Kufa Journal of Engineering
Vol. 14, No. 2, April 2023, P.P. 1-11
Article history: Received date: 21 December 2022, accepted date: 19 February 2023

PERFORMANCE EVALUATION OF THE REVERSE OSMOSIS PILOT PLANT: USING SODIUM CHLORIDE AND MAGNESIUM CHLORIDE.

Marwa Asad Salih[1] and Asmaa H. Dhiaa[2]

[1]Department of Chemical Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq - E-mail: marwa.salih@uokufa.edu.iq

[2]Department of Chemical Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq - E-mail: asmaah.alhusseini@uokufa.edu.iq

https://doi.org/10.30572/2018/KJE/140201

ABSTRACT

The conversion of saltwater and brackish water into fresh water through desalination has gained significant importance as a solution to the worldwide scarcity of fresh water resources. The Reverse Osmosis (RO) method has been effectively utilized to generate fresh water from sources of brackish water. This research aims to examine the variables that affect the performance of the reverse osmosis process. The effectiveness of the membrane was assessed through experiments that explored the impact of varying operating conditions, such as feed pressure, temperature, and concentration, on the reverse osmosis pilot plant and salt solution system (consisting of NaCl and $MgCl_2$). The selected membrane used a polymeric membrane constructed as FilmTec TW30-1812-50 spiral-wound module. The results showed that as the feed temperature and salt concentration increased, the salt rejection decreased. On the other hand, as the transmembrane pressure was raised, the membrane's salt rejection improved. The experiments revealed that the feed temperature and salt concentration have a significant impact on the membrane's performance. Among the various variables studied, operating pressure had the largest effect on the product rate. As operating pressure increased, the permeation flux and salt rejection also increased, with a salt rejection rate of 96% achieved at 5 bars. In addition to other factors, the concentration of the feed greatly influences the solute content in the final product.

KEYWORDS: Membrane Desalination; RO; Rejection; Performances.

Article information: This manuscript was handled by Abbas Al-Hdabi, Managing Editor.

1. INTRODUCTION

Water is essential for preserving life on Earth and advancing human society. While water is a renewable resource, only a small portion of the total water on the planet is freshwater, and even less is easily accessible. As a result, freshwater resources are limited. With growing populations, rapid urbanization, and the effects of climate change, traditional sources of water such as lakes, rivers, and groundwater are becoming insufficient to meet the increasing demand for clean drinking water (Zioui et al., 2018; Zhu et al., 2019; Wang et al., 2021). Due to various reasons, many countries are facing a shortage of drinking water. Thus, it's important to utilize the seawater from oceans and seas, as they make up over 97% of the world's water supply, through desalination processes (Idrees, 2020; Lin et al., 2021). One of these countries is Iraq, where there is a shortage of surface water in many regions. As a result, some regions have started exploring alternative sources, such as brackish water (Taha et al., 2021). RO (reverse osmosis) technology has been developed to desalinate both seawater and brackish water using an asymmetric cellulose acetate membrane. However, in recent times, other materials have been proposed as alternative options (Al-Obaidi, et al., 2020).

Compared to thermal desalination methods, membrane processes are considered to be more effective in water desalination. This is because they produce high-quality water at relatively low capital and operational costs (Goosen, et al., 2005; Qasim, et al., 2019).

Reverse Osmosis (RO) is a process for treating water that involves using a semi-permeable membrane to remove salts and other contaminants. The efficiency of RO systems can be measured by parameters like the rejection rate, flow rate of the purified water, and recovery rate. Furthermore, aspects such as the quality of the feed water, the design of the system, and operating conditions can also affect the performance of an RO system (Nicholas, 2002). Compared to other desalination technologies, RO is the most dependable membrane method for desalinating seawater and brackish water. It is not only more energy-efficient but also more cost-effective than thermal desalination methods (Igobo and Davies, 2018). It is crucial to understand the behavior of the membrane and identify the key parameters that impact its performance in order to operate RO systems effectively. To do this, it is important to recognize the relationship between input parameters and the performance metrics of the RO process, and determine which parameters have the greatest impact. Ruiz-Garcia et al. (2020) found a direct and linear relationship between feed pressure and water flow.

