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Physico-chemical pretreatment to seawater reverse osmosis (SWRO): organic characterization and membrane autopsy

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Abstract

In this study, different pretreatment methods such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), powdered activated carbon (PAC) adsorption and ferric chloride ($FeCl_3$) flocculation were evaluated in terms of their capability in removing seawater organic matter (SWOM) and the characteristics of the foulants on the seawater reverse osmosis (SWRO) membranes. A detailed experiment with a crossflow SWRO filtration unit was conducted with SR membrane (MWCO 100 Da) at 60 bar with seawater (conductivity = 48.9 mS/cm) drawn from south-western Korea.

The SWOM removal by UF, NF, PAC adsorption and $FeCl_3$ flocculation was 20.3, 28.9, 46 and 23.3%, respectively. SWOM used in this study predominantly consisted of small size organic matter (<1000 Da). A large amount of the hydrophobic fraction present in SWOM was removed by PAC adsorption. The SDI_{5min} significantly decreased from 12.7 (without any pretreatment) to 3.2 (MF), 1.3 (UF), 1.0 (NF) and 4.4 (PAC adsorption). RO filtration of seawater with and without pretreatment showed significant flux decline (normalized flux decline (J/J_0) = 0.17 ± 0.02) within 20-h operation. The elemental analyses made on the RO surface after direct RO filtration showed that the relative fraction of the carbon decreased, while sodium (Na), magnesium (Mg), chlorine (Cl) and iron (Fe) elements were found in the foulants extracted from the fouled membrane surface. The average roughness of the clean membrane surface was 41.5 nm. After MF and UF pretreatment, the roughness slightly increased to 54.8 and 55.6 nm, respectively. On the other hand, without any pretreatment, with PAC adsorption and with $FeCl_3$ flocculation, the roughness increased up to 69.7, 66.4 and

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110 nm, respectively. It can be concluded that the pretreatment by MF and UF could relatively preserve the RO membrane surface.

Keywords: Pretreatment; Seawater desalination; Reverse osmosis; Membrane autopsy; Organic matter

1. Introduction

Global water shortage can be solved by alternative water sources i.e. desalination and wastewater reclamation. Even if desalination has been developed, the operation is costly due to the requirement of high energy and membrane fouling. The membrane fouling of seawater reverse osmosis (SWRO) has a significant impact on operation of desalination plants. The SWRO foulants consist of (i) biofouling (48%), (ii) inorganic colloids (18%), (iii) organic compounds (15%), (iv) silicites/silicates (13%), (v) mineral deposits (6%) and (vi) coagulants (5%) [1]. Although the concentration of the organic matter in seawater is relatively low and consequently the portion of organic foulant is small in comparison with inorganic constituents, seawater organic matter (SWOM) is a more difficult problem to be solved in the desalination processes. Dudley et al. [2] reported that membranes with severe biofouling were found with 60% organic foulant. However, SWRO is difficult to predict membrane fouling in terms of filtration flux as it is nonporous membrane.

Membrane autopsy is one of the most effective techniques to determine SWRO fouling [3–7]. To identify the fouling on SWRO surface, scanning electron microscopy/energy dispersive X-ray (SEM/EDX), atomic force microscopy (AFM), zeta potential, contact angle, pyrolysis-gas chromatography/mass spectrometry (GC/MS) and attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR) have been used [8]. The zeta potential detects the electrokinetic value associating a realistic magnitude of surface charge on SWRO. ATR-FTIR confirms a detailed screen of the molecular functional groups contributing to membrane fouling. SEM/EDX is used for visual investigation of membrane fouling and elemental analysis on foulants. AFM provides information on membrane roughness. Contact angle represents hydrophobicity on membrane surface.

SWOM can be removed by applying different pretreatment processes to SWRO. Conventional pretreatment includes coagulation, filtration and activated carbon, whereas microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) are recently used as advanced pretreatment. In this study, different physico-chemical pretreatment methods were evaluated in terms of their capability in removing SWOM. Membrane autopsy was also investigated on the SWRO membrane surface after various pretreatments.

2. Materials and methods

Seawater. This study was conducted with seawater drawn from south-western Korea (approx. N35°4′56′, E126°26′26′). The typical seawater characteristics were found (pH = 8.10; conductivity = 48.9 mS/cm; total dissolved solid = 32,827 mg/L; turbidity = 0.4 NTU; specific UV absorbance (SUVA) = 1.28, SWOM = 1.56 mg/L; and alkalinity = 78 mg/L as $CaCO_3$).

Pretreatment methods. Flocculation was carried out using an optimum dose of ferric chloride ($FeCl_3$ = 20 mg/L) predetermined by standard jar tests. The seawater was placed in a 1 L container and an optimum dose of ferric chloride was added. The sample was stirred rapidly for 1 min at 100 rpm, followed by 20 min of slow mixing at 30 rpm, and 30 min of settling. The characteristics of the PAC (James Cumming & Sons Pty Ltd., Australia) are given elsewhere