 January 2014
Received in revised form
21 March 2014
Accepted 23 March 2014
Available online 2 April 2014

Keywords:
Water reuse
Reverse osmosis
Membrane fouling
Confocal laser scanning microscopy

ABSTRACT

Advanced treatment to remove trace constituents and emerging contaminants is an important consideration for wastewater treatment for potable reuse, and reverse osmosis (RO) can be a suitable technology to provide the necessary level of treatment. However, membrane fouling by biological and organic matter is a concern. This research examined the development of the RO membrane fouling layer using a bench-scale membrane bioreactor operating at different solids retention times (SRTs), followed by a custom-designed RO test cell. The RO test cell contained stacked plates that sandwich five sheets of RO membrane material, which can be extracted for autopsy at separate times over the course of an experiment without disturbing the remaining membranes. The MBR-RO system was run continuously for 2 weeks at each SRT. The RO membranes were stained for live and dead cells, protein, and carbohydrate-like materials, and visualized using confocal laser scanning microscopy. Images of the stained foulant layers were obtained at different depths within the foulant layer at each time point for all SRT conditions. As the RO foulant layer developed, changes occurred in the distribution and morphology of the live cells and carbohydrates, but not the proteins. These trends were similar for all three SRT conditions tested. RO membrane fouling increased with increased MBR SRT, and the highest SRT had the highest ratios of live to dead cells and carbohydrate-like material to dead cells. The autopsied membranes were also analyzed for protein and carbohydrate content, and it was found that the carbohydrate concentration on the membranes after 14 days increased as the SRT increased.

1. Introduction

Increasing stress on water resources has led many communities to consider reuse of treated wastewater to augment potable water supplies. Membrane bioreactors (MBRs) have been used in wastewater treatment to reduce concentrations of organic matter and nutrients to low levels (Mohammadi et al., 2012; Abdel-Shafy and El-Khateeb, 2011; Meng et al., 2009; Tao et al., 2005, Cho et al., 2005; Cicek et al., 2001). However, MBRs do not remove all trace constituents such as pharmaceuticals and personal care products (PPCPs), endocrine disrupting compounds, and viruses, which could be a

* *Corresponding author*. Tel.: +1 505 277 2702; fax: +1 505 277 1988.
E-mail addresses: fieldelizabeth@hotmail.com (E.L. Farias), howe@unm.edu (K.J. Howe), bthomson@unm.edu (B.M. Thomson).

http://dx.doi.org/10.1016/j.watres.2014.03.061
0043-1354/

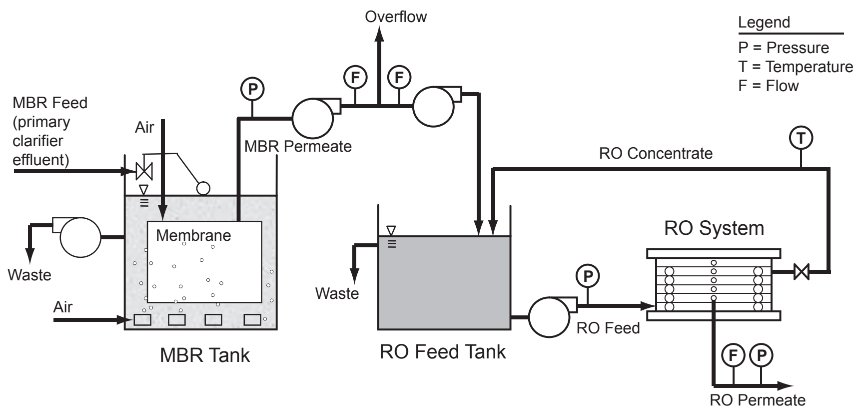

Fig. 1 – Schematic of the MBR-RO pilot plant.

concern in potable reuse applications (Lee et al., 2012; Nikolaou et al., 2007; Halling-Sorensen et al., 1998). Therefore, technologies that can remove these constituents after biological wastewater treatment are necessary if direct or indirect potable reuse is being considered. Reverse osmosis (RO) has been demonstrated to be effective at removing pharmaceutical and personal care products (PPCPs) (Lee et al., 2012; Gur-Reznik et al., 2011; Snyder et al., 2006; Drewes et al., 2002). While the performances of MBRs in wastewater applications and RO in desalination applications are both well understood, additional research on their use in sequence for advanced wastewater treatment is needed.

