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Source water quality shaping different fouling scenarios in a full-scale desalination plant at the Red Sea

Muhammad Tariq Khan [a], Carmem-Lara de O. Manes [a,b,c], Cyril Aubry [a], Jean-Philippe Croué [a,*]

[a] Water Desalination and Reuse Research Center, King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia
[b] UPMC Univ Paris 06, UMR 7621, LOMIC, Observatoire Océanologique, F-66651 Banyuls/mer, France
[c] CNRS, UMR 7621, LOMIC, Observatoire Océanologique, F-66651 Banyuls/mer, France

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ABSTRACT

The complexity of Reverse Osmosis (RO) membrane fouling phenomenon has been widely studied and several factors influencing it have been reported by many researchers. This original study involves the investigation of two different fouling profiles produced at a seawater RO desalination plant installed on a floating mobile barge. The plant was moved along the coastline of the Red Sea in Saudi Arabia. The two locations where the barge was anchored showed different water quality. At the second location, two modules were harvested. One of the modules was pre-fouled by inorganics during plant operation at the previous site while the other was installed at the second site. Fouled membranes were subjected to a wide range of chemical and microbiological characterization procedures. Drastically different fouling patterns were observed in the two membranes which indicates the influence of source water quality on membrane surface modification and on fouling of RO membranes.

1. Introduction

Reverse osmosis (RO) process is one of the main options proposed to solve the issue of fresh water scarcity (Fritzmann et al., 2007; Micale et al., 2009). Because of capital and operation cost reductions, the process of seawater reverse osmosis (SWRO) desalination has rapidly gained popularity over other desalination processes during the last 20 years. At the present time, SWRO technology is used in 50% and 72% of seawater desalination processes around the world and in Europe, respectively (Ettouney and Wilf, 2009; Fritzmann et al., 2007; Zhou and Tol, 2005).

In spite of all the efforts conducted to improve the economic viability of this technology, membrane fouling remains a major problem for RO systems (Radu et al., 2012). Fouling of RO membrane brings multiple adverse effects on the RO system sustainability (i.e., increase in hydraulic resistance and enzymatic degradation of the membrane polymeric structure) (Flemming, 1997). Membrane fouling is a very complex phenomenon as its kinetics and dynamics are prone to be affected by several factors including intake water quality, pretreatment setup, and RO system operating parameters. The complexity of the fouling process is also attributed to the fact that foulant species are of many different types and do not only contribute individually to the problem but can also co-exist and interact with each other to form a dense and compact foulant layer (Tang et al., 2009, 2011; Wiesner and Aptel, 1996).

* *Corresponding author*. Tel.: +966 (0) 2 808 2984.
E-mail address: Jp.croue@kaust.edu.sa (J.-P. Croué).
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A fouling layer can be developed as a result of i) inorganic mineral deposition due to limited solubility, ii) accumulation of dissolved organics, e.g., humic substances, iii) deposition of particulate humic substances, clay, microbial debris, etc., and iv) biofilm formation (i.e., adhesion and growth of microbes) (Chian et al., 2007).

Fouling phenomenon is driven by the quality of the RO inlet water, which is primarily contingent to the source water quality and then to the downstream pretreatment train. In reality, the best possible pretreatment setup does not guarantee a fouling-free RO membrane operation (Chen et al., 2008; Walton, 1991). In particular, biofouling cannot always be fully eradicated by pretreatment of the feed because of the self-replicating nature and adaptation capabilities of microorganisms (Mansouri et al., 2010; Zhang et al., 2011). Hence, source water quality is a key factor in the study of membrane fouling which depends upon the abundance and nature of the foulant species present (Voutchkov and Semiat, 2008). Despite similar pretreatment system, source waters with different qualities may differently influence the mechanisms and kinetics of fouling. In addition to the composition of the feed water, the fouling trends are also dependent upon the chemistry of the membrane surface, as it can potentially affect fouling by promoting or inhibiting hydrophilic/hydrophobic interactions (Liu et al., 2001). Furthermore, the presence and diversity of microorganisms in the feed water, which is environmentally driven, might also play a role in fouling profiles.

