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Analysis of raw and pre-treated seawater for potential biofouling precursors

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HIGHLIGHTS

- Assess biofouling precursors in RO desalination plants
- Main biofouling precursors were TEP and microbial community composition.
- Microbes known to be involved in biofouling and TEP production were identified.
- Low nutrient levels and high N/P ratio provoked a higher TEP production by microbes.

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ABSTRACT

Here, the biofouling precursors of raw and pre-treated seawater from a reverse osmosis (RO) feed tank were investigated using a lab-scale RO cross-flow system. The microbial communities, nutrients and TEP present in both source waters were analyzed using flow cytometry, light microscopy, flow cell injection and colorimetry. All biofilms formed were characterized using scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy and colorimetry. Evaluation of both seawater sources showed (1) low nutrient levels and a high N/P ratio known to provoke a higher TEP production by microbes, (2) the presence of microbes known to be involved in biofouling and transparent exopolymer particles (TEPs) production and (3) a high concentration of TEP known to provoke membrane biofouling.

1. Introduction

Biofouling of seawater reverse osmosis (SWRO) membranes, used for the desalination of seawater, is defined as the deposition/growth of a biofilm significant enough to lead to a decline in membrane performance [1]. This leads to a reduction in both system efficiency and the lifetime of SWRO membranes [1,2]. The mechanism of biofouling has been studied for many years [3] but is still not fully understood. Transparent exopolymer particles (TEPs) have been identified as one of the main precursors of biofouling [4]. TEPs are transparent amorphous organic substances present in marine and fresh water environments with a size ranging from few nanometers in diameter up to 100 s of mm long [5]. They are sticky and comprise mainly hydrophilic, negatively-charged, acidic polysaccharides [6]. Studies have shown that TEP is not only produced by planktonic algae [4,7], but also by bacteria and dissolved precursor material (i.e., dissolved organic carbon (DOC), fibrillar colloids and polysaccharides) released by phytoplankton [4,7]. Increased research into TEPs [4,8] has proposed that TEP comprises of sticky organic microgels with varying size range from 0.4 μm to >200 μm and is part of the exopolymeric substance (EPS) matrix embedding the biofilms [5]. However, biofouling can also occur through the attachment of polysaccharides, proteins, lipids, DNA, bacteria, diatoms, fungi and dead microorganisms to membrane surfaces, all of which are proposed to be embedded in EPS [6,7]. In order to reduce biofouling in desalination plants, pre-treatment systems are frequently used. For example, chemical treatments such as chlorination and/or the use of biocides, as well as physical treatments such as sand filtration and/or periodic cleaning of the membranes, are commonly used [2]. Modification of

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membrane surface chemistry has also proven successful in the reduction of biofilm formation [9,10].

During the desalination process, TEP from raw seawater often goes through pre-treatment systems, subsequently contaminating RO feed tanks, and increasing the possibility of biofouling of the SWRO membranes [8]. It is clear that there is considerable interplay of interactions between various microbes present in biofilms and that this plays an integral role in biofilm regulation [11]. Of particular importance in SWRO membrane biofouling is that once embedded in the biofilm microbes such as bacteria and diatoms become more resistant to biocidal and chemical treatments which make the mitigation of biofouling challenging [2].

Investigations of the microbial community that causes SWRO membrane biofouling have mainly focused on freshwater or wastewater RO treatment systems [10–12]. Additional studies revealed that the seawater biofouling microorganisms were very different than those in the wastewater and freshwater environment, and that these bacteria may respond to different triggers in the environment [13–16]. The identification and study of biofouling microbial communities is a challenge as only a small portion of the marine bacterial community can be cultivated under laboratory conditions [17,18]. Notably, these communities vary between desalination systems thus resulting in different biofouling precursors in each plant [19].

In this study, we use a lab-scale cross-flow system to assess the biofouling precursors of raw and pre-treated seawater. As a case study, biofouling experiments were conducted on raw and pre-treated seawater from the Penneshaw desalination plant (Kangaroo Island, South Australia). The microbial communities, nutrients and TEP present in both source waters were analyzed using flow cytometry, light microscopy, flow cell injection and colorimetry. All biofilms formed were characterized using scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy and colorimetry.

