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Fouling and scaling reduction by pulsed electric field treatment as pretreatment for desalination

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ABSTRACT

This study was conducted to investigate the applicability of pulsed electric field (PEF) treatment for the prevention of scaling formation and membrane fouling reduction as the pretreatment of reverse osmosis desalination. To validate the effect of the PEF and to identify the mechanism, a series of experiments with and without the PEF treatment were carried out. All the precipitated crystals in solution were calcite and there were slight differences between with and without the PEF by X-ray diffraction analysis. A rapid particle growth was observed in the case of the PEF treatment. Permeate volume and permeation flux were higher than those without the PEF case. The new PEF method presents an effective tool to mitigate $CaCO_3$ fouling as a pretreatment of membrane filtration.

Keywords: Pulsed electric field; Desalination; Pretreatment; Scaling; Fouling

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1. Introduction

Scale formation on surfaces of membrane or pipes presents a critical concern in industrial operation and maintenance. The scale formation is commonly called as mineral fouling. In particular, calcium ions reacting with carbonate ions in water form layers of $CaCO_3$ deposit on surfaces, decreasing the efficiency of the system because of the insulating effect of the deposits. Furthermore, the formed deposits reduce the flow area, thus requiring more energy consumption to achieve the flow rate of water corresponding to the clean state [1]. A 0.8-mm layer of $CaCO_3$ scale can increase the energy use by about 10% [2]. There are several methods to help lessen, control or prevent the scaling of heat exchangers, which can be primarily divided into two: chemical and non-chemical methods. In the past, the use of scale-inhibiting chemicals like chlorine and brominated compounds was the best choice for the control of mineral fouling. Although it had a high success rate, there were also many disadvantages and concerns in their use. Aside from the high cost of chemicals, more stringent environmental regulation increased the costs associated with their storage, handling and disposal. These chemicals or accumulated chemical residues over a long period of time also pose concern to the environment with accidental spills. Thus, there is a need for a new approach that is safe and clean from both environmental and

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cost points of view in the process. It is reported that the combined use of electromagnetic treatment and filtration using a 5 μm pre-size filter could prevent scaling and keep the maximum heat transfer rate almost constant [3–6]. Based on the above background, this study focused on the effect of scaling prevention in artificial hard water by the application of pulsed electric field (PEF) treatment.

