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Foulant characterization and distribution in spiral wound reverse osmosis membranes from different pressure vessels

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HIGHLIGHTS

- Membrane autopsy of BWRO spiral wound module from the different pressure vessels was performed.
- The major foulant on spiral wound RO membranes was the fulvic acid from raw ground water.
- The inorganic components including Fe and Al, which can react with fulvic acid, also partly led to the membrane fouling.
- Much more foulants were observed on the back side of the membrane leaf than on the front side.

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ABSTRACT

In this study, the origin and extent of membrane fouling on spiral wound module (SWM) elements from different pressure vessels and the distribution of membrane foulants inside the SWM elements were systematically investigated using the membrane autopsy methods. Three fouled SWM elements from different pressure vessels were examined for a quantitative and qualitative comparison of membrane foulants. Results obtained indicate that a major contributor to membrane fouling were fulvic acid components, consisting of small, hydrophilic compounds from the raw groundwater. A small amount of inorganic components such as Fe and Al, which can form a complex structure with fulvic acid, also partially contributed to the membrane fouling of lead elements in first pass RO vessels. In particular, through the elemental comparisons of two sheets (both sides) of fouled membranes obtained from identical positions of a membrane leaf, the distribution of membrane foulants inside the SWM elements was fully evaluated. Based on the data obtained, much more organic and inorganic foulants were accumulated on the back side of the membrane leaf than on the front side. Overall, these results would help improve understanding of fouling behavior inside membrane modules and pressure vessels.

1. Introduction

Spiral wound module (SWM) elements have been successfully used in desalination and water treatment plants worldwide. In particular, 65% of desalination plants have applied reverse osmosis (RO) processes, with most RO desalination plants adopting spiral wound-type RO membrane modules [1]. The use of these modules is attributed to their high packing density and ease of operation and fouling control, compared to membrane modules such as hollow fiber and tubular modules. Since the invention of SWM RO elements in 1963, continuing improvements have been carried out in terms of functionality and economic feasibility. The normalized water productivity of SWM RO elements has doubled from 1980 to 2000, while there was a corresponding sevenfold decrease in cost [2]. Because of the development of SWMs, the overall performance of desalination plants has significantly improved, with membrane-based desalination plants becoming the major water supply systems in the Middle East.

Factors including membrane materials, membrane leaf geometry (length and width), spacers (type and dimension), fouling propensity, and cleaning ability, optimizing the operation conditions and positioning of SWM elements in pressure vessels has the potential to further

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improve the performance of SWM-based RO plants [3]. Even though there have been extensive improvements in SWM elements, they still suffer from membrane fouling. However, due to the intrinsic complexities of SWM elements and membrane fouling, components and characteristics of membrane fouling and the cleaning efficiency of SWM elements remain unknown. In particular, research related to the actual transport and hydrodynamic phenomena of membrane foulants inside SWM elements and pressure vessels has been insufficient and only evaluated by means of modeling tools [4,5]. Although some researchers have reported on inorganic scaling inside SWM elements based on experimental results obtained from microscopy and 3D computational fluid dynamics (CFD) [6,7], interactions between organic contaminants and the membrane surface of SWM elements remain uncertain. In summary, a better understanding of the transport and distribution of membrane foulants inside the SWM elements is of primary importance in order to improve the operation of SWM-based water treatment plants.

The most efficient method for investigating membrane fouling and the overall performance decline has been to conduct a membrane autopsy; membrane autopsy studies are common for seawater desalination and wastewater reclamation plants [8–13]. Analytical methods for explaining the morphology of a fouled membrane surface have commonly been applied, such as the distribution of organic/inorganic and biological components onto the fouled membrane, with results usually combined with process water quality results in attempts to comprehensively understand membrane processes. The advantage of membrane autopsies is that accurate information about the composition and properties of membrane foulants and fouling mechanisms under operation conditions could be obtained. In addition, more efficient membrane elements could be developed, in addition to plant operation and maintenance technologies, by complementing the membrane autopsy results. However, physicochemical results from the membrane autopsy have been restricted to a quantitative analysis of the fouling layer, not a fundamental understanding of fouling layer formation and of foulant distribution inside the SWM elements.

The main objective of this research is to investigate the cause of membrane fouling and foulant distribution inside SWM elements from the different pressure vessels. Here, fouled membranes obtained from several SWM elements and pressure vessels are analyzed and associated with process water quality results. To date, there has been little—if any—research conducted using membrane autopsy technology to investigate membrane foulant distribution on both sides of a membrane leaf inside a spiral wound RO module. By determining the distribution of foulants inside the SWM elements, improvements for the prevention and cleaning of membrane foulants inside SWM elements could be established.

