Effect of Operating Conditions on Reverse Osmosis (RO) Membrane Performance

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ABSTRACT

The aim of this research is to study the effect of high concentrations of salts, pressure and temperature on the performance of the RO membrane with time. Four different (Na_2CO_3) concentrations (5000, 15000, 25000 and 35000) ppm and various pressures such as (1, 3 and 5) bars at different temperatures of the feed solution (i.e., 25, 35 and 45) °C were used in this work. It was found that, as the concentration of salt and feed temperatures increase, the rejection of the salt decrease. While the salt rejection of the membranes increases with increase of transmembrane pressure.

Key words: reverse osmosis, membrane, permeation flux.

تأثير الظروف التشغيلية على أداء غشاء التناضح العكسي

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الخلاصة

في هذا البحث تم دراسة تأثير التراكيز العالية للمحلول الملحي الداخل والضغط ودرجة الحرارة للمحلول على أداء الاغشية التنافذية. حيث تم إعداد أربعة تراكيز مختلفة(35000,25000,15000,5000) جزء بالمليون وعند الضغوط (١ , ٣ و٥) بار وتغيير درجة حرارة الماء الداخل (٢٥، ٣٥ و ٤٥) °م باستخدام نوع واحد من الاغشية التنافذية RO مع استخدام ملح (Na_2CO_3) لتحضير المحلول الملحي . حيث وجد انه كلما زادت تراكيز الاملاح تقل كفاءة الفصل للاملاح بينما تزداد كفاءة الفصل للاغشية عند الضغوط العالية. عند ارتفاع درجة الحرارة وجد ان كفاءة الفصل تقل.

الكلمات الرئيسية: التناضح العكسي, غشاء, معدل التدفق النافذ.

1. INTRODUCTION

The scarce availability of clean water in certain areas has led to an increased need to fresh water production via desalination of brackish and seawater or, e.g., treated wastewater. Membrane technology has revolutionized the separation industry by providing a highly selective and low-cost alternative to separation processes. Pressure-driven membrane separation processes (especially reverse osmosis) are important and attractive technologies for desalination and wastewater treatment, and this is because of the advantages of RO compared to the thermal desalination techniques, **Fritzmann, et al., 2007**. Reverse osmosis membrane technology has developed over the past 40 years to a 44% share in world desalting production capacity, and an 80% share in the total number of desalination plants installed worldwide. Recently, the use of reverse osmosis (RO) as a separation process is the leading technology for new desalination installation, and it is applied to a variety of salt water resources, **Lauren, et al., 2009**. In the late 1950's the work of Reid showed that cellulose acetate RO membranes were suitable for water desalination, **Reid and Breton, 1959, Ferguson, 1980; Lonsdale, 1982** and **Applegate, 1984.** In 1960's, **Loeb** and **Sourirajan, 1962,** developed a method for fabricating asymmetric cellulose acetate membranes with high water permeation fluxes and solute rejection ,**Loeb and Sourirajan, 1962, Loeb, 1981 and Sourirajan and Matsuura, 1985.** The development of new membranes such as the thin-film, composite membrane that can be used for a wide pH ranges, temperatures. In addition, RO membranes have found uses in wastewater treatment, production of ultrapure water, water softening, and food processing,… etc., **Bhattacharyya et al., 1992.**

Water treatment processes employ several types of membranes; these types are classified according to pore diameter. The reverse osmosis process is characterized by a membrane pore size in the range of 0.0005 microns. Reverse osmosis membranes are effectively non-porous, and therefore exclude particles and even many low molar mass species such as salt ions, organics, etc. Reverse osmosis called as hyper filtration in the past, it is regarded as another pressure driven process. In this process a solvent of the solution is transferred through a membrane and this lead to change in the concentration of the solution. In such a way, the concentration of some solute with low molecular weights (up to 500 Daltons) or other solvents is decreased, **Sath, et al., 2012**. Reverse osmosis (RO) is a physical process that uses the osmosis phenomenon. Osmosis is a natural phenomenon in which a solvent (usually water) passes through a semi permeable barrier from the side with lower solute concentration to the higher solute concentration side. Water flow continues until chemical potential equilibrium of the solvent is established. At equilibrium, the pressure difference between the two sides of the membrane is equal to the osmotic pressure of the solution. To reverse the flow of water (solvent), a pressure difference greater than the osmotic pressure difference is applied; as a result, separation of water from the solution occurs as pure water flows from the high concentration side to the low concentration side, **Mousa,** and **Salem, 2010.**