2. Materials and methods

2.1. PEF treatment system

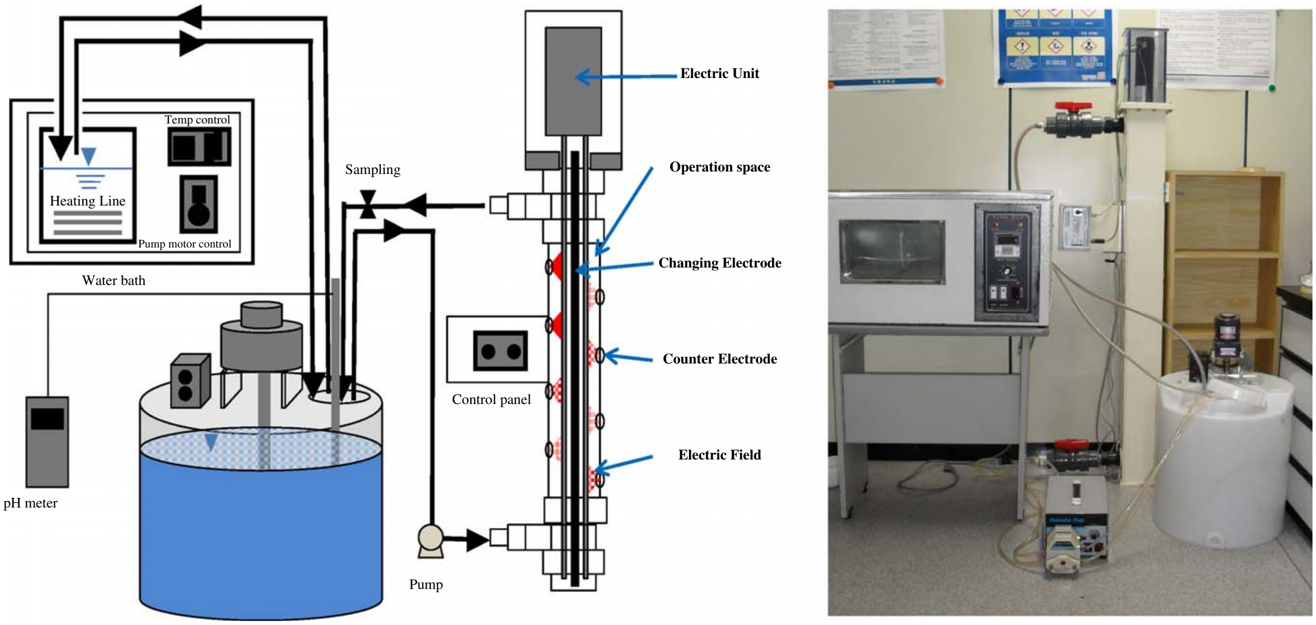
The schematic diagram of PEF treatment system is shown in Fig. 1. It was composed of a water bath for temperature control, a peristaltic pump, an electric and a switch panel and a beaker with artificial hard water. A hard water tank was made of glass with a working volume of 40 L. The applied voltage and hertz in the system were kept at 30 kV and 50–60 Hz, respectively, based on the previous experimental results for the determination of optimal voltage in bacterial inactivation, membrane fouling reduction and coagulation test [7]. Membrane (Membrana Accurel®, Germany) used in the experiment for the evaluation of fouling reduction by the PEF treatment has a nominal pore size of 0.2 μm and is made of hydrophobic polypropylene of the capillary type. The effective filtration area is 1,178 cm^2. The sampling was conducted at 10, 20, 40 and 80 cycle for the analysis. A cycle means the one circulation of prepared hard water through PEF treatment system. The temperature of prepared hard water was maintained at 25°C ± 1 by a water bath.

2.2. Preparation of artificial hard water and maintenance

Since calcium carbonate crystals do not dissolve easily in water, the simulated hard water was used as the test solution. Artificial hard water is prepared with a mixture of sodium bicarbonate ($NaHCO_3$, Shimakyu Co., Ltd, Japan) and calcium chloride ($CaCl_2$, Deoksan Chemicals Co., Ltd, Korea). The dosage of chemicals is 0.56 g/L of $CaCl_2$ and 0.84 g/L of $NaHCO_3$, respectively. The hardness was kept at 500 mg/L as $CaCO_3$ hardness. All chemicals used in the experiment were of analytical grade. After each test, a hard water tank was cleaned thoroughly. After each experiment, traces of $CaCO_3$ agglomerated deposits were drained out of the tank. No chemicals were added during the cleaning process. Used artificial hard water was completely drained, a tap water jet using a horse was then flushed onto the inside wall of tank together with a cleaning brush to remove any scales formed inside the tank.

2.3. Analysis

The concentration of calcium ion was measured by Atomic Absorption Spectrophotometer (Perkin Elmer,



(a) (b)

Fig. 1. Schematic diagram of PEF treatment system (a) and photograph (b).