2. Experimental

2.1. Description of brackish water reverse osmosis plant and SWM element

The desalination plant had been in service for nearly 5 years producing drinking water with a capacity of 170 m^3/day. Fig. 1 presents the schematic diagram of the brackish water reverse osmosis (BWRO) desalination plant used to produce drinking water using raw groundwater. This BWRO plant was composed of an intake tank, pretreatment systems (sand filtration, ion exchange resin, and microfiltration (MF)), two-pass BWRO systems, UV disinfection devices, and a product tank. The first RO pass consisted of four pressure vessels, each composed of six SWM elements; the second RO pass was composed of three vessels, each having four SWM elements, at a staging ratio of 4:3. The concentrate streams of first and second RO passes (shown as dotted line in Fig. 1) were recycled to their feed streams for high recovery. To compare the water quality and performance of the desalination processes, three water samples (raw groundwater, pretreated water, and permeate from the first BWRO pass) were collected and analyzed in terms of inorganic, organic, and microbial components.

The BWRO membrane used in this study was an 8-inch SWM element (BW30-400, FilmTec, USA) having 28 mil feed spacers. From the manufacturers, the permeate flow and salt rejection of the membrane elements under the standard conditions were 27.7 L/min and 99.5%, respectively (standard conditions: 2000 ppm NaCl, 225 psi (1.6 MPa), 77 °F (25 °C), pH 8, and 15% recovery). The BWRO SWM elements used in the study were composed of several leaves, made by gluing the three edges of two RO membrane sheets to each other. The remaining edge of the membrane sheets was then stuck onto the water collection pipes to gather the permeate water. In this way, the pretreated water can be filtered by both sides of the RO membrane sheets, and foulants can contaminate both sides of the membranes inside the SWM elements. After unpacking a rolling SWM leaf, the upper side of the membrane leaf was referred to as the front side and the other side was the back side.

2.2. Preparation of fouled BWRO membranes

2.2.1. Selection of SWM elements

To investigate the origin and propensity of membrane fouling occurring in SWM elements from different vessels, three membrane elements were extracted from the pressure vessels. In Fig. 1, the second membrane element in the first BWRO pass (denoted herein as element 2) and the first and third membrane elements from the second BWRO pass (denoted herein as elements 7 and 9) were extracted for the

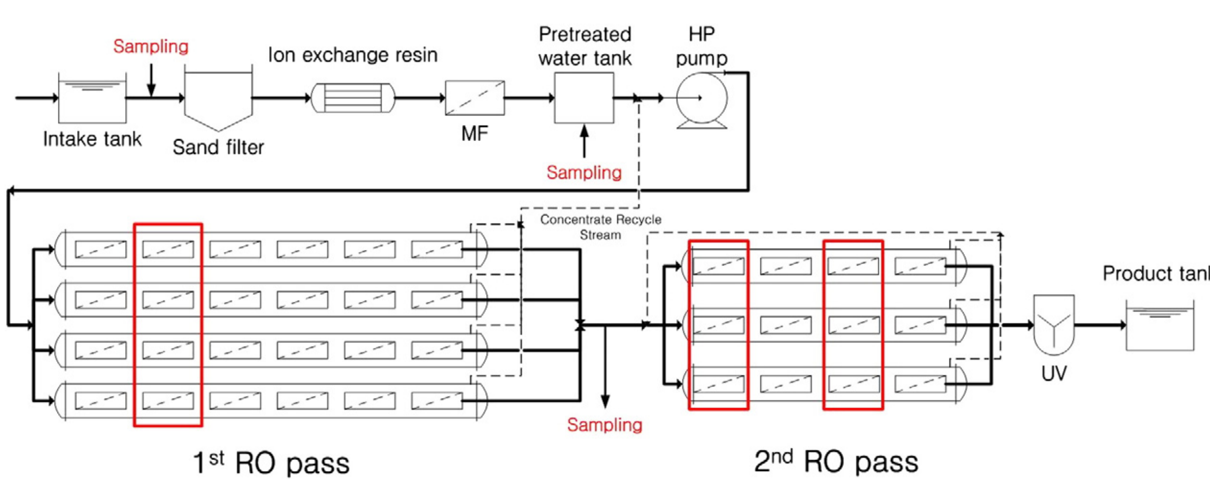

Fig. 1. Schematic diagram of BWRO plant.