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Effect of microbubbles on microfiltration pretreatment for seawater reverse osmosis membrane

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HIGHLIGHTS

- The microbubble process can be used as a pretreatment of seawater desalination. However, particle removal is more efficient for bigger particles rather than small ones (<10 μm).
- The removal efficiency is mostly enhanced by the addition of a small amount of ferric chloride during the process.
- Mbs can contribute to reducing the fouling on MF membranes when combined (Mbs–$FeCl_3$–MF).

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ABSTRACT

This study focused on the application of microbubbles (Mbs) to microfiltration (MF) pretreatment for reverse osmosis (RO) desalination. Experiments were performed using seawater as the feed water to a microfiltration system. Mbs, which were generated by a pump under 4 bars of pressure, were applied prior to MF treatment. The MF flux was adjusted from 15 L/m^2/h to 45 L/m^2/h. The effect of coagulant addition to the Mbs reactor on the MF efficiency was also examined. Results indicated that Mbs without using coagulant were not effective to regard MF fouling. Although the turbidity of the water decreased, the fouling rate increased after the Mbs treatment. This is attributed to an increase in the fraction of small particles, which lead to an increase in specific cake resistance by decreasing the particle size. Combined with coagulation, microbubbles showed a higher ability to control MF fouling. The removal of small particles (<10 μm) was also improved and the formation of cake layer was suppressed. The SDI_5 was maintained low when seawater was pretreated with a combination of coagulation–microbubble–microfiltration.

1. Introduction

As water resources are being depleted, seawater desalination has attracted increasing interest during the last decades [1–3]. Reverse osmosis (RO) is currently a major technology for seawater desalination due to its lower energy consumption than distillation-based technologies. However, one of the most serious challenges of RO is a loss of permeability decline and an increase in energy consumption due to membrane fouling [4,5]. Accordingly, the key to successful operation of RO is the selection of appropriate pretreatments for seawater to reduce fouling and maintain high permeability.

The pretreatment method must be selected according to the quality of the seawater to be treated [6]. Conventional pretreatment methods including dual media filtration (DMF) are widely accepted if the quality of seawater is moderate. Membrane-based pretreatment methods such as microfiltration (MF) and ultrafiltration (UF) are used if the seawater contains substantial amounts of foulants. In general, the quality of pretreated seawater by MF or UF is higher than that by DMF [4,7]. Nevertheless, one of the drawbacks of MF or UF is membrane fouling [8,9], which occurs by the deposition of colloidal, particulate, and dissolved organic and inorganic matters contained in the seawater [10]. Accordingly, the combination of MF/UF with other water treatment processes is recommended because it allows a reduction in fouling.

One of the available treatment processes is flotation, which is useful for fine particle separation [11–14]. In the flotation process, particle size and bubble size are the dominant physical factors affecting the removal efficiency of particles. This is why microbubbles (Mbs) are desirable. Mbs are tiny, negatively charged bubbles with a diameter of approximately tens of microns (the maximum size is <100 μm) and the ability

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to attach themselves to particles and float the bubble particle to the surface of the water for removal [11,15]. They have been found to increase the probability of particle–bubble collision [16] and have a much smaller footprint [7]. Mbs can completely encircle the pollutants, bringing them to the surface to be easily removed [17,18]. When Mbs collapse, free radicals are released into the water [19–21] as a result of the high density of ions at the gas–liquid interface and may degrade contaminants present in water. Moreover, it can be combined with coagulation to improve the water quality of treated water [22].

Although several studies have demonstrated the effectiveness of floatation in minimizing the fouling of wastewater when combined with MF [23–25], there is no report on the effect of Mbs on a MF system for a seawater RO system. Therefore, the objective of this research was to examine use of Mbs prior to MF for improving MF performance as a pretreatment for a seawater RO system, to understand the effect of Mbs on seawater quality and MF membrane fouling propensity, and to determine the suitable combination of Mbs and coagulation to reduce MF and RO fouling.

2. Materials and methods

2.1. Source of seawater

Seawater was collected from the western coast of Korea at Wolmido Island and stored at room temperature (22 ± 2 °C) prior to all tests. The turbidity, UV_{254}, and pH of the seawater were 41.03 NTU, 0.033 cm^{-1}, and 8.2, respectively. The total dissolved solid (TDS) was 30,000 mg/L.

2.2. Mbs operating conditions

Fig. 2 shows the schematics of the bench-scale Mbs and MF system. There were two phases: the first phase was the Mbs treatment and the second phase was the MF treatment. (See Fig. 1.) (See Fig. 3.)