Boulahfa et al. (2019) conducted an evaluation of the impact of operating parameters on an RO plant in Morocco over a period of five years. They compared the operating parameters with the analytical results from the ROSA software and found that a 4°C increase in feed temperature resulted in a 10% increase in permeate flow. According to Ansari, et al., (2021), the results showed that the performance of an RO unit is largely influenced by feed pressure and feed salinity. When the feed concentration was fixed, there was a strong linear relationship between feed pressure and both permeate and brine flow rates. The study found that a feed pressure of 13 bar resulted in a maximum salt rejection of 98.8% and a minimum permeate concentration of 12 ppm.

According to various studies, high feed flow rates and high operating pressures can negatively impact the quality of the permeate and product (Alsarayreh, et al., 2020). An increased feed rate can alleviate concentration polarization but also reduce permeate concentration (Kaghazchi, et al., 2010). Increasing pressure, feed concentration, and module area can lead to higher concentration at the membrane's wall (Kotb, et al., 2015). The pressure and flow rate have a positive impact on permeate salinity (Al-Obaidi, et al., 2018). Higher feed pressure leads to higher recovery rates, but also increases the possibility of contaminants entering through the membrane pores (Idrees, 2020). The solute's diffusivity in the feed solution of the membrane desalination system increases with temperature, while the water's viscosity and the membrane's resistivity both decrease when temperature drops (Lilane, et al., 2019).

The objective of this study was to investigate the ability of the reverse osmosis (RO) process to separate salt from water with varying levels of salinity. The impact of feed salt ($NaCl$ and $MgCl_2$) concentration, feed pressure, and feed temperature on the effectiveness of the process was also examined.

2. MATERIAL AND METHODS

The feed water quality and plant operating conditions have a significant impact on the Spiral-wound membrane system's performance (FilmTec TW30-1812-50 spiral-wound module), Fig.

1 depicts a laboratory reverse osmosis unit in this study. This unit consists of a feed tank, pump, and RO membrane. The fluid solution was formed in the tank by dissolving the solid salts (NaCl and $MgCl_2$) individually as shown in Table 1, with different solute concentrations (150, 250, 350, 450, and 550 ppm) in the feed tank, then it passes at a pressure of (1-5 bar) , and the temperature of the feed solution (15, 25, and 35 ºC), an electronic meter used to measure the TDS and temperature.

Table (1) physical and chemical characteristics of the substance used.

Type of substance	Molecular weight	Solubility	Conductivity
NaCl	58.44 g/mol	is highly soluble in water	NaCl is an excellent conductor of electricity in its aqueous solutions.
$MgCl_2$	95.21 g/mol	is highly soluble in water, forming a clear, colorless solution	$MgCl_2$ is an excellent conductor of electricity in its aqueous solutions

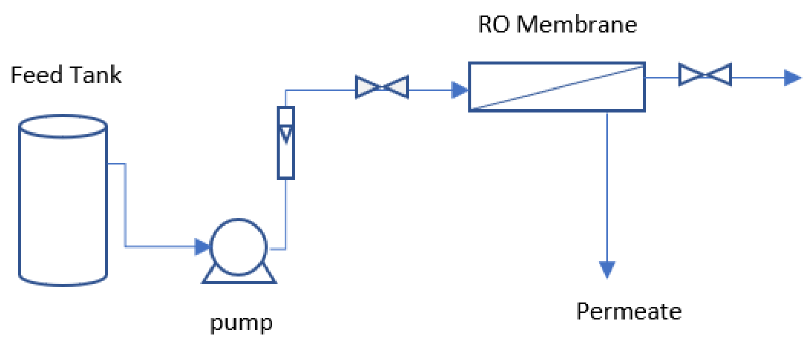

Fig. 1. The lab scale setup of the reverse osmosis process.

3. RESULT AND DISCUSSION

The average permeation flux, which describes permeating generation, and rejection, which established permeate quality, are the key characteristics of a RO membrane unit. Operating conditions like feed pressure, feed concentration, temperature, etc. might affect on these two parameters. These variables affect the effectiveness of the RO membrane system.