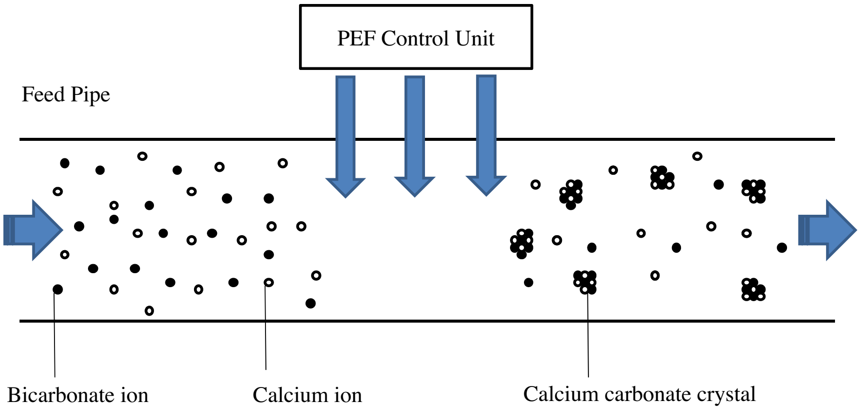
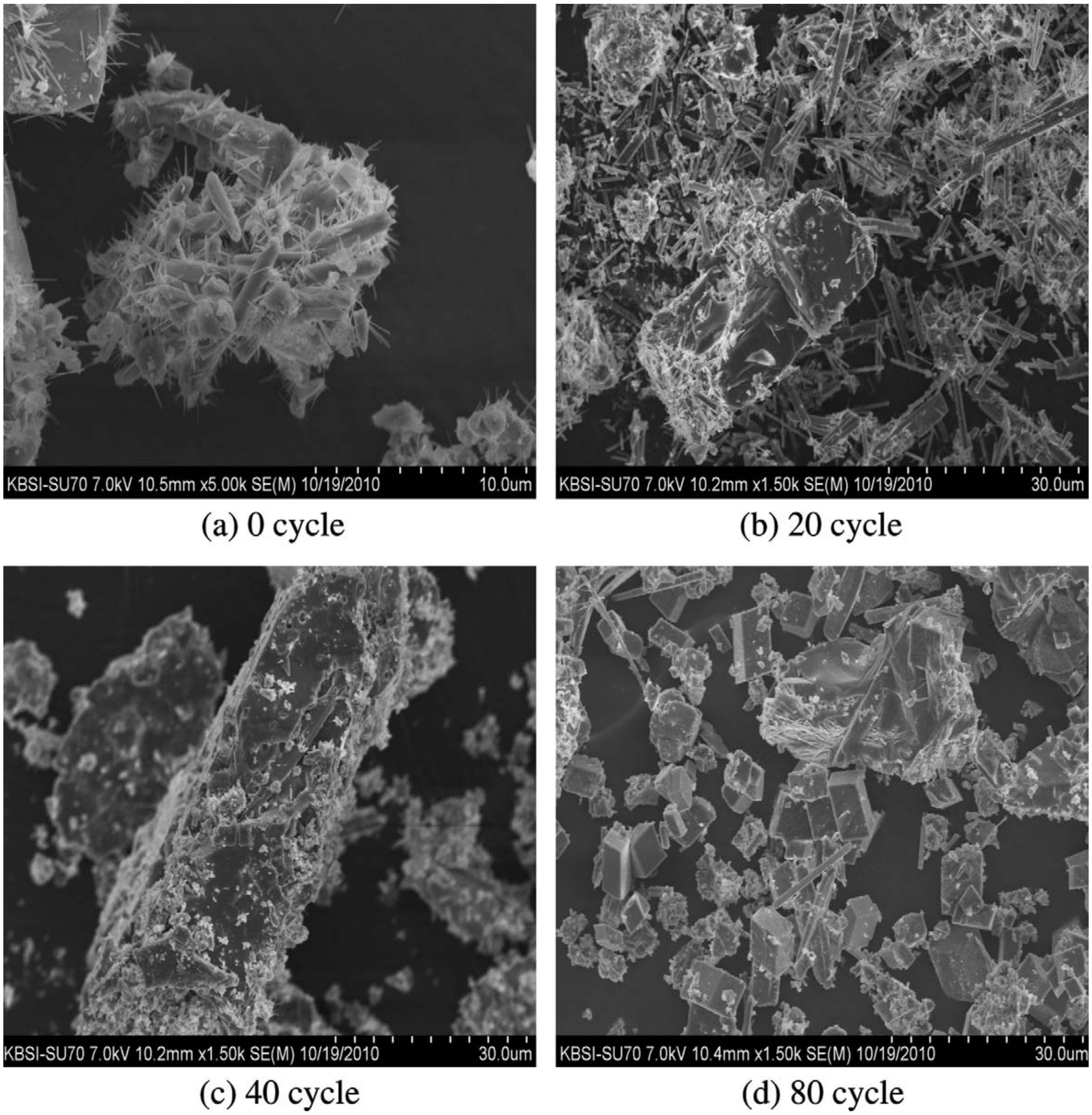