In the RO process, the pressure projecting on the primarily treated water raising to the limit that suitable for the type of membranes and concentrations of total dissolved solids (TDS) in the water to be treated. That mean the amount of pressure required directly relates to the TDS concentration of the feed water. The RO process is effective for removing TDS concentrations of up to 45,000 mg/L, so the RO technique can be used to desalinate both brackish water and seawater. Reverse osmosis needs energy to operate the pumps that raise the hydraulic pressure of the feed water to the enough limits to exceed the natural osmosis pressure and produce the required quantity of treated water. The objective of this work was to investigate the separation of salt from different salinity water using the

RO process. The effect of Na_2CO_3 concentration of the feed stream, transmembrane pressure and feed temperature on salt rejection and permeate flux were determined.

2. EXPERIMENTAL WORK

A laboratory reverse osmosis unit is used and shown in **Fig.1**. The feed solution is pumped from the feed tank to the membrane module by using diaphragm pump. The Permeate solution was collected in a glass beaker placed on a electronic balance. The Permeate was periodically returned to the feed container to prevent change in the feed concentration. The operating conditions using RO membrane process were commenced with the following ranges:

1. Solute concentration (5000, 15000, 25000 and 35000) ppm.
2. Temperature of Feed (25, 35 and 45) °C.
3. Operating Pressure (1, 3 and 5) bar.

2.1 Materials

1-The RO membrane used in this work was (Hidrotek RO membrane model TW30-1812-50, NSF certified, technology USA). It is supplied from Hidrotek company.

2- Distilled water.

3- Na_2CO_3 as a solute.

3. RESULTS & DISCUSION

Different salinity water is treated by using reverse osmosis system. Performance of RO system is examined by performing experiments under different operating conditions. The resulting salt rejection and permeation flux are presented in **Figs. 2** to **7** under various operating conditions. The salt rejection can be found by the following equation:

$$R\,(\%) = (C_f - C_p / C_f) \times 100 \qquad (1)$$

Fig. 2 shows the effect of salt concentration in feed solution on salt rejection (R %). It can be noticed that increasing of salt concentration from 5000 ppm to 35000 ppm results to decrease of salt rejection from 88% to 65%. Moreover, using 15000 and 25000 ppm of salt concentration led to small decrease in salt rejection as shown in **Fig. 2**. This is because when the salt concentration increases in feed water, the salt passage through the membrane increase. The results obtained are in agreement with **Lingyung,** and **Shingjiang**. Effect of feed solution temperature (i.e., 25, 35 and 45) ^oC on the salt rejection is shown in **Fig. 3**. It can be seen that the salt rejection decrease with increase of feed temperature from 25 to 45 ^oC. The reason of this effect is attributed to the decrease of feed solution viscosity which is lead to decrease of fouling on the membrane surface. Furthermore, effect of transmembrane pressure on the salt rejection is shown in **Fig. 4**. Increase of transmembrane pressure from 1 to 5 bar results to increase of salt rejection from 82% to 94%. It is worthy to mention here that there is a significant effect of transmembrane pressure on the salt rejection. Because RO membranes are not completely retained dissolved salts in feed water, there is always some salt passage through the membrane. Therefore when increasing feed water pressure, this salt passage decrease as water is pushed through the membrane. So the permeate concentration was diluted by the higher rate of water flow through the membrane, resulting in an increase in salt rejection , **Abou Rayan,** and **Khaled, 2002**.

