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# Evaluation of potential particulate/colloidal TEP foulants on a pilot scale SWRO desalination study

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## HIGHLIGHTS

- TEP fouling was investigated through a SWRO pilot study.
- Chlorination caused a higher TEP concentration in water.
- Cartridge filters served as an incubator for the regrowth of bacteria.
- Chemicals addition in pretreatment may have enhanced the biofouling potential.
- RO membrane fouling is proportionally related to TEP concentration in feed water.

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## ABSTRACT

This pilot study investigated the variation of potential foulants and different fractions of transparent exopolymer particles (TEP), along the treatment scheme under different conditions. The objectives are to provide a comprehensive understanding on which fraction of TEP is more problematic in seawater reverse osmosis (SWRO) fouling, and which pretreatment can better reduce the concentration of TEP. Results showed that TEP deposited on the RO membranes, and the extent of RO fouling increased with the increase of TEP concentration in RO feed water. More TEP was produced in water after chlorination, probably because of the breakdown of bacterial cells and thus the release of internal exopolymers. Moreover, the cartridge filters could behave as an incubator for the regrowth of bacteria deactivated by chlorination and a spot for potential foulant (bacterial TEP) production, and thus enhance the RO membranes fouling. The presence of residual iron and addition of phosphate based antiscalant may also contribute to the higher biofouling of RO membranes. This pilot study provided an opportunity to identify the TEP related issues under different operational conditions in RO desalination of Red Sea water.


## 1. Introduction

Because of the shortage of fresh water sources, seawater desalination is a potential solution for water supply in the Middle East region. Since 1980s, membrane technology has become the main technology applied in the desalination field due to its lower energy consumption compared to the traditional thermal technology [1]. Nowadays, about 63% of established desalination capacity around the world is using membrane technology, mainly reverse osmosis (RO). RO is good at removing the microorganisms, salts and organics from seawater, but membrane fouling issues are still a big obstacle in SWRO desalination.

Transparent exopolymer particles (TEP) and TEP precursors have been reported as potential foulants in SWRO membrane filtration [2–4]. TEP is mainly composed of acidic polysaccharides and/or protein, and operationally defined as particles larger than 0.4 μm and stainable with alcian blue [5]. Spontaneous self-assembly of dissolved precursors is a major process of TEP formation [6,7]. Both bacteria and algae have been generally considered to be major source of TEP in marine ecosystems [8,9], either releasing dissolved TEP precursors during exponential growth [9,10] or excreting TEP directly via sloughing and lysis of senescent cells [11]. It has been reported that algal TEP contains more polysaccharides than bacterial TEP, while the protein content in bacterial TEP is higher than algal TEP [12]. Even after removing the particulate TEP (>0.4 μm), the remaining bacterial TEP precursors can lead to a severe RO membrane fouling [13]. It has also been reported that algae-derived TEP substances can cause fouling of ultrafiltration (UF) and RO membranes [14].

In the Red Sea region, membrane based desalination plant consists mainly of: intake, chemical addition, in-line coagulation, dual media filters (DMF), cartridge filters and RO process. This traditional treatment scheme often suffers from fouling issues. Low pressure membranes, such as UF, are also used with/without combination with conventional

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pre-treatment processes. The performance of pre-treatments is normally evaluated by the fouling index, mainly the silt density index (SDI). Other fouling indices, such as modified fouling index (MFI) are developed but not used at industrial scale yet [15]. Lot of recommendations in terms of SDI value of RO feed water have been reported by researchers to improve the RO pretreatments and reduce fouling in the RO unit [16, 17]. However, these fouling indices are related to the amount and size of particles in seawater. Organic and biological fouling issues are still a challenge for the desalination plant in this region. Especially during the algal bloom season, a considerable amount of TEP/TEP precursors could be produced. In 2008, some of desalination plants were forced to shut down for a couple of months during the algal bloom events because of the clogging problem of pretreatments and fouling of RO units, probably caused by the produced TEP/TEP precursors [18]. It is possible that TEP/TEP precursors form a chemical conditioning layer on the membrane surface when they deposit on membranes. This chemical conditioning layer can be thickened by the accumulation of deposited TEP/TEP precursors. Moreover, bacteria may agglutinate and grow on this TEP conditioning layer. Consequently, a biofilm can be formed and enhanced with the growth of bacteria on the conditioning layer. However, there is limited research evaluating the variation of TEP/TEP precursors (potential foulants) along the treatment scheme, especially the variation of different fractions of TEP substances in the treatment scheme. Some of the measures were applied to reduce seawater reverse osmosis (SWRO) membrane fouling, such as chlorination and filtration, but their impacts on TEP/TEP precursors concentration are not clear.

Chlorination has been considered as a main method to control the RO biofouling by destroying bacteria in water to be treated. Karnaugh et al. [19] showed the good biofouling control by periodic direct chlorination. Friedler et al. [20] reported the success of chlorination as pretreatment in gray water desalination. However, Khan et al. [21] reported opposite results on cellulose triacetate (CTA) RO membranes and indicated that both continuous and intermittent chlorination were not capable on preventing biofilm formation. Because of these opposite findings from different researchers, the impact of chlorination on the biofouling of RO membranes is still not clear, especially the relationship between chlorination and the concentration of TEP/TEP precursors (potential foulants) in seawater.