A challenge for the use of RO in advanced wastewater treatment is membrane fouling (Howe et al., 2012; AWWA Membrane Technology Research Committee, 2005). The quality of wastewater treatment plant effluent is very different from the typical feed water for desalination applications; while the feed water for desalination applications is high in inorganic salt concentrations, the feed water for a wastewater reuse application is typically lower in inorganic salts but higher in organic materials. Thus, issues of membrane fouling for RO in reuse applications can also be expected to be different from desalination applications. Scaling from precipitation of inorganic minerals and fouling from particulate matter are common concerns in desalination applications but less of an issue in treating MBR effluent, since the MBR membranes are effective at removing particles and the potential for supersaturation of sparingly soluble salts is lower. Instead, organic and biological fouling can be the primary concerns. Membrane cleaning can reverse fouling and prolong the usable lifespan of membranes, but requires chemicals that may degrade the membranes (Chesters, 2009; Li and Elimelech, 2004). To optimize membrane performance, knowledge of the characteristics of the foulant layer and how it develops on membrane surfaces under different MBR operating conditions is necessary.

Confocal laser scanning microscopy (CLSM) is a powerful tool that can be used to study biofilms and foulant layers on membranes. Studies have been conducted using fluorescently labeled stains and CLSM to characterize the structure and composition of membrane foulant layers (Herzberg et al., 2009; Chen et al., 2006). Baek et al. (2011) used CLSM to investigate the effect of the surface properties of RO membranes, including hydrophobicity, surface charge, and roughness on membrane biofouling, and concluded that these properties had no effect. Kuehn et al. (2001) used CLSM to demonstrate that biofilm development was strongly dependent on the presence of extracellular polymeric substances (EPS). EPS has been implicated in RO membrane fouling in other studies (Wang et al., 2009; Dvořák et al., 2011).

The biofouling of RO membranes used in wastewater treatment should be dependent on the quality of the feed water, particularly with respect to nutrients and carbon sources. When the feed water to an RO system is the effluent from an MBR, the operation of the MBR would affect the MBR effluent quality and hence the RO membrane fouling. A key operating parameter that directly affects concentration and characteristics of dissolved organic matter in MBR effluent is the solids retention time (SRT) (Tchobanoglous et al., 2002). Increasing the SRT increases the degradation of influent organics, leaving only degradation products and recalcitrant organics in the effluent. Thus, the SRT of the MBR is expected to affect the fouling of membranes in a subsequent RO process. A study by the authors found that an increase in the SRT of an MBR process to 20 days increased the fouling of a subsequent RO process (Farias et al., 2014).

Biofilms are complex, heterogeneous coatings that develop over time due to both deposition and internal growth of microorganisms (Dvořák et al., 2011). It typically has been difficult to study this temporal and spatial development because the autopsy procedure for examining RO membranes requires the modules to be destroyed to extract the membranes. Flat-sheet RO membrane cells such as the Osmonics Sepa CF-II can be used to simplify membrane extraction, but it is still difficult to study temporal evolution of foulant layers because a new experiment must be performed and operated for the desired time which introduces uncertainty because the conditions (i.e. feed water chemistry) may vary between experiments. To allow temporal development of membrane fouling to be studied, the authors developed an innovative, multi-chamber flat-sheet RO cell. The system allowed an RO membrane sheet to be removed and autopsied without disturbing the remaining membrane sheets in the system.

The first objective of this study was to determine the temporal and spatial evolution of foulant layers on RO membranes used to treat MBR effluent. RO membranes were