Regarding the permeation flux of the RO membrane, **Figs. 5** to **7** show the effect of feed solution temperature, transmembrane pressure and salt concentration in feed solution on the RO membrane permeation flux. It can be seen that the permeation flux of RO membrane increase with increase of feed temperature as shown in **Fig. 5**, this is due primarily to the decrease in both viscosity and density of water when increase the temperature of feed water, so the permeability coefficient of water increase, as reported in the work of **Al-Mutaz ,** and **Al-Ghunaimi, 2001.** Also, from **Fig. 5,** it can be conclude that the best permeation flux was at 35 ^{o}C especially after 70 min from operation and that for a given feed water temperature, the permeation flux decrease with progress in time. In **Fig. 6**, it is expected to find that the transmembrane pressure has the highest effect on permeation flux among the other operating parameters. The permeation flux of RO membrane increases with increasing of transmembrane pressure. This behavior can be attributed to the fact that when increase transmembrane pressure, apportion of the feed water is forced through the membrane to emerge as purified product water (i.e. permeation flux is increased). This is because when increase transmembrane pressure the net driving force is increased also, so the permeation flux is increased**, Lingyung,** and **Shingjiang**. The effect of salt concentration in feed solution on permeation flux is shown in **Fig. 7**. The permeation flux decreases with increasing of salt concentration. This is due to increase the osmotic pressure difference across the membrane. The osmotic pressure is a function of the type and concentration of salts or organics contained in feed water. Therefore if feed pressure remains constant, under higher salt concentration results in higher osmotic pressure and this leads to much higher driving force. The increasing in salt concentration in feed water also leads to surface cake or fouling phenomenon on the membrane surface. A similar behavior has been reported by **Marwan,** and **Owee, 2006**.

4. CONCLUSIONS

In this research, different salt solutions were treated by reverse osmosis system. The salt rejection and permeation flux are studied under different operating conditions. The permeation flux experiments are conducted by operating reverse osmosis system for 3 hrs. This study leads to the following conclusions:

- The permeation flux is reduced with increasing time of operation at different conditions.
- The operating pressure has the stronger effect in the reverse osmosis system.
- The permeation flux and salt rejection are enhanced with increasing operating pressure, where the salt rejection is reached to 94% at 5 bars.
- The rejection decrease when increasing feed temperature, while the permeation flux increase.
- Both salt rejection and permeation flux are decreased when increasing the salt (Na_2CO_3) concentration from 5000 to 35000 ppm in the feed solution.

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NOMENCLATURE

C_f = concentration of salt in the feed water, ppm.

C_p = concentration of salt in the permeate water, ppm.

R = rejection of salt, dimensionless.

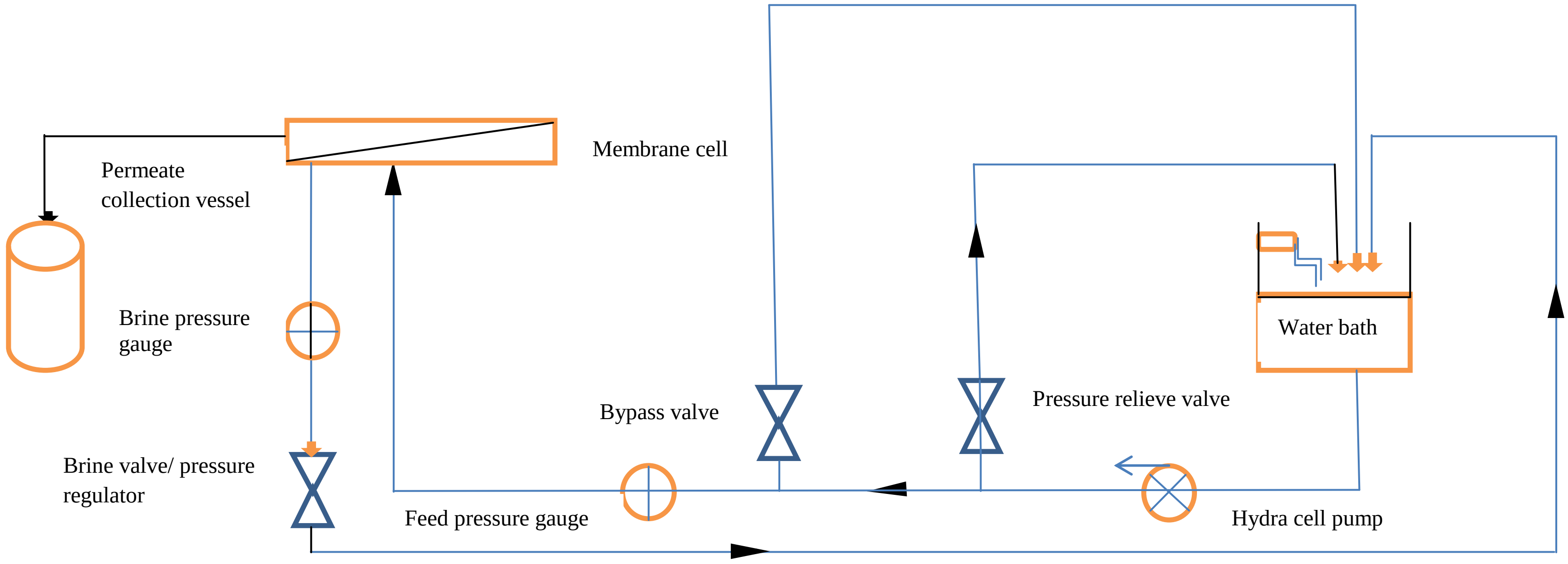

Figure 1. A schematic diagram of RO experimental system.