The following criteria are employed to assess the effectiveness of the RO process: flow, water recovery, and solute rejection:

$$Jv = \frac{Volume\ of\ water\ collected\ (L)}{Membrane\ area\ (m2) * Time(h)} * 100 \quad (1)$$

$$WR = \frac{Qp}{Qf} * 100 \quad (2)$$

The percentage of the feed flow that crosses the membrane is considered the recovery rate.

Where Q_p is the permeated flow, Q_f is the feed flow, WR is the recovery %, and J_v is the water flux. The quantity of solute retained by the RO membrane is expressed as a percentage called salt rejection, which is calculated as follows:

$$R = \frac{Cf - Cp}{Cf} * 100 \quad (3)$$

Where R, rejection; Cf, and Cp are the concentrations of solutes (total dissolved solid) in feed and permeate samples, respectively.

The impact of operating pressure on the rejection percentage for sodium chloride and magnesium chloride is shown in Fig. 2. With growing effective pressure, the rejection and flux will also growth. The product rate, rejection, and flux will all growth along with the effective pressure. The rejection rate is larger than the product rate because of the compacting and polarization that occur on the membrane surface (Junaidi et al., 2020; Pervov, et al., 2018). With increased operating pressure, there is a significant increase in TDS rejection (Junaidi et al., 2020).

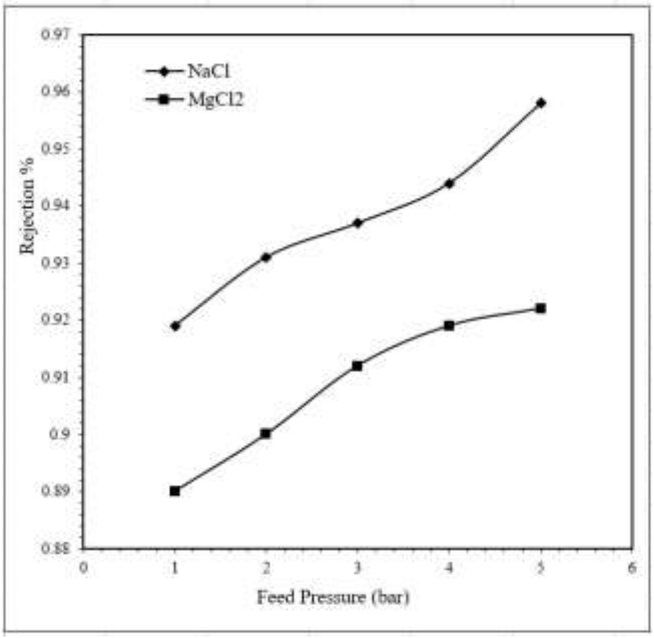

Fig. 2. Rejection as the function of Feed Pressure.

As the supply pressure increased, the permeate concentration progressively decreased, suggesting that less permeate TDS is generated. Fig. 3 shows how the concentration of permeate decreases as pressure increases (Sarai Atab, 2016).

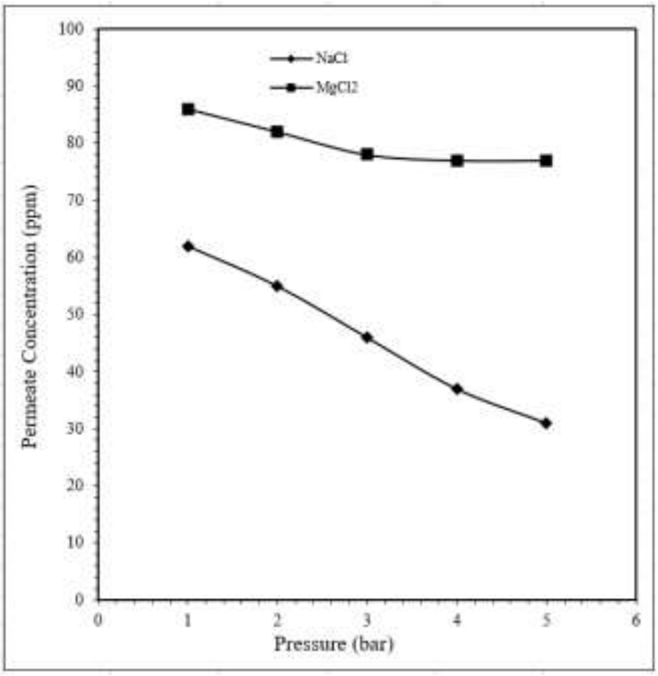

Fig. 3. Permeate Concentration as the function of Pressure.