Fig. 2. Schematic diagram of a PEF treatment unit.



(a) 0 cycle
(b) 20 cycle
(c) 40 cycle
(d) 80 cycle

Fig. 3. SEM images at without (0 cycle) and with the (20, 40 and 80 cycles) PEF treatment.

AAnalyst 700, USA). The crystal structure of $CaCO_3$ was measured by scanning electron microscope (SEM) (Hitachi, Hitachi SU-70, Japan) and X-ray diffraction (XRD) (PANalytical, Xpert Pro MPD, Netherlands). Particle size distribution was measured by Malvern, Master-Sizer 2000, England.

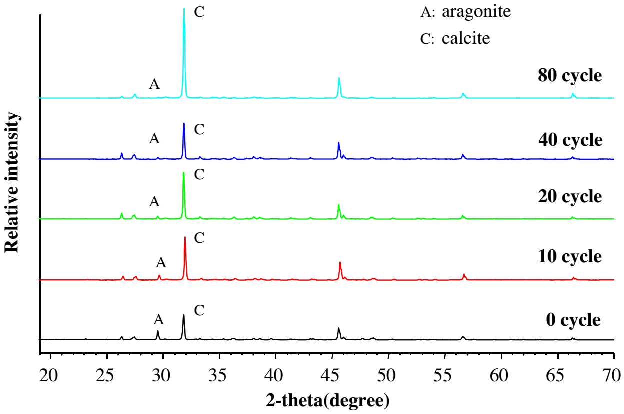


Fig. 4. XRD analyses of the scales without PEF and with PEF treatment cases at 500 mg/L as $CaCO_3$ hardness.