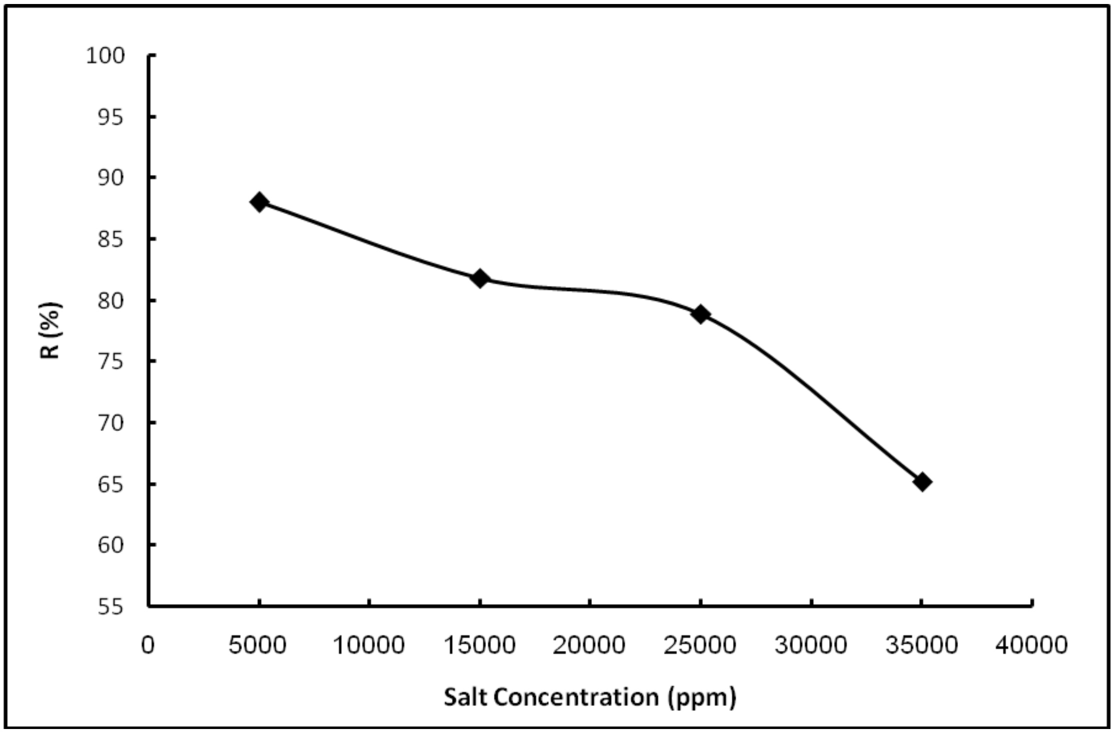

Figure 2. Effect of salt concentration on salt rejection (temp.: 25 °C; pressure: 1bar).