Additionally, as seen in Fig. 4, salt rejection rises with decreasing temperature, indicating that the amount of TDS in permeate increases as temperature rises. This results from the pore size impact and a decrease in solvent viscosity. The amount of TDS in permeate is regulated by both temperature and pressure.

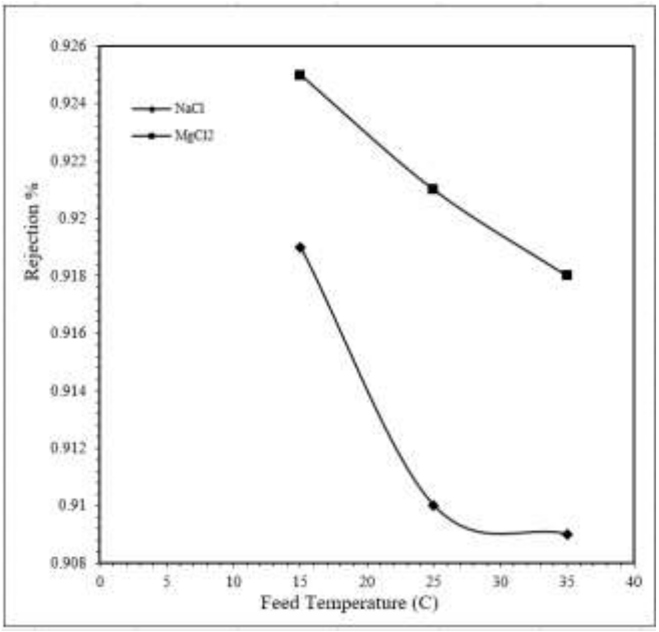

Fig. 4. Rejection as the function of Feed Temperature.

Another significant factor that influences the product water quality is permeate TDS. Fig. 5 demonstrates how the solute concentration is affected by feed concentration at various feed salts (NaCl and $MgCl_2$). An increase in solute flow is caused by raising the feed concentration for the sodium chloride-water system, which is seen as an increase in solute concentration in the finished product (Al-Alawy, 2002).

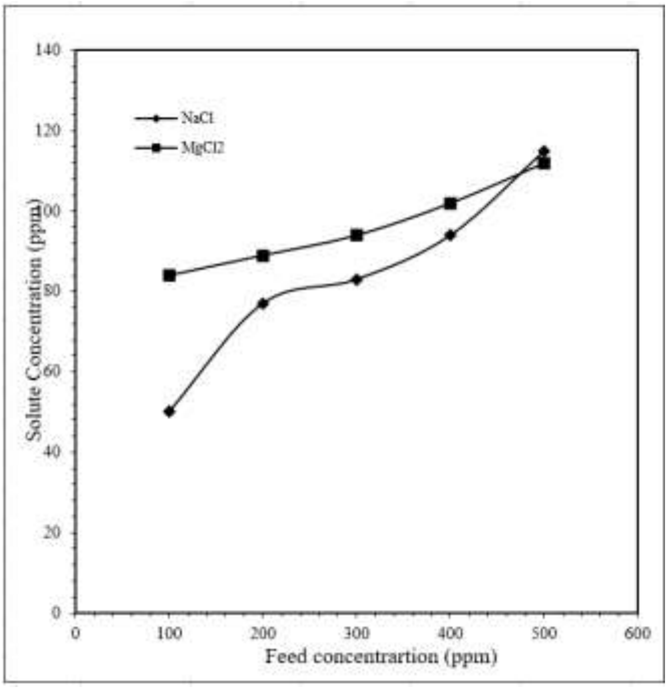

Fig. 5. Solute Concentration as the function of Feed Concentration.

