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Effect of electromagnetic field on membrane fouling in reverse osmosis process

Mohammad Rouina [a], Hamid-Reza Kariminia [a,*], Seyyed Abbas Mousavi [a], Eshaq Shahryari [b]

[a] Department of Chemical and Petroleum Engineering, Sharif University of Technology, P.O.Box: 11155-9465, Azadi Ave., Tehran, Iran
[b] Bikaran Ab Mahna Co., P.O.Box: 74431-56868, Maaliabad Ave., Shiraz, Iran

HIGHLIGHTS

- Investigating the effect of electromagnetic field (EMF) on membrane salt rejection, membrane pressure drop and deposits formed on membrane for the first time.
- Applying EMF on the surface of RO membranes significantly increased the performance of the membrane
- Applying EMF caused a delay in the formation of concentration polarization layers on the membrane surface
- Applying EMF increased the nucleation of anions and cations in the bulk fluid and created soft and powdery crystals

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ABSTRACT

In the present study, the effect of electromagnetic field on the salt and water transport and reduction of carbonate deposit during reverse osmosis desalination was investigated. The electromagnetic field was generated by AC current through a solenoid wound around the membrane separation module. The current intensity and frequency was 25 A and 50 Hz, respectively. Experiments were conducted using $CaCO_3$ solution at the concentration of 5.5 mmol/L. For comparison purposes, desalination by the membrane, in the presence and absence of an electromagnetic field was conducted. While the desalination process temperature was kept constant, the product temperature increased by less than 2 °C when the electromagnetic field was applied. The system performed sustainably when it was exposed to the electromagnetic field. During the experiments, salt rejection, permeate flow rate and membrane pressure drop were compared in the presence and absence of an electromagnetic field. Moreover, scanning electron microscopy (SEM) was used to investigate the morphology of the precipitates. It was found that the salt rejection and permeate flow rate increased when the electromagnetic field was applied. Furthermore, SEM analysis proved that $CaCO_3$ precipitations formed in the presence of an electromagnetic field were in a powdery form with a lower density than the precipitation formed in case of not using electromagnetic field.

1. Introduction

Reverse osmosis (RO) process is a usual and appropriate process for saline water and brackish desalination to produce pure water for drinking and industrial applications. One of the drawbacks of this process is biological and particulate fouling formation on the reverse osmosis membrane surface which severely affects the membrane performance and increases energy consumption. Nowadays a variety of methods are used to prevent sediment formation on the membrane surface or reduce its undesirable effects. These methods include pretreatment of feed solution, adjustment or tailoring of membrane properties, hydraulic, chemical and electrical cleaning and improvement of operating conditions [1]. In this paper, electromagnetic field (EMF) is used as a new method to reduce fouling on the membrane surface.

According to Brower, the history of water magnetic treatment dates backs to 1803 [2] though the history of magnetic treatment application is not clear. Studies on water magnetic and electromagnetic treatment have been done for decades and in that time many scientists and researchers had investigated the impact of magnetic and electromagnetic fields on the properties of water and quality of water treatment but reported results are still conflicting. Russian scientists found that the magnetic field applied on water causes increasing water purity and treatment by reducing fouling formation [3]. In addition, many researchers have noted that when water passing the magnetic field, the fouling formed on the equipment wall reduces and forms in a very thin and non-adhesive feature [4–9]. In the studies conducted on the magnetic fields effect on the water and aqueous solutions, calcium carbonate ($CaCO_3$) is severely taken into consideration because of its wide applications and the fact that it creates a hard and harmful sediment (or precipitation). Calcium carbonate fouling is found in three different forms of calcite, aragonite and vaterite. Aragonite sediments have less

* Corresponding author.
E-mail address: kariminia@sharif.ir (H.-R. Kariminia).

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adhesion but calcite sediments are in a dense and sticky form. Donaldson proved that after applying a magnetic field, the formation of aragonite sediments (or precipitation) increases [10]. Other studies also have confirmed a similar effect for the magnetic field [5,11–13]. According to Banejad and Abdosalehi studies, in the presence of a magnetic field, the size of crystals become smaller while there is an increase in their number which is in favor of nucleation [14]. Other researchers have also reported the same observation [15,16]. There have been other studies on the impact of magnetic treatment on membrane separation systems. Jianxin Li et al. used electromagnetic field as a pretreatment stage to nanofiltration process. They investigated the effect of electromagnetic field on the amount of $CaCO_3$ sediment formation. They observed that in the presence of an electromagnetic field, the thickness and density of sediments forming on the surface of the membrane decreased and the percentage of aragonite crystals increased [17]. In 2011, Marek Gryta studied the effect of a constant magnetic field as a pre-treatment stage of a membrane filtration process. He observed that applying magnetic field decreased 10 to 25% of sediments, increased the size of crystals and increased the flux through the membrane [18]. As for RO processes, the first study was conducted in 1996 by Al-Qahtani. He observed that using a constant magnetic field as a pretreatment stage to a RO process for sea water purification could reduce the amount of salt passing through the membrane. [3]. However, Baker et al. reported a different result. They examined passing a solution saturated by calcium carbonate through a magnetic field followed by a membrane filtration. They observed that the presence of the magnetic field increased the efficiency of RO membrane but it also increased the fouling on the membrane surface. They noted that in the presence of a magnetic field, the amount of sediment formation increased in the preliminary filtration stage [15]. Vedavyasan investigated the combined effects of turbulence generating flow distributor and electromagnetic fields on biological fouling of RO membranes. According to his observation, electromagnetic field decreases biological fouling on membrane surface and decreases the pressure drop across the membrane [19]. Zhang et al. examined the effect of electromagnetic field on the critical flux of sediment formation on RO membranes and observed that applying an electromagnetic field increased the critical flux of sediment formation and decreased the fouling [20]. The effective performance of EMF can cause reducing both the sedimentation on the membrane surface and the pressure drop. By applying EMF, reduced amount of antiscalants are needed to suppress the sedimentation. Therefore, there are benefits by eliminating the usage of chemicals that are destructive to the environment. Moreover, enhanced membrane performance is expected due to the operational pressure decrease of the system.