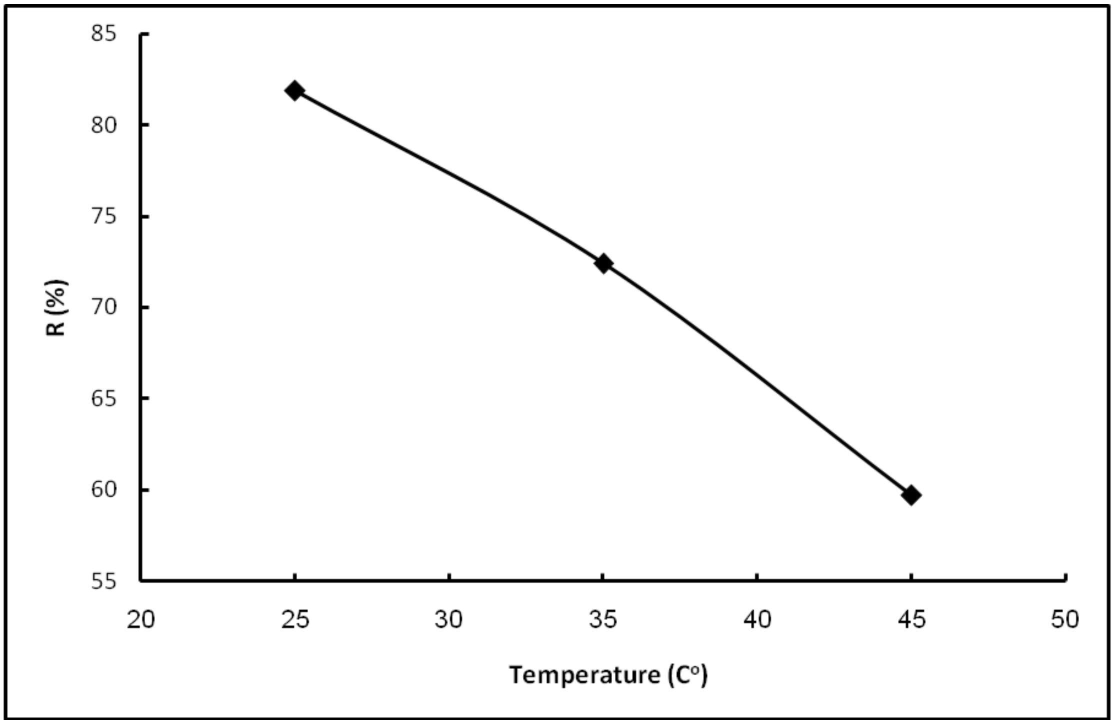

Figure 3. Effect of temperature on salt rejection (conc.: 15000 ppm; pressure: 1bar).

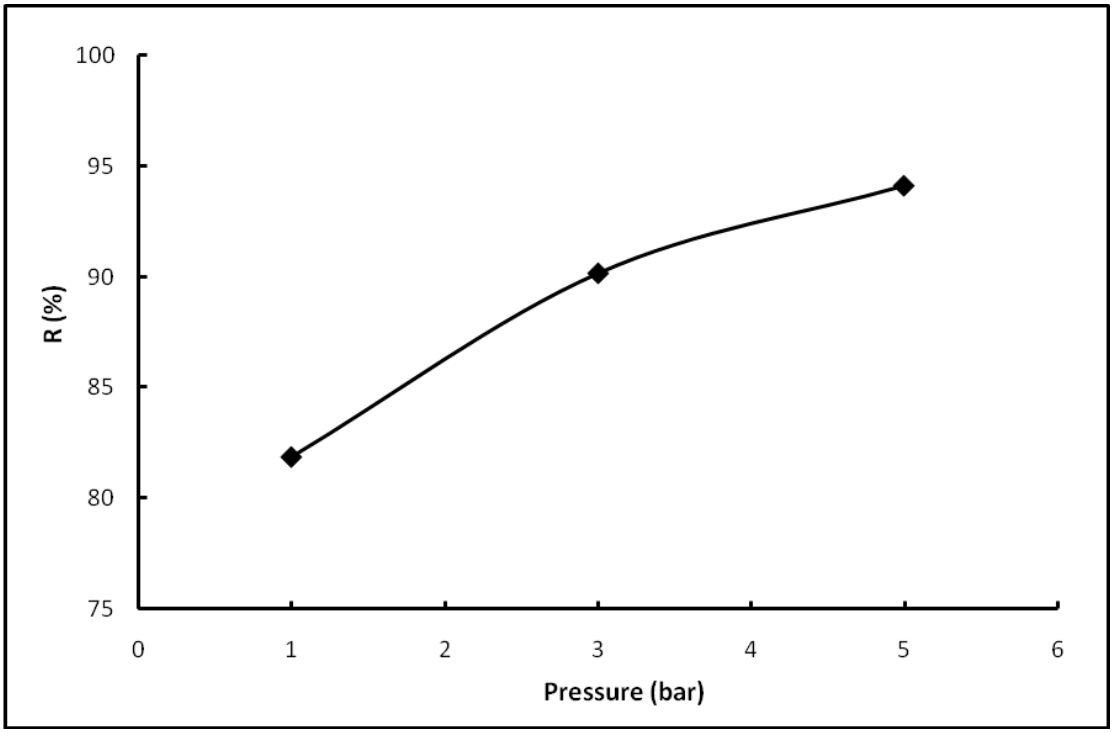

Figure 4. Effect of transmembrane pressure on salt rejection (temp.: 25°C; conc.: 15000 ppm).