The Mbs treatment system consists of a feed tank, a floatation tank, a high-pressure gas cylinder, and an Mbs generator. An acrylic column with an internal diameter of 30 cm and an effective height of 90 cm was used as the feed tank for Mbs treatment. The volume of water used was 40 L. In the reactor, flotation was continuously conducted with a constant water flow rate of 8 L/min and a gas flow rate of 0.64 L/min using suction pumps and a Toshiba 3 phase induction

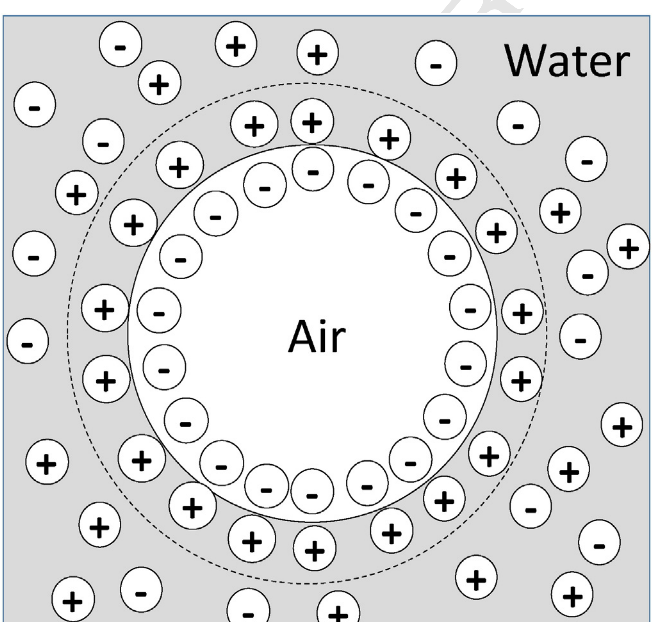

Fig. 1. Schematic view of the air bubble in aqueous solution.

motor (KTM15N1D042M-000). Mbs were generated using a gas–water circulation type generator, and fed at the bottom of the tank under a specific pressure of 4 bars. This allowed releasing a large amount of bubbles with an approximate diameter of 8 μm in the flotation column. The flotation was operated in continuous flow mode during 15 min. Intermittent samples (7 min flotation and sampling) were taken. Three (3) samples were obtained after all tests.

Two series of Mbs tests, without and with coagulant addition, were also conducted. Ferric chloride ($FeCl_3$) was used as the coagulant because it is widely applied for seawater treatment [26]. Prior to the Mbs experiments, the optimum dosage of $FeCl_3$ was determined through a jar test, which was found to be 2 mg/L.

2.3. Microfiltration experiment method

2.3.1. MF experimental setup

A schematic diagram of the experimental setup for MF used in this study is shown in Fig. 5. The system includes submerged hollow fiber MF modules and feed tanks containing the pretreated water. As shown in Fig. 6, each membrane was connected to a pressure transducer to continuously monitor transmembrane pressure.

The operating conditions for the MF test are summarized in Table 1. A polyvinylidene fluoride hollow fiber membrane (LG Electronics, Korea) was used in a dead-end configuration. According to the manufacturer, the membrane was prepared by thermally induced phase separation (TIPS). First, prior to microfiltration, the fibers were wetted with ethanol for approximately 30 min and then rinsed with pure water. Next, the membranes were vertically immersed in a 1 L feed water tank. In each tank, a magnetic stirrer was used for continuous mixing of the feed water. The pure water permeability was measured using the de-ionized water and then the filtration experiments were carried out using the feed water. A multichannel cartridge peristaltic pump (model 7535-08, Cole Palmer, USA) was used to provide sufficient suction pressure to the membranes.

The filtration experiments were conducted under the constant flux mode. The transmembrane pressure (TMP) was monitored by a pressure transducer attached to each membrane module. The MF system was operated at three different fluxes. The flux was first set at 15 L/m^2/h and then raised in 15 L/m^2/h increments every 2 h until the last one at 45 L/m^2/h. The variation in TMP measurements was used to express the degree of membrane fouling. All data were collected in the LAB-View 2011 program, a data acquisition software program employed to continuously log data during the process.

2.3.2. Theoretical model of membrane fouling

Membrane fouling is a common problem in most membrane processes, which results in loss of permeability [27]. In this study, we applied a simple filtration model to estimate the fouling rates in the dead end of MF. As a simple quantification of membrane fouling, a pseudo-cake filtration model was adopted for simple analysis of data using a modification of Darcy's equation:

$$\Delta P = \mu(R_m + R_c)J \tag{1}$$

where J is the permeate flux, ΔP is the transmembrane pressure, μ is the absolute viscosity of water, R_m is the clean membrane resistance, and R_c is the cake resistance. The cake resistance is given by the following formula:

$$R_c = \frac{\alpha m_c}{A_m} \tag{2}$$

where α is the specific cake resistance, m_c is the mass of the cake deposited on the membrane, and A_m is the membrane area. Here m_c is proportional to the flux of the foulants.

$$m_c = J A_m c t \tag{3}$$

where c is the effective foulant concentration.

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