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How different is the composition of the fouling layer of wastewater reuse and seawater desalination RO membranes?

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ABSTRACT

To study the effect of water quality and operating parameters on membrane fouling, a comparative analysis of wastewater (WW) and seawater (SW) fouled reverse osmosis (RO) membranes was conducted. Membranes were harvested from SWRO and WWRO pilot plants located in Vilaseca (East Spain), both using ultrafiltration as pretreatment. The SWRO unit was fed with Mediterranean seawater and the WWRO unit was operated using secondary effluent collected from the municipal wastewater treatment plant. Lead and terminal SWRO and WWRO modules were autopsied after five months and three months of operation, respectively. Ultrastructural, chemical, and microbiological analyses of the fouling layers were performed. Results showed that the WWRO train had mainly bio/organic fouling at the lead position element and inorganic fouling at terminal position element, whereas SWRO train had bio/organic fouling at both end position elements. In the case of WWRO membranes, *Betaproteobacteria* was the major colonizing species; while Ca, S, and P were the major present inorganic elements. The microbial population of SWRO membranes was mainly represented by *Alpha and Gammaproteobacteria*. Ca, Fe, and S were the main identified inorganic elements of the fouling layer of SWRO membranes. These results confirmed that the RO fouling layer composition is strongly impacted by the source water quality.

1. Introduction

To overcome the growing water scarcity problem in the planet, several water management approaches (i.e., water conservation or improvement of distribution systems) have been implemented and different water treatment processes have been introduced (Elimelech and Phillip, 2011). Due to its versatility, Reverse Osmosis (RO) process is one of the available solutions for the purification of water that has quickly

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expanded worldwide. This semi-permeable membrane technology provides high removal of dissolved solids, organics, colloidal matter, and microbes from feed water. Because of this attractive contaminant rejection feature and efficiency profile, RO process is been widely used for seawater desalination (Ettouney and Wilf, 2009) and it is also finding increased application in the domain of municipal and industrial wastewater treatment (Bartels et al., 2005).

Despite the wide applicability of RO, membrane fouling is still an important shortcoming limiting the efficiency of this process. RO membrane fouling is driven by the quality of inlet water and by the downstream pretreatment train (Khan et al., 2013a). Today, many seawater reverse osmosis (SWRO) desalination and advanced wastewater reverse osmosis (WWRO) treatment plants are applying microfiltration (MF) or ultrafiltration (UF) prior to RO to guarantee high removal of suspended and colloidal matter. Regardless of the tight pores of MF and UF membranes, a fraction of foulants/foulant precursors passes through these pretreatment barriers and consequently induces RO membrane fouling (Mo et al., 2008; Rapenne et al., 2007). Due to this limited fouling inhibition role of these pretreatment technologies, the source water composition remains as a major factor that governs membrane fouling phenomenon.

To understand and overcome membrane fouling, many studies have focused on investigating the fouling cake layer occurring during WWRO reclamation (Ang et al., 2011; Zhu et al., 2012) and SWRO desalination processes (Flemming and Schaule, 1988). Nevertheless, due to dissimilar source water, pretreatment processes, and membrane characteristics, the composition of the fouling layers characterized in previous studies have significantly differed from each other. Therefore, the fundamental mechanisms governing fouling phenomena could not be precisely elucidated and a comparative analysis between these systems could not be established. In the present work, polyamide thin film composite RO membrane elements from SWRO and WWRO treatment trains positioned after similar ultrafiltration pretreatment process were autopsied. Although operating parameters were different to some extent, the main dissimilarity between two systems was the use of two different source waters (i.e., wastewater and seawater). The autopsy of fouled membrane modules is a commonly used technique that offers an important insight on the characteristics of foulants and the structure of fouling layers (Darton et al., 2004). Two end position modules (i.e., lead and terminal end modules) from both treatment trains were selected for characterization. The fouling layers were characterized by Fourier Transform Infrared (FTIR) spectrometry, Pyrolysis Gas Chromatography coupled with Mass Spectrometry (Pyrolysis/GC–MS), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), elemental analysis, and microbial phylogenetic examination procedures. The aim of this study was to investigate the effect of the drastically different microbial and chemical quality of the source water on the structural characteristics and nature of the fouling layer formed on RO membranes. The differences in microbial and chemical composition of the fouling layers of two sets of membranes were rigorously analyzed and discussed in detail.

2. Materials and methods

2.1. Pilot scale RO units

Membrane samples were obtained from two pilot plants located at DOW Global Water Technology Development Center in Spain. Both pilot plants were similar in principle but were operated with two different source waters, a treated urban wastewater and the Mediterranean seawater collected from an open intake.

2.2. SWRO pilot unit

The seawater project was conducted on the Mediterranean Sea, and the feed water was captured in the port of Tarragona. The port of Tarragona is relatively shallow with about 5 m water depth; its water quality is impacted by ship traffic and occasionally (during rain events) by the river that ends in the port.

The source water was captured, shock-chlorinated (every 4 h with 2–5 ppm NaOCl), and then transported via a 10 km pipe through a 250 μm screen size ring filter (Arkal, Israel), to the feed tank of the pilot unit at the DOW Water & Process Solutions Global Water Technology Center in Tarragona. Source water was characterized by: pH of 8.1, conductivity of 57.4 ms/cm, Total Organic Carbon (TOC) of 2 mg/L, turbidity of 2 NTU, Total Suspended Solids (TSS) of 10 mg/L, and a Total Dissolved Solids (TDS) of 40,000 mg/L. Occasionally, peaks of 3 mg/L, 15 NTU, and 50 mg/L were observed for TOC, turbidity, and TSS, respectively. The temperature ranged from 13 to 30 °C during operation.

The pilot unit consisted of a feed tank supplying two ultrafiltration lines equipped with DOW™ SFP-2660 modules (30 nm nominal pore diameter, hydrophilized PVDF outside-in hollow fibers, pressurized, vertical). The SWRO line fed by the UF filtrate was positioned after a 5 μm cartridge filter. The RO line used 6 elements (4-inch diameter FILMTEC™ SW30XLE-4040) in series configuration operated at 60 bar feed water pressure, 17 L/m^{2}h average permeate flux, and at 45% recovery rate. Moreover, feed water flow rate for RO system was 1.5 m^3/h with cross flow velocity values of 0.12 and 0.06 m/s at the lead and terminal position elements, respectively (Fig. 1A). Modules of 1st (SM1, lead element) and 6th position (SM6, terminal element) of the RO line 1 were autopsied after approximately 5 months of operation.

2.3. WWRO pilot unit

The wastewater UF–RO project was carried out at the Vilaseca wastewater treatment plant, which treats wastewater from the cities of Vilaseca, La Pineda, and Salou. This urban wastewater (low industrial discharge) showed strong variations in quality due to touristic influence. The pretreatment included: coarse screening (1 mm), sand filtration followed by primary sedimentation, aerobic sludge treatment (designed for partial nitrification), and secondary sedimentation. The treated wastewater collected after secondary sedimentation was fed to the UF–RO pilot unit (Fig. 1B) with the following physicochemical characteristics: pH of 7.0, conductivity of