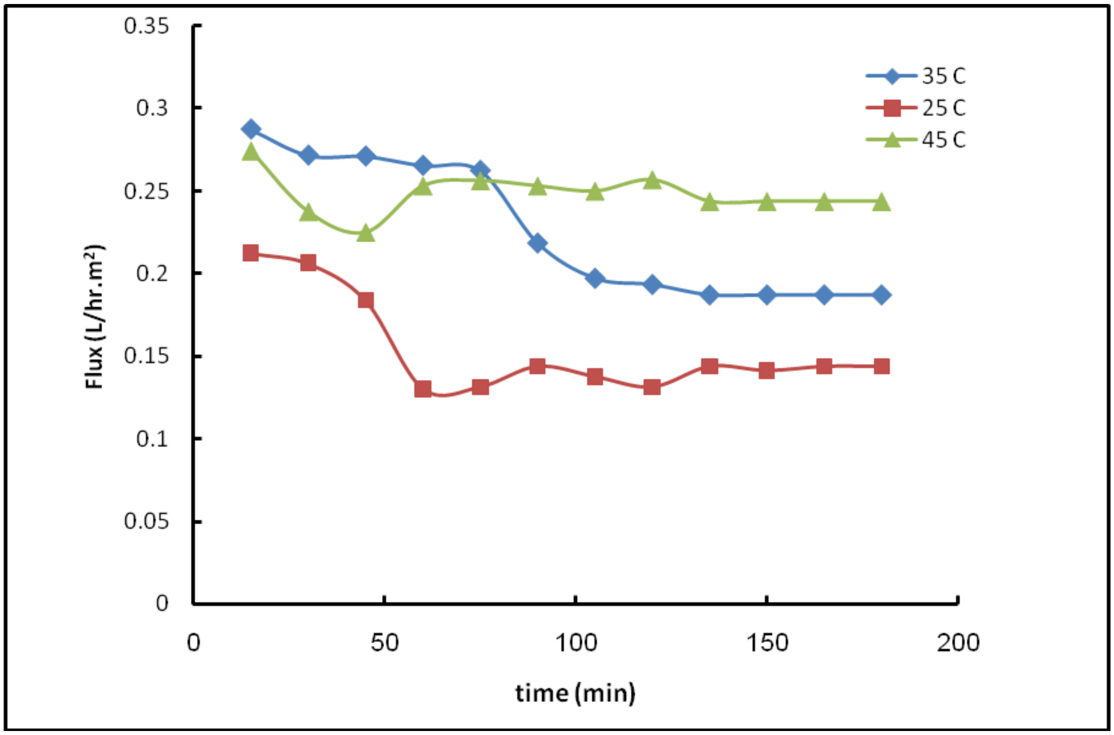

Figure 5. Effect of temperature on permeation flux (conc.: 15000 ppm; pressure: 1bar).