Fig. 6 shows that the rejection ratio decreases significantly as feed concentrations increase. This is due to the requirement for significantly higher transmembrane osmotic pressure and increased difficulties in resisting brine diffusion.

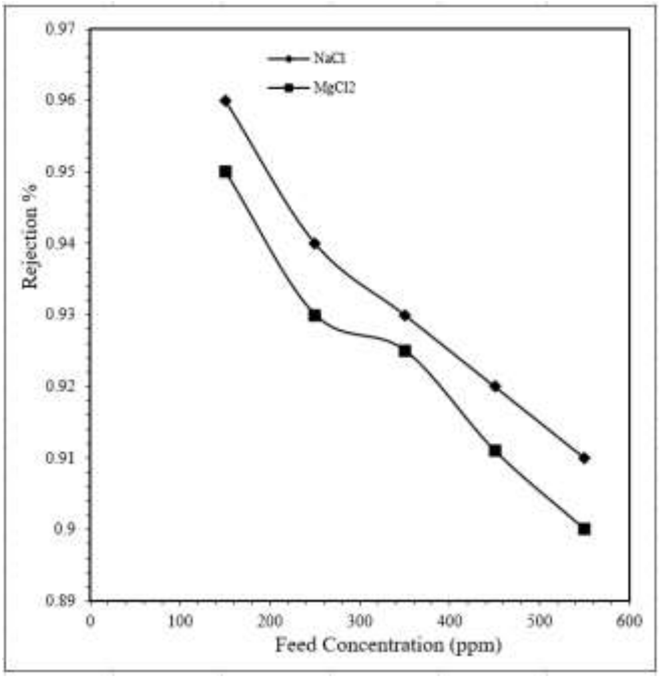

Fig. 6. Rejection as the function of Feed Concentration.

4. CONCLUSIONS

The performance of the reverse osmosis process is examined in this study, and it is enhanced through with of an experimental approach. In this study, a reverse osmosis system was used to treat various salt solutions (Sodium Chloride and Magnesium chloride). Under different working circumstances, the permeation flux and salt rejection are examined. The results show that the permeate salinity increases when the feed water temperatures increase from 15 to 35 ^{o}C. This demonstrates how sensitive to feed temperature the spiral-wound membrane is. It is recognized that different salt inputs should not require a separate mechanism to maintain reverse osmosis selectivity.

The reverse osmosis system responds more strongly to operating pressure, with increasing effective pressure, the permeation flux and salt rejection improve, with the salt rejection reaching 96% at 5 bar. Beyond a particular maximum value, increasing the pressure will cause the product's quality to decrease.

Contrary to popular belief, raising the feed rate past a specific optimum value will result in a decrease in the rate at which water is produced because the high frictional pressure drop will result in a decrease in the net transmembrane pressure differential.

REFERENCES

Al-Alawy, A.F. (2002) "Study of the Factors Affecting the Efficiency of Reverse Osmosis Process", Vol. 3, March, P. (49-55). https://www.researchgate.net/publication/340950317

Al-Obaidi, M.A., Alsarayreh, A.A., Al-Hroub, A.M., Alsadaie, S., & Mujtaba, I.M. (2018) "Performance Analysis of a Medium-sized Industrial Reverse Osmosis Brackish Water Desalination Plant", Vol. 443, 1 October, P. (272-284).

https://doi.org/10.1016/j.desal.2018.06.010

Al-Obaidi, M.A., C. Kara-Zaitri, Mujtaba, I. (2020) "Wastewater Treatment by Reverse Osmosis Process", 17 March. https://doi.org/10.1201/9781003019343

Alsarayreh A. A., Al-Obaidi M.A., Patel R., & Mujtaba I.M. (2020) "Scope and Limitations of Modelling, Simulation, and Optimization of a Spiral Wound Reverse Osmosis Process-Based

Water Desalination", 12 May. https://doi.org/10.3390/pr8050573

Ansari M., Al- Obaidi M. A., Hadadian Z., Moradi M., Haghighi A., Mujtaba I. M. (2021) "Performance evaluation of a brackish water reverse osmosis pilot-plant desalination process under different operating conditions: Experimental study", Vol. 4, October. https://doi.org/10.1016/j.clet.2021.100134