A review of the literature has revealed that most of researchers reported successful applications of magnetic field in order to feed pretreatment in membrane desalination. Current study, presents the results obtained by applying an electromagnetic field (EMF) on the surface of RO membrane and studying its effect on improving the membrane performance in filtration process of $CaCO_3$ solution, as well as the amount of deposits formed on the membrane surface. The parameters investigated in this study including the effect of electromagnetic field on membrane salt rejection, membrane pressure drop and deposits formed on the membrane have not been investigated previously.

2. Materials and methods

Reverse osmosis water treatment system used in this study was WS1250FS Residential RO system with a nominal capacity of 50 ~ 100 GPD manufactured by WaterSafe, Canada. This system has three pretreatment stages including a 5 μm fiber filter, carbon filter and carbon black filter which was modified by eliminating the second and third pretreatment stages and bypassing the feed to the final stage. An overview of the used setup is shown in Fig. 1.

This setup includes a 50 L feed storage tank, feed pump, 5 μm cartridge filter, high pressure pump, membrane module, electromagnetic field generating device and manometers.

The high pressure pump is a diaphragmatic model that provides pressure around 80–120 psig. All fittings and storage tank used in this setup are made of steel and PVC. RO membrane used in the experiments was DOW FILMTEC™ TW30-1812-50, manufactured by DOW, USA. The membrane specifications are given in Table 1.

To keep similarities between the tests conducted, after each experiment a new membrane was replaced. Electromagnetic field was designed in a manner that was continuously applied over the membrane. According to Faraday's law, alternating electric current passing through a solenoid creates variable magnetic and electric fields. Therefore, to create a magnetic field, a copper solenoid with 20 cm length and 40 rounds was wrapped around the membrane module. Flow of alternating electric current (25 A, 50 Hz) through the solenoid, creates an electromagnetic field in the solenoid and on the surface of the RO membrane. The pattern of designed electromagnetic field is shown in Fig. 2. The electric field was

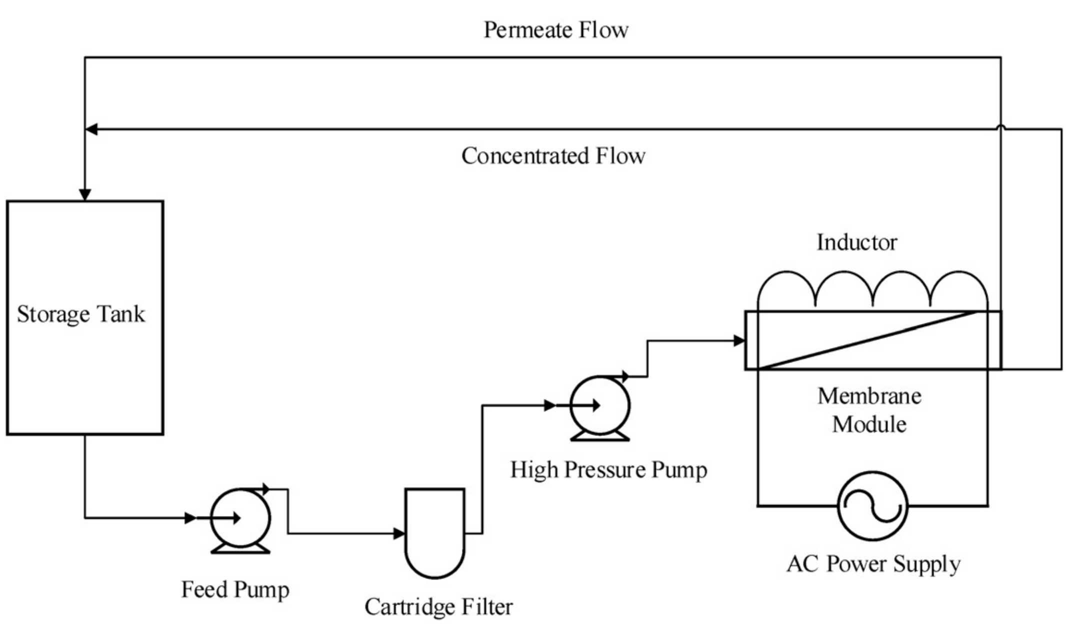

Fig. 1. Schematic diagram of reverse osmosis unit and EMF generator.