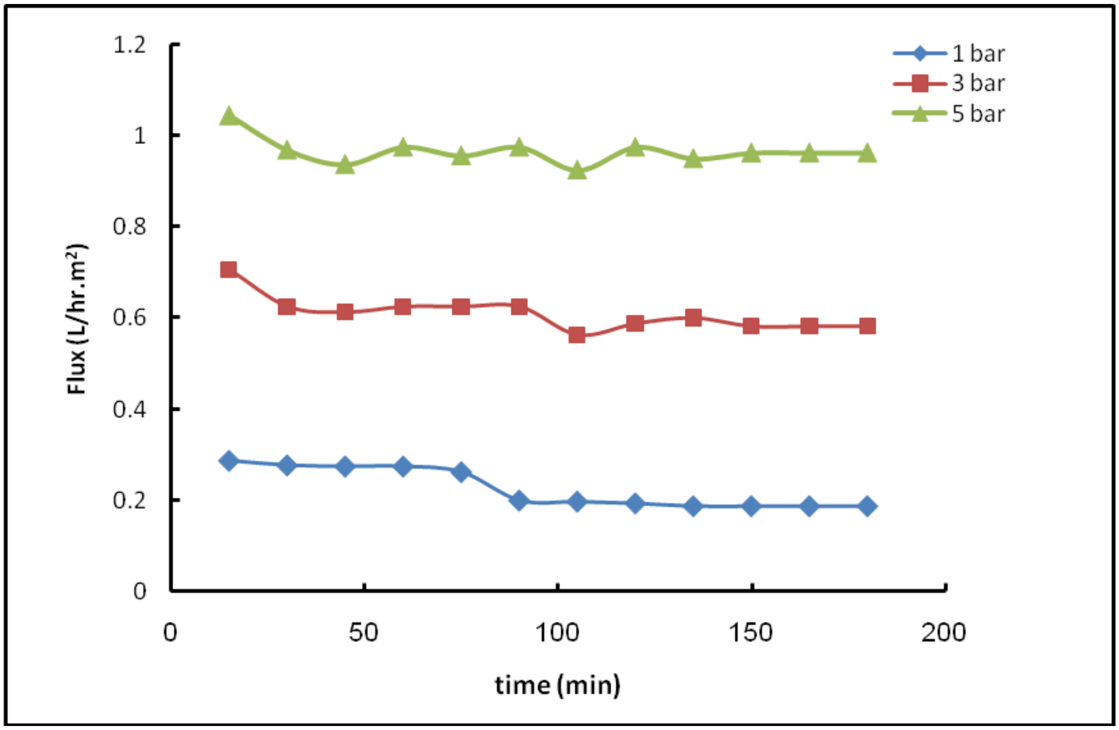

Figure 6. Effect of transmembrane pressure on permeation flux (conc.: 15000 ppm; temp.: 25°C).

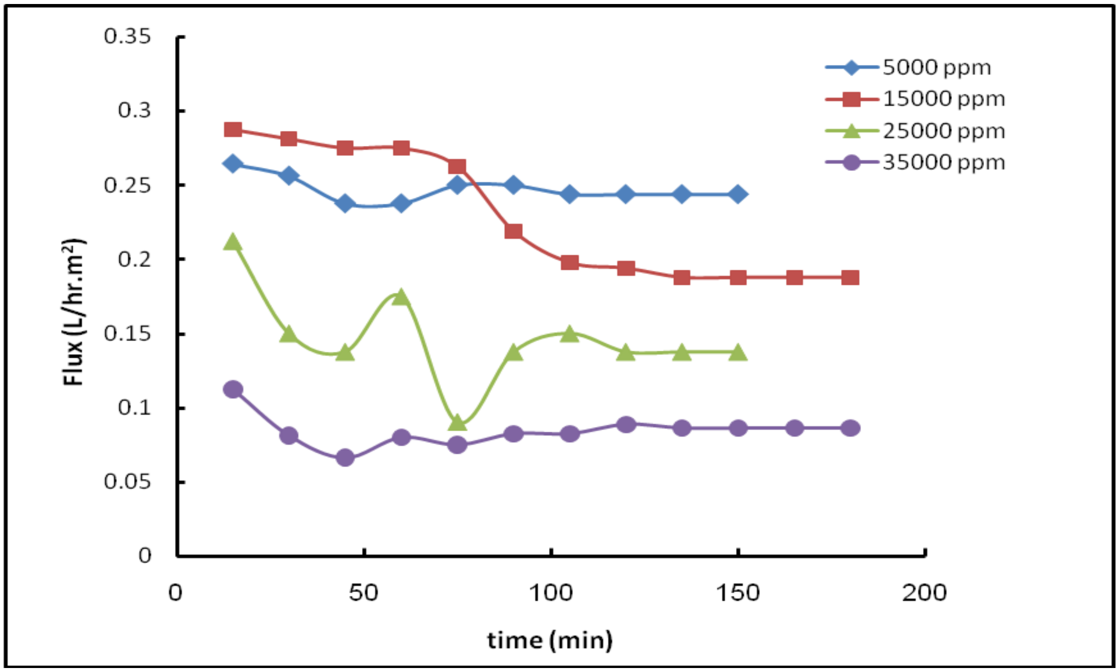

Figure 7. Effect of salt concentration on permeation flux (temp.: 25°C ; pressure: 1bar).

Table 1. Specification of RO membrane, Hidrotek RO Membrane.

Hidrotek RO membrane model	TW30-1812-50
Active area (ft^2 m^2	3.5(0.32)
Max pressure	300 psi (21 bar)
Max feed flow rate	2 gpm
Max operating temp	45°C
Max SDI (inlet)	5
Free chlorine tolerance	< 0.1 ppm
pH range (continuous operation)	3~10
pH range (chemical cleaning)	2~11