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Effect of feed spacer thickness on the fouling behavior in reverse osmosis process — A pilot scale study

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HIGHLIGHTS

- Long term pilot test with RO modules applied different feed spacers was conducted.
- Membrane fouling mitigation effect of thicker feed spacer was validated.
- Fouling load distribution effect of thicker feed spacer case was investigated.
- Fouling intensities were compared by instrumental analysis of membrane coupons.

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ABSTRACT

The performance deterioration of RO membrane processes caused by the accumulation of rejected solutes on membrane surface is an inevitable phenomenon in membrane processes. The feed spacer in spiral wound reverse osmosis (RO) membrane modules can provide the structural support to keep feed channel open and also allow turbulent flow to mitigate solute concentration build-up at the vicinity of membrane surface. The objective of this study was to investigate the effect of feed spacer thickness on both membrane fouling behavior and cleaning efficiency in a pilot test during a 659 h operation. Furthermore, fouling load distribution was studied by measuring normalized differential pressure of individual elements in pressure vessels. Foulant analysis according to feed spacer thickness was also conducted to compare fouling propensities. This study showed that a thicker feed spacer could reduce membrane fouling and subsequently decrease membrane cleaning frequency and allow an even fouling load distribution along the modules installed in a pressure vessel.

1. Introduction

Reverse osmosis (RO) is a demineralization process using semipermeable membrane to separate the dissolved solids from solution. The semipermeable membrane allows liquid and some ions to pass, but rejects the majority of the dissolved substances. RO membrane process has been proven to be the most economically feasible separation technology not only for the desalination of seawater, but also for purifying surface water contaminated with heavy metals, pesticides and other micro-pollutants. Furthermore, the applications of RO process include food and beverage processing along with recycling wastewater and reclaiming valuable resources from industry waste streams. However, there are still demands on RO process such as reducing operational cost, prolonging membrane life, and improving membrane module and system configuration designs [1–13]. Incorporation of functionalized feed spacer in RO module can accomplish some of these demands.

Spiral wound membrane modules are the most common type of RO module used for today. The major benefit of spiral wound module is the moderately dense packing density higher than, for example, plate and frame or tubular modules. Due to a relatively high surface-to-volume ratio, spiral wound module has a high productivity per unit volume. Spiral wound module contains several flat membrane envelopes that are sandwiched between feed spacers and are then rolled around a perforated central tube. Feed spacer in spiral wound module is the plastic netting or mesh between the membrane leaves, and it provides a space or flow channel for the water to pass over the membrane surface. The feed spacer also can be referred as mesh spacers, channel spacers or feed channels [1,2] and it provides favorable mass transfer and mixing behavior, hence reducing membrane fouling.

It is well known that feed spacer geometry and surface characteristics have a major impact on spiral wound RO membrane performance. Many studies considering the effect of feed spacer on RO membrane performance have been conducted in terms of permeate flux, salt rejection, and fouling propensity. Most of these studies were mainly intended to (1) estimate the effect of feed spacer surface modification

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on fouling resistance [14–17], (2) investigate the effect of feed spacer geometry on membrane performance in terms of permeate flux, salt rejection and fouling susceptibility [14,18–23], and (3) perform simulation studies on fluid dynamics with regard to feed spacer geometry allowing interpretation of solutes and membrane surface interactions [16,24–34]. Previous studies have shown that the thicker feed spacers may influence the hydrodynamics of flow to provide turbulence at the membrane surface and eventually lower concentration polarization [1, 2,18,19,23,32]. The majority of these studies, however, were primarily based on laboratory tests using membrane coupons or intended to monotonically compare fouling rate with feed spacers having different characteristics. A more thorough study about feed spacer thickness is necessary for a better understanding of the feasibility of thicker feed spacer for spiral wound RO membranes.

The objective of this study was to run a long-term performance test of RO system with two types of feed spacers with different thicknesses and evaluate the effect of the feed spacer thickness on performance of the system and individual elements. At first, the performance of RO system was monitored throughout the test period in terms of normalized differential pressure and normalized salt rejection. Fouling inclination trends and cleaning efficiencies were also estimated within this period. After finishing the pilot test, the fouling distribution of the elements of a pressure vessel was investigated to directly compare the fouling propensity with regard to feed spacer thickness. Finally, RO module autopsy study was conducted to further compare the fouling intensities [35,36].

