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Transparent exopolymer particles (TEP) removal efficiency by a combination of coagulation and ultrafiltration to minimize SWRO membrane fouling

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This study investigated the impact of coagulation on the transformation between colloidal and particulate transparent exopolymer particles (TEP) in seawater; and the effectiveness of a combined pretreatment consisting of coagulation and UF on minimizing TEP fouling of seawater reverse osmosis (SWRO) membranes. Coagulation with ferric chloride at pH 5 substantially transformed colloidal TEP (0.1 −0.4) into particulate TEP (>0.4) leading to a better membrane fouling control. Both 50 and 100 kDa molecular weight cut-off (MWCO) UF membranes removed most of particulate and colloidal TEP without the assistance of coagulation, but coagulation is still necessary for better UF fouling control. The improvement of combined SWRO pretreatment with coagulation and 50 kDa UF membranes was not that much significant compared to UF pretreatment with 50 KDa alone. Therefore, the minimal coagulant dosage for seawater containing TEP should be based on the UF fouling control requirements rather than removal efficiency.

1. Introduction

Seawater reverse osmosis (SWRO) membrane filtration process has been widely applied in seawater desalination globally for a few decades due to its relatively low cost compared to traditional distillation processes (e.g., multi-stage flash (MSF) and multi-effect distillation (MED)) (Ghaffour et al., 2013). However, biofouling of SWRO membranes continues to be the main problem in seawater desalination (Mansouri et al., 2010; Matin et al., 2011).

Transparent exopolymer particles (TEP) have been reported as a major component of biofilms (Bar-Zeev et al., 2009; Berman et al., 2011). TEP are ubiquitous in both sea and fresh waters, and are defined as sticky particles larger than 0.4 μm, mainly composed of acidic polysaccharides that are stainable with alcian blue (Passow, 2002b). Algae and bacteria have been generally considered to be the major source of TEP in water ecosystems (Passow, 2002a; Wetz and Wheeler, 2007), either releasing dissolved TEP precursors during exponential growth (Alldredge et al., 1993; Passow, 2002a) or excreting TEP directly via sloughing and lysis of senescent cells (Beauvais et al., 2003). Some studies demonstrated that spontaneous self-assembly of dissolved precursors is a major process of TEP formation (Chin et al., 1998; Passow, 2000). In the Red Sea and Arabian Gulf, some desalination plants have been forced to shut down due to serious fouling during an algal bloom period, which may have been attributable to the presence of TEP in seawater (Richlen et al., 2010). A recent pilot study using real Red Sea water as feed has also revealed a severe SWRO membrane fouling where the conventional dual media filtration performance was poor in removing TEP substances (Li et al., 2016a,b). Membrane fouling studies have been extensively conducted using humic substances and algal organic matter (AOM) as model compounds (Panglisch et al., 2008; van de Ven et al., 2008; Villacorte et al., 2015). However, TEP is different from these model compounds in terms of size and composition. Comparing to humic substances, TEP has a higher molecular weight and more carbohydrates and protein contents (Li et al., 2015). TEP released from bacteria are mainly detected as biopolymers in the liquid chromatography with organic carbon detection (LC-OCD) analysis, whose molecular weight is around 20,000 Da and higher than the 1000 Da of humic substances (Li

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et al., 2015). AOM was also proven to be one of the major foulants on SWRO membranes (Villacorte et al., 2013). A significant amount of TEP is present within the AOM, but AOM also includes some other biopolymers and low molecular weight neutrals which are not TEP and not stainable with alcian blue dye (Villacorte et al., 2015). Therefore, the studies on RO membrane fouling control based on AOM removal do not truly reflect the impact of TEP pre-removal on membrane fouling. Due to the composition difference between TEP and other model fouling compounds, a study on the pre-removal of TEP on minimizing SWRO fouling is meaningful. However, membrane fouling caused by TEP and how it can be minimized via TEP pre-removal has not been systematically investigated.

