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Nanofiltration (NF) and Reverse-Osmosis (RO) Membranes for Aqueous Ammonium Nitrate Salt Rejection: Experimental Studies †

Zulfiqar Ali [1,*] and Tahir Maqsood Qaisrani [2]

1 National Centre for Nanotechnology (NCN), Department of Metallurgy and Materials Engineering (DMME), Pakistan Institute of Engineering and Applied Sciences (PIEAS), Nilore 45650, Islamabad, Pakistan

2 Department of Chemical Engineering (DChE), PIEAS, Nilore 45650, Islamabad, Pakistan; tmqaisrani@pieas.edu.pk

* Correspondence: alizulfiqar161@gmail.com

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Abstract: Herein, two commercially available spiral-wound nanofiltration (NF) and reverse-osmosis (RO) membrane elements were tested for aqueous ammonium nitrate salt separation. The effect of feed concentration and salt rejection as a function of transmembrane pressure were evaluated. NF and RO membranes exhibited 60% and 92% ammonium nitrate salt rejection, respectively, upon the initial feed concentration of 0.1 wt% at a seven-bar operating pressure. High ammonium nitrate salt rejection by the RO membrane was owing to its relatively small pore size compared to the NF membrane. It was found experimentally that the commercially available RO and NF membrane elements can be used for ammonium nitrate salt rejections from industrial effluents at ambient conditions.

Keywords: nanofiltration (NF); reverse osmosis (RO); spiral-wound membranes; ammonium nitrate (NH_4NO_3); industrial effluents

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1. Introduction

Water contamination by inorganic salt is one of the major concerns worldwide in the face of declining freshwater reservoirs [1,2]. Many countries in Asia including Pakistan have been water-stressed regions since the free-of-cost availability of fresh water to most of the people is unavailable at the doorstep. Membrane-based separation processes, such as ultrafiltration (UF), nanofiltration (NF), and reverse-osmosis (RO) systems, have found widespread applications at a commercial level, especially in drinking-water production from brackish water [3–6]. The success rate of commercial membrane water-purification systems can be estimated from the fact that the Middle East, including the Kingdom of Saudi Arabia, employs mega-industrial RO systems for seawater desalination and drinking-water production. Hence, salt removal from water by a membrane-based separation process is an effective and practical technique. Generally, inorganic salts such as aqueous ammonium nitrate salt are generated in many chemical industries in huge volumes, which often need the separation of salts for the recycling of process water. In this context, commercial NF and RO membranes have demonstrated promising solutions to salt separation. For instance, F. Gholami et al. [7] have developed polysulphone (PS)-based nanofiltration membranes for heavy metals and salt rejections. L. Zou et al. [8] have modified commercial NF membranes with NaOH to achieve better performance for nitrate removal from groundwater and have reported better results towards nitrate rejection by modified membranes compared to as-received commercial membranes. In another work, S. Alzahrani et al. [9] assessed the removal efficiency of salts by employing commercial RO and NF membranes, concluded that indirect potable water can be produced by employing hybrid mem brane systems, and suggested the NF membrane as a pre-filtration step for RO membranes. Ammonium nitrate dissolved salt in water is also one of the challenges faced by many chemical industries, such as fertilizer and nuclear. In this study, two commercially available spiral-wound NF and RO membrane elements were evaluated regarding ammonium nitrate salt rejection in simulated water containing ammonium nitrate.

2. Materials and Methods

Lab-grade ammonium nitrate (NH_4NO_3) salt was supplied by Sigma Aldrich. A multimeter with an electrical conductivity (EC) probe was used to determine the concentration of ammonium nitrate salt in water. The specifications of the commercial NF and RO membrane elements are shown in Table 1. Schematics of the experimental setup are shown in Figure 1. Salt rejection and volumetric flux were calculated as follows:

$$\textbf{Salt Rejection}(\%) = \left(1 - \frac{\text{CF}}{\text{CP}} \times 100\right) \rightarrow (\textbf{i})$$

$$\textbf{Volumetric Flux}\ (\textbf{J}) = \frac{\text{V}}{\text{A}} \rightarrow (\textbf{ii})$$

$$\textbf{Permeate Flux} = \frac{\text{J}}{P} \rightarrow (\textbf{iii})$$

where, CF = concentration of salt in feed line solution (wt % or ppm), CP = concentration of salt in a permeate line solution (wt% or ppm), V = volume flow rate (L/h), A = effective area of membranes (m^2), and P = transmembrane pressure (bar).

