Chemical Engineering Journal 294 (2016) 30–39

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Effect of microbial community structure on organic removal and biofouling in membrane adsorption bioreactor used in seawater pretreatment

Sanghyun Jeong [a,b,c], Kyungjin Cho [f], Hyokwan Bae [f], Pejhman Keshvardoust [c,d], Scott A. Rice [c,e,g], Saravanamuthu Vigneswaran [a,*], Seockheon Lee [f], TorOve Leiknes [b]

[a] Faculty of Engineering and IT, University of Technology, Sydney (UTS), PO Box 123, Broadway, NSW 2007, Australia
[b] King Abdullah University of Science and Technology (KAUST), Water Desalination and Reuse Center (WDRC), Biological and Environmental Science & Engineering (BESE), Thuwal 23955-6900, Saudi Arabia
[c] The Centre for Marine Bio-Innovation, The University of New South Wales, Sydney, NSW 2052, Australia
[d] The School of Biotechnology and Biomolecular Sciences, The University of New South Wales, Sydney, NSW 2052, Australia
[e] The School of Biological, Earth and Environmental Sciences, The University of New South Wales, Sydney, NSW 2052, Australia
[f] Center for Water Resource Cycle, Korea Institute of Science and Technology, Hwarangno 14-gil 5, Seongbuk-gu, Seoul 136-791, Republic of Korea
[g] The Singapore Centre on Environmental Life Sciences Engineering and The School of Biological Sciences, Nanyang Technological University, Singapore

HIGHLIGHTS

- Microbial community structure in a MBR as a pretreatment for SWRO was studied.
- Adding PAC differentiated a bacterial community compared to the conventional MBR.
- Addition of PAC was also associated with significantly reduced AOC and biofouling.

ARTICLE INFO

Article history:
Received 19 October 2015
Received in revised form 23 February 2016
Accepted 24 February 2016
Available online 3 March 2016

Keywords:
Biofouling
Membrane bioreactor
Microbial community composition
Powder activated carbon
Seawater
Sequencing

ABSTRACT

Membrane bioreactors (MBRs) were operated on-site for 56 d with different powdered activated carbon (PAC) dosages of 0, 1.5 and 5.0 g/L to pretreat seawater for reverse osmosis desalination. It was hypothesized that PAC would stimulate adsorption and biological degradation of organic compounds. The microbial communities responsible for biofouling on microfiltration (MF) membranes and biological organic removal in MBR were assessed using terminal restriction fragment length polymorphism fingerprinting and 454-pyrosequencing. The PAC addition improved assimilable organic carbon removal (53–59%), and resulted in reduced biofouling development on MF (>50%) with only a marginal development in trans-membrane pressure. Interestingly, the bacterial community composition was significantly differentiated by the PAC addition. *Cyanobacterium*, *Pelagibaca* and *Maricoccus* were dominant in the PAC-free conditions, while *Thiothrix* and *Sphingomonas* were presumably responsible for the better reactor performances in PAC-added conditions. In contrast, the archaeal communities were consistent with predominance of Candidatus *Nitrosopumilus*. These data therefore show that the addition of PAC can improve MBR performance by developing different bacterial species, controlling AOC and associated biofouling on the membranes.

1. Introduction

Biofouling remains one of the most difficult challenges in seawater reverse osmosis (SWRO) technology. One major effect of biofouling, through the development of a biofilm on RO membranes, is an increase in membrane resistance and a reduction in performance such as water permeation and rejection of solutes. The development of biofilms in RO modules is affected by the biofouling potential in the feed water, which is influenced by the

Abbreviations: AOC, assimilable organic carbon; CA, correspondence analysis; DOC, dissolved organic carbon; LC-OCD, liquid chromatography with organic carbon detection; MBR, membrane bio-reactor; MF, microfiltration; NMDS, non-metric multidimensional scaling (NMDS); PAC, powder activated carbon; RO, reverse osmosis; SMABR, submerged membrane adsorption bio-reactor; SMBR, submerged membrane bio-reactor; SW, seawater; SWRO, seawater reverse osmosis; TMP, trans-membrane pressure; T-RFLP, terminal restriction fragment length polymorphism.

* Corresponding author. Tel.: +61 2 9514 2641; fax: +61 2 9514 2633.
E-mail address: Saravanamuth.Vigneswaran@uts.edu.au (S. Vigneswaran).

http://dx.doi.org/10.1016/j.cej.2016.02.108
1385-8947/

concentration of bioavailable organic compounds and the presence of biofilm-forming bacteria [1,2]. The integration of microfiltration (MF) with physico-chemical treatments such as adsorption and/or coagulation could significantly reduce organic matter in seawater, especially biopolymer and humic materials, which are associated with membrane fouling. This reduces the amount of organic foulants reaching the RO membrane and alleviates the problem of flux decline during RO operation. Also, bacterial cell numbers and cell viability decline significantly, indicating reduction of biofouling potential through the separation and the inactivation of microbes [2].

In this regard, biological pretreatment systems such as biofiltration [3] and a membrane bioreactor (MBR) [4], utilizing biological degradation have been tested for SWRO. However, biofouling is also a problem for MF membranes in the pre-treatment MBR [4]. For these pretreatment systems, it has been observed that biofouling causes the trans-membrane pressure (TMP) to increase when the submerged MBR was operated at a constant flux [5]. In one study, the *ex situ* observation by confocal laser scanning microscopy (CLSM) demonstrated that biofilms formed on the MF membranes, and they were correlated with reduction in system performance [6]. Thus, the control of biofouling is also required in the MBR system when used as pretreatment for SWRO.

