Journal of Environmental Management 223 (2018) 586–599

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Review

Review – Bacteria and their extracellular polymeric substances causing biofouling on seawater reverse osmosis desalination membranes

Veena Nagaraj*, Lucy Skillman, Dan Li, Goen Ho

School of Engineering and Information Technology, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia

ARTICLE INFO

Keywords:
Biofouling
Seawater reverse osmosis (SWRO) membranes
Desalination
Bacteria
Extracellular polymeric substances (EPS)
Control

ABSTRACT

Biofouling in seawater reverse osmosis (SWRO) membranes is a critical issue faced by the desalination industry worldwide. The major cause of biofouling is the irreversible attachment of recalcitrant biofilms formed by bacteria and their extracellular polymeric substances (EPS) on membrane surfaces. Transparent exopolymer particles (TEP) and protobiofilms are recently identified as important precursors of membrane fouling. Despite considerable amount of research on SWRO biofouling, the control of biofouling still remains a challenge. While adoption of better pretreatment methods may help in preventing membrane biofouling in new desalination setups, it is also crucial to effectively disperse old, recalcitrant biofilms and prolong membrane life in operational plants. Most current practices employ the use of broad spectrum biocides and chemicals that target bacterial cells to disperse mature biofilms, which are evidently inefficient. EPS, being known as the strongest structural framework of biofilms, it is essential to breakdown and disintegrate the EPS components for effective biofilm removal. To achieve this, it is necessary to understand the chemical composition and key elements that constitute the EPS of major biofouling bacterial groups in multi-species, mature biofilms.

However, significant gaps in understanding the complexity of EPS are evident by the failure to achieve effective prevention and mitigation of fouling in most cases. Some of the reasons may be difficulty in sampling membranes from fully operational full-scale plants, poor understanding of microbial communities and their ecological shifts under dynamic operational conditions within the desalination process, selection of inappropriate model species for laboratory-scale biofouling studies, and the laborious process of extraction and purification of EPS. This article reviews the novel findings on key aspects of SWRO membrane fouling and control measures with particular emphasis on the key sugars in EPS. As a novel strategy to alleviate biofouling, future control methods may be aimed towards specifically disintegrating and breaking down these key sugars rather than using broad spectrum chemicals such as biocides that are currently used in the industry.

1. Introduction

Water, an essential element for life, makes up 71% of the planet's surface, of which only 3.5% is suitable for human consumption, to be found in lakes, rivers and springs to supply our everyday needs. The remaining 96.5%, located in seas and oceans, is not drinkable due to its high level of salinity. In many arid parts of the world, for e.g. Middle East, Australia, Northern Africa and Southern California, more than 75 percent of the population is concentrated along the coast. Seawater desalination provides a logical solution for the sustainable, long-term management of the growing water demand.

The most widespread and advanced system of seawater desalination is the use of reverse osmosis membrane separation, whose implementation is more widespread compared to other systems such as thermal evaporation or membrane distillation processes. In recent years, up to 150 countries host desalination plants and overall, these plants supply with desalinated water to approximately 300 million people (Association, 2015). As for the global implementation of this technology, there are more than 18,000 desalination plants worldwide producing 86.55 million cubic meters of desalinated water daily (Association, 2015).

However, reverse osmosis membrane desalination is not free from the problems of fouling. RO membranes are affected by four major types of fouling, namely, a) crystalline, b) organic, c) particulate and

Abbreviations: SWRO, seawater reverse osmosis; RO, reverse osmosis; PSDP, Perth seawater desalination plant; EPS, extracellular polymeric substances; TEP, Transparent exopolymer particles; CIP, clean-in-place; NGS, next generation sequencing; GSL, glycosphingolipids; OTUs, operational taxonomic units; MALDI-TOF MS, matrix assisted laser desorption ionization-time of flight mass spectrometry; ConA, Concanavalin A; HPAEC-PAD, High Performance Anion Exchange Chromatography-Pulse Amperometric Detection; NO, nitric oxide

* Corresponding author. 8 Audley Place, Canning Vale, Western Australia 6155, Australia.
E-mail addresses: veena1546@outlook.com, veena.nagaraj@murdoch.edu.au (V. Nagaraj), l.skillman@murdoch.edu.au (L. Skillman), l.li@murdoch.edu.au (D. Li), g.ho@murdoch.edu.au (G. Ho).

https://doi.org/10.1016/j.jenvman.2018.05.088
Received 12 December 2017; Received in revised form 25 May 2018; Accepted 26 May 2018
0301-4797/