Table 1. Specification of commercial NF and RO membrane elements.

Specification	NF-1812-150	RE-2012-100
Material	Polyamide Thin Film	Polyamide Thin Film
Pore size	2 nm–10 nm	0.01 nm–0.1 nm
Diameter	45.72 mm	50.80 mm
Length	304.8 mm	304.8 mm
Effective surface area	0.49 m^2	0.71 m^2
Flow rate with (DMW)	25 $L{\cdot}h^{-1}$	16.67 $L{\cdot}h^{-1}$

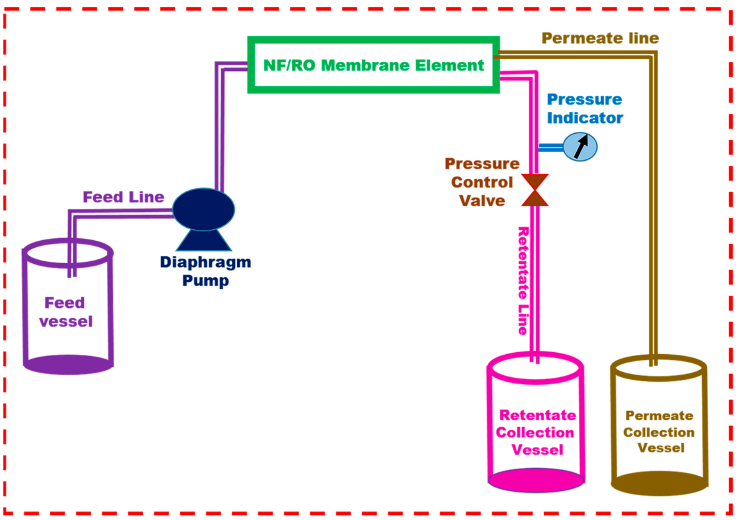

Figure 1. Schematics of the experimental setup.

3. Results and Discussion

Figure 2a–d shows the volume flow rates and fluxes with an increasing ammonium nitrate salt concentration (0.1–2wt %) for the NF membrane as a function of pressure at pH 3.8. Similarly, Figure 2e–h shows the trends for RO membranes at identical conditions. It can be seen that both volume flow rates and fluxes increase as the trans-membrane pressure rises. It is because, with an increase in pressure, the solute counts per unit time in the permeate line increase at a similar membrane area to those who experience less force per unit area. On the other hand, at a constant pressure with an increase in the aqueous ammonium nitrate salt concentration, the salt rejection decreases. These observations are in accordance with the Spiegler–Kedem model. Generally, the % salt rejection increases for the bigger-sized cations and anions with the rise of their concentration in the feed solution at a constant pressure [9]. However, in the present work, it was observed that the aqueous ammonium nitrate salt rejection decreases with the rise of the feed concentration at constant pressure, as shown in Figure 3 for both the NF and RO membranes. It seems that the repulsive forces between the surface charges of the membranes and ammonium nitrate ions are not big enough to result in higher rejections. This is a useful feature of commercial NF and RO membranes for the recovery and waste disposal of ammonium nitrate salt streams. It is worth noting here (Figure 2a–h) that similar trends of increasing pressure on flow rates and fluxes for both RO and NF membranes were observed; only the difference was observed in the low permeability of RO compared to the NF membrane.