2. Materials and methods

2.1. Pre-treatment system at Penneshaw desalination plant

The Penneshaw SWRO desalination plant (Kangaroo Island, SA) has a capacity of 3×10^5 L·day^{-1} and has been described in detail in previous studies [20]. Seawater is pumped at a depth of 6 m from the coastal waters north of Kangaroo Island at a site located 190 m from the Penneshaw desalination plant. Raw seawater enters the system (Fig. 1) through two pre-filtration screens (10 cm and 0.5 mm pore sizes, respectively), followed by the pre-treatment system, which includes a medium pressure ultra violet (MP-UV) disinfection unit, four parallel multi-media filters (MMFs) (i.e., gravel, garnet, sand and coal with a grain size ranging from 0.3 to 10 mm), and two consecutive sets of three cartridges filters (CFs) each with a pore size of 15 μm and 5 μm, respectively. The flow rate through the system is typically 504 L·min^{-1} after which the raw seawater enters the reverse osmosis (RO) feed tank (Fig. 1). Seawater was collected at two sampling points within the desalination plant: (1) raw seawater, located prior to any treatment, and (2) pre-treated seawater, within the RO feed tank located directly after the CFs (Fig. 1). These will be referred to as $T_{initial}$ throughout the following sections.

2.2. Cross-flow experiments

Raw seawater (1) and pre-treated seawater (2) were collected at the end of November 2013 and used as feed water in a custom built laboratory cross-flow filtration system. The experimental system consisted of six Sterlitech CF042 membrane cross-flow filtration cells, connected as two parallel sets of three. The water from the cross-flow filtration system feed tank was recirculated through the cross-flow system. The pressure was set at 500 psi and the flow at 1.5 L·min^{-1}. DOW Filmtec® SW30HR RO membranes were used for the experiments as they are the RO membranes used at Penneshaw. The cross-flow experiments were conducted for seven days to emulate the RO desalination process in the laboratory and to assess biofouling formation, with $T_{initial}$ being samples as received from RO desalination plant and T_{7d} the end of the experiment (day 7). The pH and salinity were measured using an AquaRead multi-parameter probe. Samples were analyzed to elucidate (1) TEP quantification, (2) abundance of microbes and (3) nutrient concentrations. After 7 days the RO membranes were removed from the cross-flow system and analyzed using colorimetric TEP quantification, SEM and FTIR spectroscopy.

2.3. Analysis of seawater prior to and post-cross-flow experiments

2.3.1. Nutrient quantification

The concentration of dissolved silica, ammonium, and orthophosphate and the combined concentrations of nitrate and nitrite (nitrate/nitrite) were measured using a Lachat QuikChem Flow Injection Analyzer (FIA), following published methods [21]. Triplicates at $T_{initial}$ and of the feed tank water of the cross-flow system at T_{7d} (10 mL) were filtered through bonnet syringe Minisart filters (0.45 μm pore size, Sartorius Stedim, Dandenong, Australia) to remove any large particles and

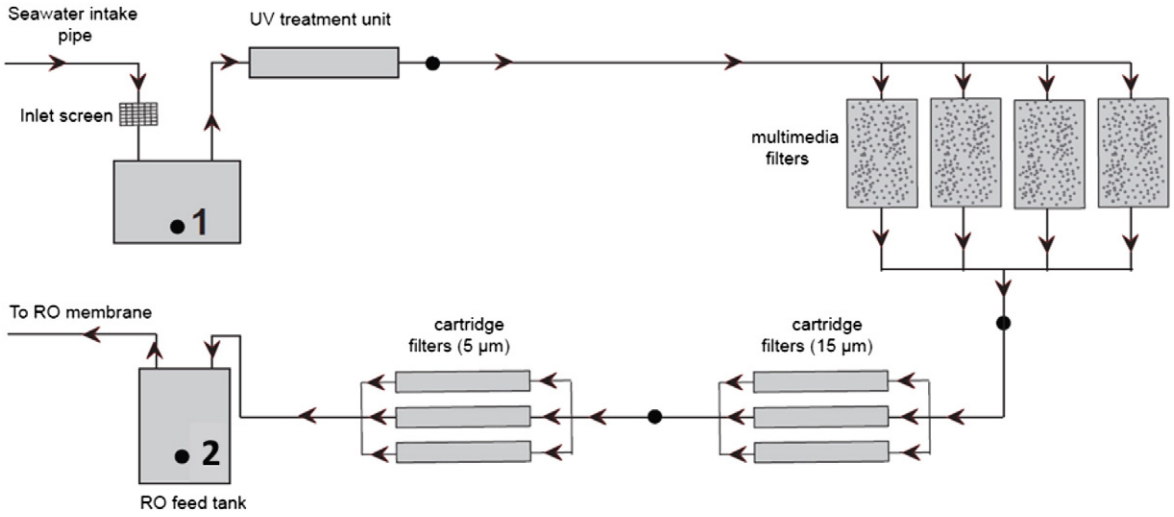

Fig. 1. Schematic diagram of the Penneshaw desalination plant pre-treatment system prior to reverse osmosis (RO). Numbers indicate the two different sampling points: (1) raw seawater and (2) pre-treated seawater.