Coagulation followed by ultrafiltration (UF) is currently a common pretreatment practice to prevent SWRO fouling. Most of investigations on using coagulation and UF combination as pretreatment for SWRO membrane fouling prevention have been conducted in terms of dissolved organic carbon (DOC) removal (Kumar et al., 2006; Shon et al., 2008). TEP has been reported to appear on fouled ceramic UF membranes used as SWRO pretreatment (Hamad et al., 2013), and the combination of coagulation and UF has been reported to be efficient for TEP removal in some RO plants' performance evaluation studies (Kennedy et al., 2009; Schurer et al., 2013; Villacorte et al., 2009, 2010). However, these studies did not optimize the coagulation and UF for the TEP removal due to the difficulty of changing the operation parameters in the RO plants. The pretreatment optimization using coagulation and UF was still based on the DOC removal, instead of TEP (Hamad et al., 2013). Because TEP is only part of DOC, using DOC removal to evaluate RO membrane fouling control might underestimate the influence of coagulation and UF on TEP pre-removal. To our knowledge, there is no reported research on the effect of coagulation on aggregating colloidal TEP into particulate TEP. Moreover, the combined effectiveness of coagulation and UF on minimizing TEP fouling on SWRO membranes has not been investigated.

In this study, the effect of coagulation on aggregating colloidal TEP released from marine bacteria and its impact on UF/SWRO membrane fouling were investigated. Variations in the particulate and colloidal TEP concentrations in seawater were determined under different coagulation conditions, and the MFI-UF (MFI: modified fouling index) of different coagulated waters was also determined on two UF membranes having different pore sizes of 50 KDa and 100 kDa to check whether the reduction of colloidal TEP can reduce the fouling potential of the corresponding coagulated water or not.

2. Materials and methods

2.1. Marine bacteria cultivation and BOM harvesting

Bacterial TEP substances were harvested by culturing marine bacteria isolated from the Red Sea. Detail of the isolation and harvesting procedure has been reported elsewhere (Li et al., 2015). Since TEP and TEP precursors can be produced from bacteria, the harvested bacterial organic matter (BOM) included bacterial TEP and its precursors. As reported previously, during marine bacteria growth, different organics were produced, including biopolymers, building blocks and low molecular weight neutrals. Bacterial TEP and its precursors are mainly biopolymers as detected.

2.2. Feed water quality

The feed water of each experiment is composed of real Red Sea water and isolated BOM. Seawater was collected from the intake pipe located about 2.5 km from King Abdullah University of Science and Technology (KAUST) coastline, Saudi Arabia (Rahmawati et al., 2012). Raw water quality is presented in Table 1. 2.5 mg TOC/L BOM was added to seawater to mimic a high TEP concentration event. This TOC concentration was encountered in Oosterschelde area, South-Western of the Netherlands during high TEP events that coincided with very high fouling potential in UF systems (Schurer et al., 2012). The 2.5 mg TOC/L BOM contained 1.5 mg xanthan gum eq./L particulate and colloidal TEP (analyzed by alcian blue assay).

2.3. Coagulation protocol

Coagulation was performed on a standard jar-tester (PB-900). The pH of water samples was first adjusted to 5 with H_2SO_4. Afterwards, since the preliminary UF tests with different coagulated feed water showed that there were no significant differences in terms of UF membrane fouling when the coagulant dosage was more than 1.0 mg Fe/L, different amounts of coagulants were dosed in the TEP added seawater (0, 0.1, 0.2, 0.5, and 1 mg Fe/L). Besides that, in order to investigate an over dosage of coagulant on the performance of SWRO, 6 mg Fe/L was also tested. After rapid mixing for 1 min at 300 rpm, the coagulated water was analyzed via a spectrophotometric method for TEP, and the MFI-UF_{100kDa} of coagulated water was also determined to evaluate their fouling potential.

2.4. Ultrafiltration protocol

The UF setup used in this study is fully automated. There are two working phases: filtration and backwash. The duration of each phase and the order of phases can be controlled by a LabVIEW program. The UF system was operated at a constant flux mode with on-line transmembrane pressure (TMP) monitoring. The other water quality parameters, such as pH, turbidity, temperature, were measured via sampling, along with TEP reduction. Six types of feed water were prepared for the UF tests (Table 2). Experiments were conducted using two types of membranes: Multibore® PESM inside-out membranes with molecular weight cut-off (MWCO) of 100 kDa and 50 kDa. Each experiment contained 24 cycles, and one cycle included 30-min filtration and 1 min backwash. UF permeate was used for backwash. Experiments were carried out at constant flux of 130 L/(m^2h) in filtration mode and 260 L/(m^2h) in backwash mode.

Table 1
Feed water quality used in this study.

	Red sea water	Red sea water with TEP
pH	7.9–8.1	7.9–8.1
Turbidity (NTU)	0.75–0.85	1.04–1.15
Conductivity (mS/cm)	59.0–60.1	59.0–60.1
TOC (mg/L)	0.92–1.01	3.41–3.59
Particulate TEP (mg xanthan gum eq./L)	0.25	0.95
Colloidal TEP (mg xanthan gum eq./L)	0.15	0.55