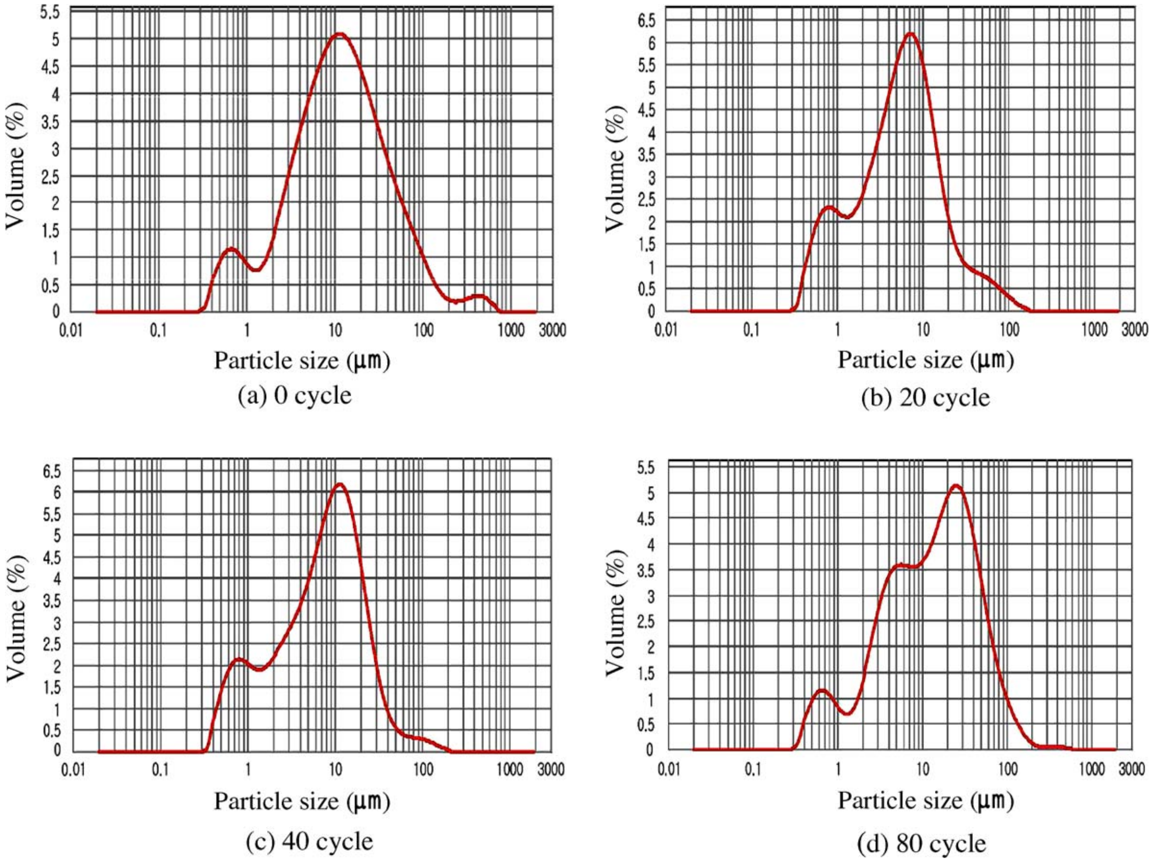
2.4. Mechanism of PEF

Fig. 2 shows a schematic diagram of the PEF treatment unit. The PEF unit produces a pulsing current to create an electric field inside the feed pipe. The induced electric field, which oscillates with time, provides molecular agitation for charged mineral ions, that is, the dissolved mineral ions of calcium and bicarbonate collide and precipitate with the help of impurities in water [8]. Since the combined surface area of the calcium carbonate particles can be greater than the surface area of the equipment, the fouling at the equipment surface can be mitigated and prevented.

3. Results and discussion

3.1. SEM images

In order to validate the PEF treatment, SEM was used to visualize the crystal structure of the scales. Fig. 3 shows the SEM images of $CaCO_3$ crystal formed without (corresponds to 0 cycle) and with the PEF treatment at 20, 40 and 80 cycles.



(a) 0 cycle

(b) 20 cycle

(c) 40 cycle

(d) 80 cycle

Fig. 5. Particle size distributions as a function of treatment cycle.

Table 1
Average concentration of calcium ion in solution after filtration using a 0.1 μm filter

PEF cycle	Measured No.	Concentration after dilution (mg/L)	Dilution	Average concentration (mg/L)	Standard Deviation	% RSD
0 cycle	1	0.899	100.6	91.8	0.012	1.333
	2	0.912				
	3	0.923				
10 cycles	1	0.632	98.2	62.5	0.004	0.641
	2	0.637				
	3	0.640				
20 cycles	1	0.515	98.8	52.5	0.010	1.969
	2	0.534				
	3	0.531				
40 cycles	1	0.365	95.4	35.9	0.011	2.879
	2	0.385				
	3	0.382				
80 cycles	1	0.208	99.2	20.5	0.002	0.777
	2	0.208				
	3	0.205				
Correlation Coefficient			0.999			

The SEM photographs of the scales formed without the PEF treatment (Fig. 3(a)) revealed that $CaCO_3$ scales were mainly aragonite, while the scales formed with the PEF treatment (Fig. 3(d)) present quite a different structure. There showed lots of calcite phase being of rhombohedral shape in the crystal scales produced with the PEF treatment. It can be speculated that small-size $CaCO_3$ particles were initially produced in the bulk water by the PEF and they eventually grew in size. The sharp and pointed crystal tips could have increased the attachment capability of the deposit to adhere on the membrane surface more strongly than blunt crystals for PEF cases. XRD analyses given in Fig. 4 confirm the crystal structures. The needle-like structures at no-PEF treatment case suggest that the crystals might have grown directly on the membrane surface through crystallization reaction with additional ions [9].