2. Materials and methods

2.1. Detailed description of the pilot test

Mobile RO filtration system with two independent sets of pressure vessels located in A Steel (Dangjin City, Korea) was used for the pilot test. The schematic of the pilot testing mobile long-term test machine is shown in Fig. 1. The system was operated in a single feed pass mode that allowed parallel evaluation of two pressure vessels each equipped with a separate type of RO elements. Each pressure vessel housed three 8-in. diameter RO elements in series having an effective are of 380 square-feet. The RO elements in vessel A used a 34-mil feed spacer, and the elements in vessel B used a 28-mil spacer (Table 1). The mil, which is widely used in measuring the diameter of fiber strands, is a length unit equal to one thousand of an inch (1-mil = 0.0254 mm). The elements in vessels A and B all had the same membrane type, effective area, composing materials and so on, and were identical except for the feed spacer thickness. Almost all feed spacers used in commercial RO membrane manufacturing are extruded netting which are made by two sets of intersecting strands. Strand spacing, angle and diameter are critical design parameters of feed spacer. Strand diameter, which determines the spacer thickness, was solely varied in this study (Fig. 2). The configuration in this study was intended to simulate the first stage of a three-staged commercial RO system used for producing cooling water from a conventionally-pretreated surface water. In multi-staged RO system, the concentrate of the preceded RO stage becomes the feed water for the following RO stage. A multi-staged RO system is suitable for a high water recovery treatment system.

2.2. Long-term filtration testing

The pilot system was operated at a constant flux and recovery but in variable pressure mode. The feed water, which passed through 5.0-μm microfilter, was fed into 2 pressure vessels.

The RO membrane fouling was evaluated by monitoring the increase in the normalized differential pressure to keep the same flux and recovery. Membrane performance deterioration due to fouling was expressed as normalized differential pressure (NDP) variation trend.

$$\text{Differential pressure (DP)} = P_f - P_c$$

P_f	Feed pressure
P_c	Concentrate pressure

$$\text{Normalized differential pressure (NDP)} = DP_1 \times \left((2 \times (Q_{f0} - Q_{p0}) + Q_{p0})^{1.5} \right) / \left((2 \times (Q_{f1} - Q_{p1}) + Q_{p1})^{1.5} \right)$$

DP_1	Differential pressure at certain point of time
Q_{f0}	Feed flow rate at the initial start up
Q_{p0}	Permeate flow rate at the initial start up

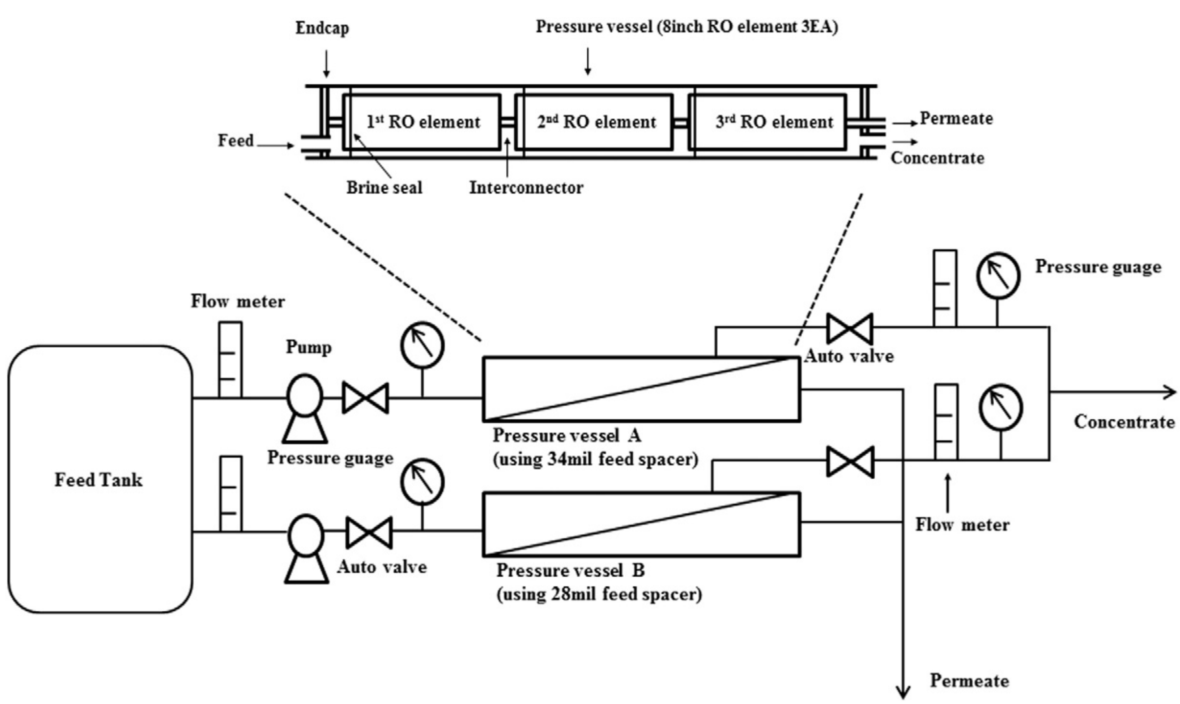

Fig. 1. Schematic diagram of mobile long-term test machine.