Boulahfa, H., Belhamidi, S., Elhannouni, F., Taky, M., El Fadil, A., Elmidaoui, A. (2019) "Demineralization of brackish surface water by reverse osmosis: the first experience in Morocco", Volume 7, Issue 2, April. https://doi.org/10.1016/j.jece.2019.102937

Goosen M., Sablani S., Al-Hinai H., Al-Obeidani S., Al-Belushi R., Jackson. (2005) "Fouling of reverse osmosis and ultrafiltration membranes: a critical review", Vol. 39, Issue 10.

Idrees M. F. (2020) "Performance Analysis and Treatment Technologies of Reverse Osmosis Plant – A Case Study", Vol. 2, September. https://doi.org/10.1016/j.cscee.2020.100007.

Igobo, O., Davies, P. (2018) "Isothermal Organic Rankine Cycle (ORC) driving Reverse Osmosis (RO) desalination: experimental investigation and case study using R245fa working fluid", Vol. 136, 25 May, P.(740-746).

Junaidi, R., Hasan, A., Muhammad, D. Y., and Purnamasari, I. (2020) "The Performance of Reverse Osmosis (RO) Membrane in Producing Pure Water", Vol. 1500. 10.1088/1742-6596/1500/1/012057

Kaghazchi, T., Mehri, M., Ravanchi, M.T., & Kargari, A. (2010) "A mathematical modeling of two industrial seawater desalination plants in the Persian Gulf region", Vol. 252, Issues 1–3, March, P. (135-142).

Kotb, H., Amer, E., & Ibrahim, K. (2015) "Effect of operating conditions on salt concentration at the wall of RO membrane", Vol. 357, 2 February, P.(246-258).

Lin S., Zhao H., Zhu L., He T., Chen S., Gao C., Zhang L. (2021) "Seawater desalination technology and engineering in China: A review", Vol. 498, 15 January.

Lilane A., Saifaoui D., Hariss S., Jenkal H., Chouiekh M. (2019) "Modeling and simulation of the performances of the reverse osmosis membrane", Vol. 24, Part 1, P. (114-118).

10.1016/j.matpr.2019.07.694.

Nicholas P. Cheremisinoff. (2002) "Handbook of Water and Wastewater Treatment Technologies".

Pervov, A., Tikhonov, K. and Nikolay Makisha, N. (2018) “Application of reverse osmosis techniques to treat and reuse biologically treated wastewater”, Vol. 365, Issue 6. 10.1088/1757-899X/365/6/062026.

Qasim M., Badrelzaman M., Darwish N.N., Darwish N.A., Hilal N. (2019) “Reverse osmosis desalination: a state-of-the-art review”, Vol. 459, 1 June, P.(59-104).

Ruiz-García, A., Nuez, I., Carrascosa-Chisvert, M.D., Santana, J.J. (2020) “Simulations of BWRO systems under different feedwater characteristics. Analysis of operation windows and optimal operating points”, Vol. 491, 1 October, 114582.

Sarai Atab, M., Smallbone, A.J., and Roskilly, A.P. (2016) “An operational and economic study of a reverse osmosis desalination system for potable water and land irrigation”, Vol. 397, 1 November, P. (174-184).https://doi.org/10.1016/j.desal.2016.06.020

Taha A.H., Joshi H., Garg M.C., Manhee H.K. (2021).” Case Study of Evaluation RO Desalination Systems for Potable Water in Safwan, Iraq”, Vol.9 No.2, February .

Wang Z., Zhang Y., Wang T., Zhang B., Ma H. (2021)” Design and energy consumption analysis of small reverse osmosis seawater desalination equipment”, 18 April.

Zhu Z., Peng D., Wang H. (2019) “Seawater desalination in China: An overview”, 9 (2): 115–132.

Zioui D., Aburideh H., Tigrine Z., Hout S., Abbas M., Merzouk N.K. (2018), “Experimental Study on a Reverse Osmosis Device Coupled with Solar Energy for Water Desalination”, 30 September.