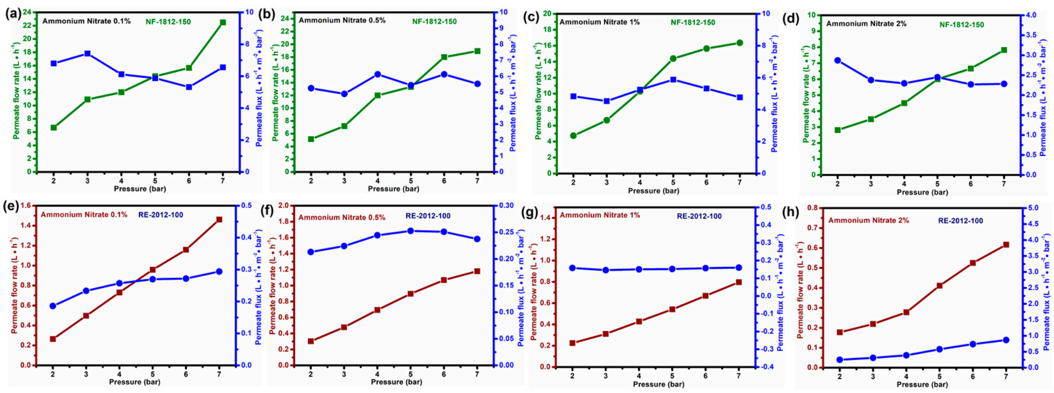

Figure 2. Effect of pressure on permeate flow rate and flux for commercial spiral-wound NF (**a**–**d**) and RO membrane elements (**e**–**h**).

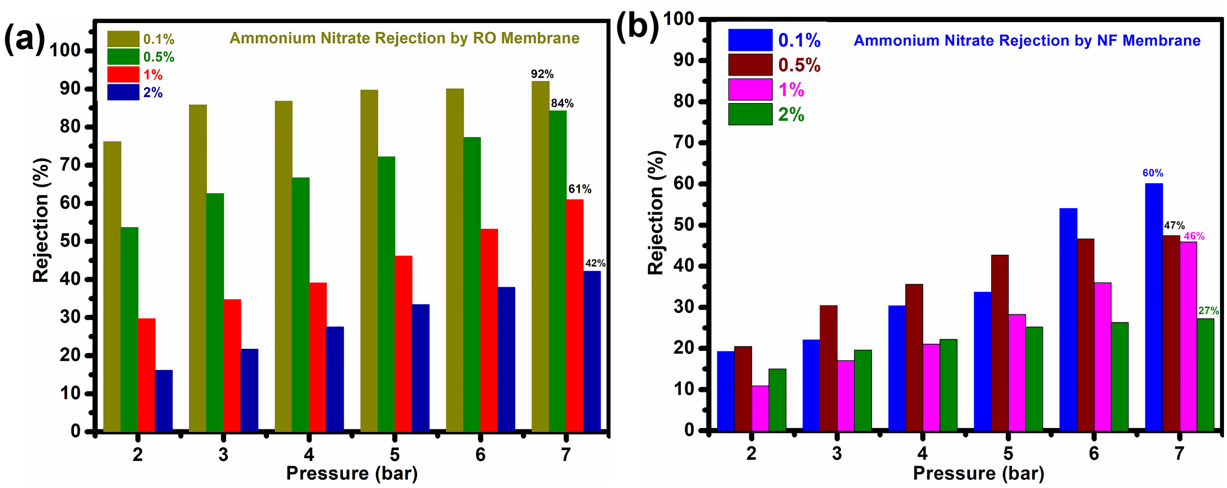

Figure 3. Aqueous ammonium nitrate salt rejections by spiral-wound membrane elements (**a**) RO and (**b**) NF.

Figure 3a,b show the % rejection of aqueous ammonium nitrate salt by RO and NF membrane elements as functions of pressure and concentrations, respectively. It can be seen that, with an increase in pressure, salt rejection increases, while, with the increase of the feed salt concentrations, it decreases for the reasons as discussed above. Moreover, the RO membrane exhibits 92% salt rejection, while at similar conditions, the NF membrane shows 60% salt rejection. It is revealed that the RO exhibits higher rejections compared to NF, which is presumably due to its relatively smaller pore size than that of the NF membrane.

4. Conclusions

Commercially available spiral-wound NF and RO membrane elements were investigated for ammonium nitrate salt separation from water. RO and NF membranes exhibited 92% and 60% rejection of ammonium nitrate salt at a 0.1 wt % (1000 ppm) feed concentration and seven bar operating pressure, respectively. The permeate fluxes for NF membrane were higher than those of RO membranes at similar conditions, while the rejection of salts at various feed concentrations was found to be higher for the RO membrane.

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