In this study, we investigated two different fouling profiles of RO membranes used at the same plant with analogous pretreatment and operating setup. The RO plant is installed on a floating barge operated successively at two different locations on the Red Sea coastline. The source water quality of the two sites was substantially different. At the final barge location, two modules were harvested from lead positions in the RO train. While one of the modules remained in operation on both sites, the other one was installed when the barge reached the second site. The change in plant locality presented the opportunity to conduct this unique study on the evolution of RO fouling trends with severe source water quality change at full scale operation. The impact of membrane surface character and feed water quality on shaping different fouling scenarios is discussed based on the results obtained from multistep fouling characterization including imaging (i.e., a novel application of Scanning Transmission Electron Microscopy (STEM) combined with Energy Dispersive X-ray Spectroscopy (EDS or EDX) has been used), chemical and microbiological techniques.

2. Materials and methods

2.1. *Description of the SWRO plant*

Two thin film composite (TFC) polyamide seawater fouled RO membranes, named as A and B, received as 8″ spiral wound modules, were analyzed. Full scale SWRO trains installed on two barges were operated first for one year in the southern region (i.e., Red Sea coastline) of Saudi Arabia, herein site A. The barges were anchored in a very shallow (i.e., nearly 4 m in depth) channel of a multi stage flash (MSF) distillation plant. The intake was positioned at approximately 2 m in depth in water enriched in suspended solids (i.e., silt and sand particles). The barges were then moved more north on the Red Sea coastline to site B; with intakes positioned in open sea at approximately 20 m from the shore and several meters in depth (approximate turbidity 0.3 NTU). Both modules were operated as lead elements. Module/membrane A was initially used for approximately 1 year on site A before operating for 2 months at site B. Before harvested, membrane B was only used on site B for 2 months.

The plant had a design capacity of 52,000 m^3/d. The first pass (i.e., SWRO trains) was operated at 60 bar with a 40% recovery. Pretreatments included chlorination (0.5–0.6 ppm) at the intake, ultrafiltration (UF) unit (polyvinylidene difluoride, PVDF, membranes with nominal pore size of 0.02 μm), dechlorination with sodium bisulfite (1.0–1.5 ppm), and polymeric antiscalant dosing steps before RO.

2.2. *Seawater characterization*

The seawater (SW) quality, before/after UF treatment, was analyzed through measurements of pH (Cyberscan pH6000, Eutech, USA), conductivity (CON 510, Oakton, USA), Total Dissolved Solids (TDS), turbidity (2100AN, HACH, USA), Silt Density Index (SDI), Total/Dissolved Organic Carbon (TOC/DOC; TOC-V_{CPH} Analyzer, Shimadzu, Japan), Ultraviolet Absorbance at 254 nm (UV_{254}, Spectrometer UV-2550, Shimadzu, Japan) and Heterotrophic Plate Count (HPC). Silt Density Index, SDI, was determined according to the ASTM D4189-07 method. HPC was performed following Reasoner and Geldreich's method (Reasoner and Geldreich, 1985). Additionally, bacterial diversity analysis of waters before and after pretreatments was also performed (Manes et al., 2011a).

2.3. *Autopsy and fouling characterization*

Modules were harvested and the membrane leaves unfolded. Membrane surface and feed spacer were visually examined to distinguish the apparent morphological features and distribution patterns of the fouling layer. Samples for microbiological and ultrastructural analysis were immediately transferred to petri dishes and were kept at −20 °C and 4 °C, respectively, until further analysis. Additionally, chemical analyses of the dry foulant material, isolated through physical scrapping and lyophilization process, were conducted. Fouling load was measured by weighing the dry foulant mass recovered from a measured surface area (performed in triplicate).

All the characterization procedures described hereunder were carried out either on fouled membranes (i.e., direct characterization) or recovered foulant material (i.e., indirect characterization) except for phylogenetic analysis, which was carried out on both water and fouled membranes.

2.3.1. *Chemical analysis*

Lyophilized foulant material recovered from both membranes (A and B) were subjected to the following chemical analyses.

2.3.1.1. *% Loss on ignition (% LOI) test.* Lyophilized foulant material was dehydrated overnight at 105 °C and then