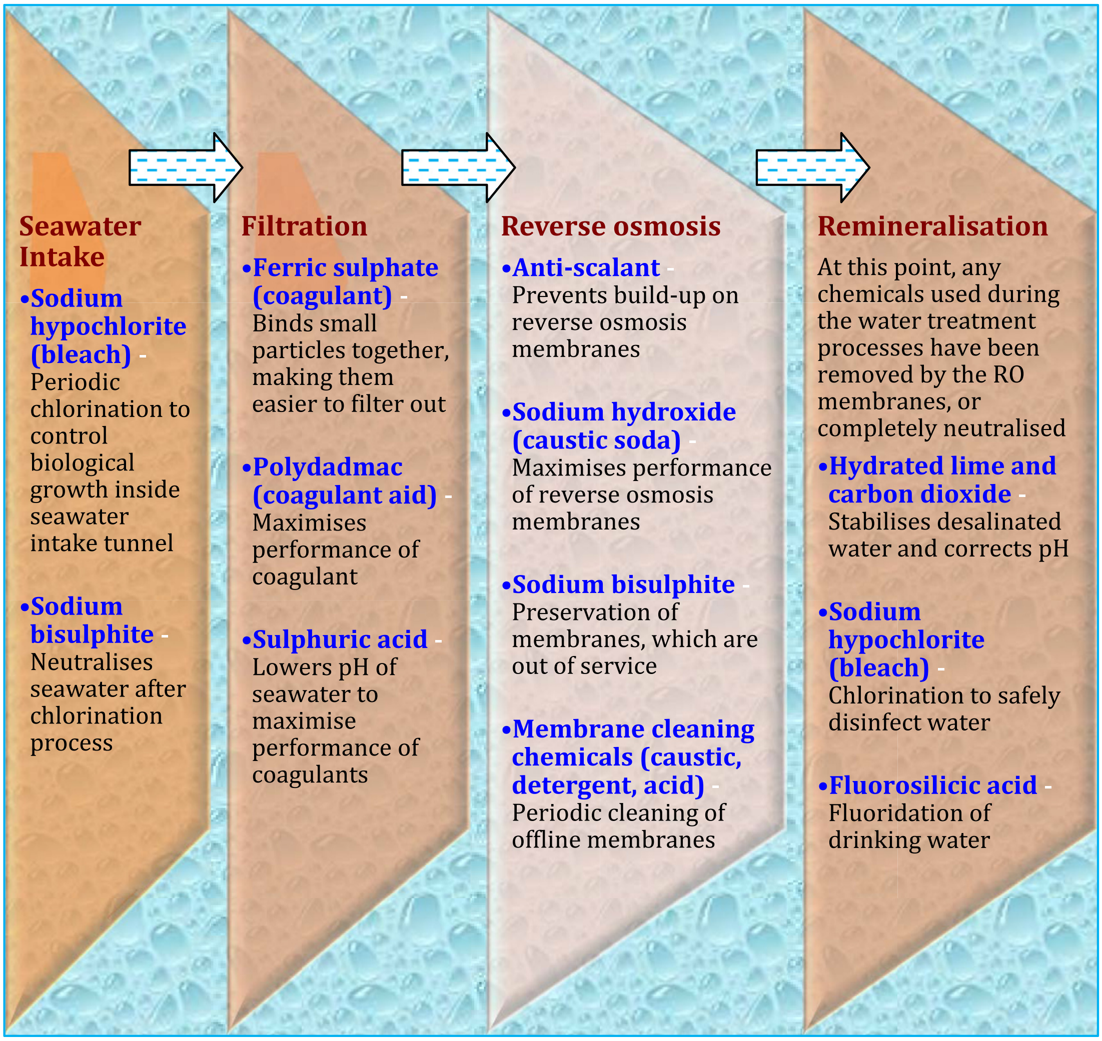

Fig. 1. Chemical treatment and the purpose of chemicals used in the Perth Seawater Desalination Plant. (http://www.aquasure.com.au/uploads/files/Water%20Treatment%20Fact%20Sheet.pdf).

colloidal, and d) microbiological or biofouling (Flemming, 1997). Among these, biofouling is the most problematic, causing reduced operational efficiency and economic losses to the industry. SWRO desalination plants are in need of urgent solutions to alleviate fouling, due to the increasing demand for fresh water and the cost of production. Pre-treatment can be very effective in mitigating biofilms. However, even with the most effective pre-treatments that remove 99.99% of bacteria, a few bacterial cells that penetrate the filters or are resistant to biocides can enter the RO system and proliferate effectively to form recalcitrant biofilms on membrane surfaces over time (Flemming et al., 1997). The rate of membrane fouling is dependent on the efficacy of the pretreatment system. At present, there are several methods to slow down the process of biofilm formation, but none of them completely reverse it, and biofouling eventually leads to membrane disposal. Most broad-spectrum cleaning chemicals damage the membrane surface with frequent use (Baker and Dudley, 1998). They are effective in scouring only the top layers of the biofilm, which eventually grows back (Bereschenko et al., 2011a). If we had an efficient method to target irreversible biofouling by breaking down the recalcitrant biofilm structure, for example, disintegration of specific key EPS molecules, then the membrane life-span could be drastically improved.

It is a well-known fact that EPS has a critical role in biofilm formation and biofouling on membranes (Herzberg et al., 2009). Purified bacterial EPS alone, with no bacterial cells has been shown to cause fouling of RO membranes and reduce permeate flux significantly (Xie et al., 2017). In recent years, free-floating polymers like transparent exopolymers (TEP) and protobiofilms are gaining importance as critical precursors of biofilm formation in aquatic environments (Berman and Holenberg, 2005; Bar-Zeev et al., 2012). In order to design effective control measures to break down irreversibly attached biofilms, a thorough knowledge of the structural components of EPS is necessary. For the characterization of EPS, we need good model culturable bacteria that represent the full-scale system and as a benchmark of comparison for selecting model bacteria, we also need information on the diverse microbial communities and the key groups that cause biofouling in SWRO membranes. Although there is an extensive body of literature related to SWRO membrane bacterial communities, culture and EPS characterization studies are relatively limited. In this paper, we review and discuss the novel findings on key aspects of SWRO membrane fouling, with particular emphasis on the importance of EPS and directing future control strategies towards removal of mature recalcitrant biofilms by targeting the EPS. Targeting of EPS may also help break up protobiofilms and TEP, which are integrated into the biofilm structure. When coupled with efficient pretreatment methods, EPS breakdown may serve as an excellent solution to prolong the life-span of RO membranes.