Cartridge filter is used as a last-step protection to ensure that the RO feed water with low SDI values. However, it is possible that the cartridge filters can serve as a hub for the regrowth of bacteria. Khan et al. [21] indicated in their research that one of the failures of chlorination on preventing biofouling is the chlorine adaptation of certain bacterial populations. Especially, in order to protect the polyamide RO membranes (polyamide material is easy to be damaged by chlorine), sodium bisulfate (SBS) is normally used in front of cartridge filter to quench the residual chlorine before the seawater enters the RO units. The removal of residual chlorine may even enhance the regrowth of chlorine adapted bacteria in the cartridge filters. If the bacteria grew in cartridge filters, they would release TEP/TEP precursors into the RO feed and then foul the RO membranes. To verify this, it is interesting to investigate the variation of TEP/TEP precursors over the cartridge filters.

In summary, this pilot study investigated the variation of different fractions of TEP substances along the treatment scheme under different conditions, to provide a comprehensive understanding on variation of different fractions of TEP and their impacts on SWRO membrane fouling. The effectiveness of pretreatments on potential foulants (TEP) removal was also evaluated.

## 2. Materials and methods

### 2.1. Description of the pilot plant

The pilot desalination plant was designed to mimic the full-scale RO membrane based plant. Real Red Sea water was used as feed solution. The design was based on the visits of four full-scale SWRO desalination plants located in different regions of Saudi Arabia and consisted of open water intake, pre-chlorination, followed by acid addition (lowering pH) and in-line coagulation followed by DMF, 5 μm cartridge filter (CF), and spiral wound SWRO membranes, as shown in Fig. 1. Chemicals (including chlorine, sulfuric acid, and coagulant) were injected after the intake pumping and then properly mixed by a static mixer. Phosphate based antiscalant and sodium bisulfate (SBS) were injected in front of the cartridge filters to prevent scaling on downstream RO membranes and quench residual chlorine, respectively.

The DMF is composed of 12.7 cm of gravel and 35.5 cm of sand; the filtration rate of DMF was 13 m/h, with a treatment capacity up to 18 $m^3$/h; backwash pressure of 0.7–1.2 bar. After the DMF treatment, pretreated seawater passed through a 5 μm cartridge filter (preventing the entrance of big particles into the SWRO unit) and then was used as feed water for SWRO.

The SWRO pilot system was loaded with two DOW SW30-4040 RO membranes (with a total surface area of 14.8 $m^2$). The SWRO unit (AMI, USA) was equipped with two pressure vessels, and each vessel with one membrane element. The Pilot was operated at 0.5 $m^3$/h feed flow with 38–40% recovery rate.

### 2.2. Chemicals used

Sodium hypochlorite (NaOCl) was used to disinfect incoming seawater and to maintain proper chlorine residuals in water before entering RO system. Sulfuric acid ($H_2SO_4$) was applied to adjust pH for the incoming seawater and to maintain targeted water pH (6.5) for coagulation. $FeCl_3$ (Sigma Aldrich) was selected as coagulant in this study to improve removals of organic and particulate substances. Antiscalant (Berkosafe-SW) was added before the cartridge filter (CF) to prevent scaling. SBS (Sigma Aldrich) was continuously injected on the suction side of the high-pressure pump (HPP) to quench residual chlorine in the feed water of SWRO with adequate mixing. Produced SWRO permeate was neutralized with NaOH before its discharge back to the Red Sea.

### 2.3. Experimental runs

Experiments were conducted at three conditions: (1) Baseline (BL); (2) After cleaning in place (After CIP); and (3) Low coagulant dose (LD). The details of each experimental condition are shown in Table 1. CIP was conducted by a series of caustic and acidic cleaning listed in Table 2.

During each experiment, the transmembrane pressure (TMP) of SWRO system was continuously recorded under an initial permeate flux of 13 L/$m^2$·h. Samples were taken from the locations presented in Fig. 1 in the Section 2.1 under each condition for quality analyses to investigate the performance of each treatment step, especially the variation of TEP substances within the treatment scheme.

In order to investigate the impact of chlorination on the TEP concentration in water, the chlorination was disabled for 30 min during the "After CIP" condition and then samples were taken to compare with those taken when chlorination was enabled.

### 2.4. Water quality analysis

Water temperature, pH, conductivity, turbidity and residual chlorine were measured twice daily. Total iron was measured using an inductively coupled plasma optical emission spectrometry (ICP-OES) (Varian 720ES ICP optical Emission Spectrometer). Total organic carbon (TOC) and dissolved organic carbon (DOC) were measured using a TOC analyzer (Shimadzu TOC-VCPN). DOC was determined by a pre-filtration with 0.45 μm filters. In terms of the concentrations of different fractions of DOC, they were analyzed by liquid chromatography-organic carbon detection (LC-OCD), from DOC-LABOR Dr. Huber. The principle of the LC-OCD is size exclusion chromatography, and the definition of different organic fractions and their concentration calibration was