To reduce fouling in the MBR system, powder activated carbon (PAC) in suspension has been used in previous studies. PAC is a porous adsorbent with a significant surface area to volume ratio and facilitates the adsorption of macromolecules in an amended MBR (PAC–MBR) system [7]. The PAC also becomes colonised by microorganisms that can utilize the adsorbed compounds for growth. In this way, the simultaneous adsorption and biodegradation of those macromolecules, rather than in a single biological process, reflects an advantage of the PAC–MBR system over conventional MBR [8]. Adding PAC can also improve membrane filtration by altering the floc characteristics in the bulk mixture and lowering the foulant concentrations [9].

Recently, the PAC–MBR system has been developed as a new pretreatment option for SWRO [4,10] and is referred to here as a submerged membrane adsorption bioreactor (SMABR). Microorganisms were found to colonise on the PAC and this was hypothesised to increase biodegradation of the organic substances previously adsorbed. PAC thus has several benefits including enhanced scouring and initial coating of the membrane surface by PAC particles and adsorption of organic foulants with subsequent biodegradation [10]. However, the key microbial community species, which mainly remove organic matter in the SWRO process, remain largely not well understood.

The growth and species composition of microbial communities on SMABR may play a crucial role in removing organics from seawater [10]. It is also likely that the efficiency of biological treatment strategies could be improved through a thorough and complete understanding of microorganisms and their metabolism when growing on a biological activated carbon (BAC) filter [11]. The study of the bacterial community composition on the biofouled SWRO membrane revealed that the predominant microorganisms were α-proteobacteria as well as Firmicutes, Actinobacter, Planctomycetes and Bacteroidetes phyla [12,13]. Analytical methods for DNA sequencing have improved and become significantly less expensive over the last 30 years allowing for increasingly detailed analysis of microbial communities. New developments enable meta-community sequencing based approaches, such as through barcode tagged sequencing of 16S rRNA genes amplified from the environment, without having to isolate individual organisms.

Technological advances such as pyrosequencing enable rapid characterization of microbial communities at a greater sequence depth than Sanger sequencing [14]. In addition, fingerprinting techniques such as terminal restriction fragment length polymorphism (T-RFLP) that produce readily interpreted patterns of microbial community diversity serve as useful tools for investigating the relative abundance and diversity of microbial communities, and can complement or supplement meta-community sequencing based approaches [15]. T-RFLP-based community assessment was used in this study to characterize the community composition and to correlate with the composition to see how well the system performed.

In this study, MBR (or submerged MBR; SMBR) and SMABR were used as a biological pretreatment to SWRO and their performances were evaluated in terms of organic removal, especially assimilable organic carbon (AOC), and TMP increase. T-RFLP and 454-pyrosequencing technologies were then employed to elucidate the composition of microbial communities responsible for biofouling of the MF membranes in MBR and removing organic compounds in SMABR.

2. Materials and methods

2.1. Experimental design and performance

In this study, a SMBR was operated at 10 L/m^{2}h (LMH) without adding PAC. At the same time, two SMABR systems were run with different PAC doses (SMABR-1.5 and SMABR-5.0; 1.5 g/L and 5.0 g/L PAC initially added, respectively) at 30 LMH. High fouling of SMBR (without PAC addition) even at 10 LMH and low fouling of SMABR (with PAC addition) at high flux of 30 LMH led us to perform the subsequent SMABR at high flux of 30 LMH. The SMABR experiment at lower flux will be performed in our future study. The long-term operation of SMABR revealed the synergistic effects of PAC adsorption/biodegradation and membrane rejection in removing organic matter [10]. With PAC addition, the submerged membranes did not become clogged. This was due to fact that PAC removes the majority of organics prior to their entry to the membranes. The membrane functioned mainly to retain the PAC and other suspended solids. Hence, SMABR functions like a biofilm reactor. In both SMABR reactors, the amount of PAC replaced was 1.5% on a daily basis (based on total volume of reactor), which corresponds to a 66 d residence time (note: SMBR contained only small amount of sludge, which was not activated sludge but accumulated from suspended solids including naturally present and grown biomass). The SMBR and SMABRs (Fig. 1) were operated at the Sydney Institute of Marine Science, Chowder Bay in Sydney, Australia with continuous feeding of seawater for 56 d. Daily backwashing was performed with MBR permeate (filtered water) withdrawn using a peristaltic pump at 30 LMH (water flux) for 2 min. The specification of MF membrane and detailed experimental design have been documented elsewhere [10].

The membrane-filtered effluent was obtained by suction using a pump connected to the membrane modules. The TMP development (in kPa) was monitored by a pressure gauge. While the SMBR was in operation, a gradual increase in TMP was observed followed by a rapid increase with fouling. In this study, a newly developed bioluminescence method was used to measure AOC concentration of seawater and pretreated seawater samples [10,16]. This method used *Vibrio fischeri* MJ-1 and glucose was employed as an AOC standard carbon compound in this test. AOC measurement procedure has been provided in other studies [10,16]. The AOC method is an indicative measure of the biological growth potential of water (or biofouling potential) since it represents the fraction of labile DOC that is readily assimilated and utilized by microorganisms resulting in increased biomass concentration. Subsequently, in this study, the extent of biological organic availability was monitored in terms of changes in AOC concentration. After 14 d of pre-acclimation, mixed liquor suspended solids (MLSS) in SMBR