Fig. 4 shows the results of XRD analyses for 0–80 cycles of PEF treatment. Calcite peak intensity increased with treatment cycle, while the peak of aragonite corresponding to $2\theta = 29$ decreased with cycle. In general, the aragonite is a more troublesome form of calcium carbonate than the calcite, because it forms a harder and denser deposit than the calcite. This XRD result supports the SEM images given in Fig. 3. From the results, it is believed that the PEF treatment may be effective for the prevention of scale formation.

Fig. 5 presents the particle size distribution in solution as a function of treatment cycle. The *x*-axis stands for the particle size and the *y*-axis stands for the volume percentage of particles. From the curve of parti-

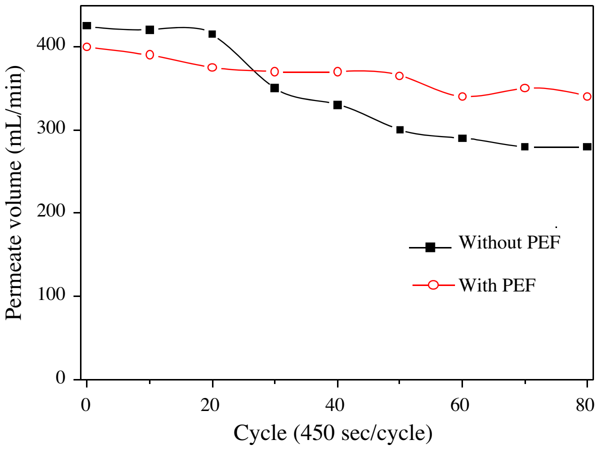


Fig. 6. The variation of permeate volume as a function of treatment cycles (Conditions; filtration pressure 80 kPa, temperature 25°C, pore size 0.2 μm).

cle size distribution, we can understand that the volume percentage of particles greater than 10 μm increased with treatment cycle. Table 1 shows the average concentration of calcium ion in solution after filtration using a 0.1 μm filter. The average concentration of calcium ion in solution at 0 and 80 cycles was 91.8 mg/L as $CaCO_3$ and 20.5 mg/L as $CaCO_3$, respectively. It decreased by 78% from the values. Due to the fact that the PEF treatment effectively increases to total ion collision frequency and effectiveness of the collisions by utilizing the induced PEF treatment at 25°C, the precipitation process in solution is much faster and more effective.

Fig. 6 shows the variation of permeate volume of membrane in the case without the PEF treatment and with the PEF treatment as a function of treatment cycle. The decreased rate of permeate volume without the PEF indicated a greater value than that with the PEF case. The permeate volume without the PEF treatment case dropped by about 26% compared with that obtained with the PEF treatment. The PEF treatment is considered to be an effective method for the fouling reduction that is caused by the scale formation on the membrane surface.

4. Conclusions

This study focused on the effectiveness of a new physical water treatment method using PEF for the reduction of calcium carbonate fouling in membrane filtration system. The SEM photographs of the scales formed without the PEF treatment revealed that $CaCO_3$ scales were mainly aragonite, while the scales formed with the PEF treatment showed lots of calcite phase.

Particle size of mineral compounds increased with respect to the treatment cycle, which means that it is favorable for the reduction of calcium carbonate fouling in membrane filtration system. The permeate volume without the PEF treatment case dropped by about 26% compared with that obtained with the PEF treatment. Based on the above experimental results, it is concluded that the novel PEF treatment technology as pretreatment is an effective method to mitigate mineral fouling in membrane filtration system.

Acknowledgements

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