Performance Evaluation of Reverse Osmosis Process in Al-Dura Power Station

Dr. Hasan Ferhood Makki
Chemical Engineering Department – College of Engineering – University of Baghdad – Iraq

Summary

The present work aims to study the performance of reverse osmosis process at Al-Dura power station. The selected membrane which is used in this work is made from polyamide (thin film composite membrane (TFC)) constructed as spiral wound module. The basic advantages of this type of membrane are the higher productivity compared with the total volume of the module, and stability of the polymer towards the chemical effect.

It was found that recovery percentage (or product rate), rejection percentage (or solute concentration in product), and concentration factor decreases with increasing operating time for reverse osmosis unit, whereas, the operating pressure for reverse osmosis unit increase with time. Maximum salt rejection percentage and Maximum recovery percentage were determined to be 96% and 75% respectively for polyamide membrane.

تقييم اداء عملية التنافذ العكسي في محطة كهرباء الدورة

د.حسن فرهود مكي
قسم الهندسة الكيمياوية – كلية الهندسة – جامعة بغداد – العراق

الخلاصـــــــة

يهدف البحث الى دراسة اداء عملية التنافذ العكسي في محطة كهرباء الدورة . الغشاء المستعمل في هذا البحث مصنوع من (البولي أمايد) ومتوضع من النوع الحلزوني . الفائدة الاساسية من هذا النوع من الغشاء يعطي انتاجية عالية مقارنة بالحجم الكلي للموديل واستقرار البوليمر نحو التأثير الكيميائي.

لقد وجد بأن النسبة المئوية للاستعادة (أو معدل الناتج)، النسبة المئوية للرفض (أو تركيز المذاب في الناتج)، وعامل التركيز يقل بزيادة الزمن التشغيلي لوحدة التنافذ العكسي، بينما، الضغط التشغيلي لوحدة التنافذ العكسي يزداد مع الزمن. أعلى نسبة مئوية للرفض وأعلى نسبة مئوية للاستعادة تم تحديدها وهي 96% و 75% على التوالي لغشاء البولي أمايد.

Introduction

Reverse Osmosis (RO) is a physical process that uses the osmosis phenomenon, i.e., the osmotic pressure difference between the saltwater and the pure water to remove salts from water. In this process, a pressure greater than the osmotic pressure is applied on saltwater (feed water) to reverse the flow, which results in pure water (freshwater) passing through the synthetic membrane pores separated from the salt. A concentrated salt solution is retained for disposal. The RO process is effective for removing total dissolved solids (TDS) concentrations of up to 45,000 mg/L, which can be applied to desalinate both brackish water and seawater [1, 2].

Reverse osmosis needs energy to operate the pumps that raise the pressure applied to feed water. The amount of pressure required directly relates to the TDS concentration of the feed water. For brackish water, the pump pressure requirement is between 140 and 400 psi. For seawater, pumps may need to generate up to 1200 psi. Therefore, the TDS concentration of the feed water has a substantial effect on the energy use and the cost of the product water [3].

Two common types of membranes used in RO process for desalination include Cellulose Acetate (CA) membranes and Non-CA membranes. Cellulose Acetate membranes were developed in the 1960s and various modified and improved blends of CA membranes are currently used in the desalination process. The CA membrane has a relatively smooth surface that is resistant to fouling. It is theorized that if the membrane surface is rather smooth, the material that may cause fouling cannot deposit in the membrane crevices [4]. Non-CA membranes, typically called "thin-film composite membranes" include aromatic polyamide (PA) membranes and composite membranes using common organic materials such as polysulfone. These membranes have a higher flux rate (volume of freshwater per membrane surface area) and, compared to CA membranes, allow passage of lower salt concentration. Non-CA membranes are more stable over a broader pH range than the CA membranes, but are susceptible to degradation by chlorine [5].

Pre-treatment of feed water is essential in order to protect the RO membrane, reduce energy costs, and increase salt retention. It should be free of large particles, organic matter, bacteria, oil and grease. Typical pre-treatment involves multimedia, cartridge, and sand filtration to remove larger particles, organic matter and other materials; and adding chemicals to prevent the formation of precipitates and scaling of the membrane. Often, pH adjustment is also needed. The problem of membrane fouling is much more severe than either membrane compaction or concentration polarization, although the latter does contribute to the onset of fouling. Surface fouling takes place when there is a deposition of sub-micrometer particles on the surface, as well as crystallization and precipitation of smaller solutes [6]. It occurs when rejected solids are not transported from the surface of the membrane back to the bulk stream. Fouling can also occur in the pores of the membrane and is more difficult to rectify than surface fouling. In general, there are four major types of fouling – dissolved solids, suspended solids, non-biological organics and biological organisms. The different types of fouling frequently occur simultaneously and each can influence the rate of fouling from the other mechanisms [7, 8].

Membranes should be cleaned when there is 10–15% decreases in system performance, manifested by either a 10–15% reduction in permeate flow or a 10–15% increase in the pressure needed to maintain the same flow. Failure to clean according to the 10–15% rule may result in serious and irreparable damage to the membranes. Acid and sodium hexametaphosphate (SHMP) are usually added to prevent scaling in brackish water system [9].

In the present study, performance of reverse osmosis in Dura power station was investigated experimentally. The effect of operating time for brackish water on recovery percentage, rejection percentage, concentration factor and operating pressure have been determined.

Recovery

Recovery rate is a major parameter for evaluating membrane effectiveness. Recovery is defined as the volume of freshwater produced as a percentage of the volume of feed water processed.

$$\text{Recovery} = \left(\frac{Q_p}{Q_f}\right) \times 100 \qquad ...1$$

Where Q_p is the permeate (or product) flow rate and Q_f is the feed flow rate. Typical recovery rates for RO systems can be 30 percent to 80 percent depending on the quality of feed water, pressure applied, and other factors. Reverse osmosis membranes that operate at low pressures but maintain high recovery rates have been developed. Typically, these ultra low-pressure reverse osmosis membranes (ULPRO) are made of thin film composites of polymers, with an active surface layer that is negatively charged with improved fouling resistance properties [10, 11].

Salt Rejection

Salt rejection expresses the effectiveness of a membrane to remove salts from the water. It can be calculated from the following equation;

$$R = \left(\frac{C_f - C_p}{C_f}\right) \times 100 \qquad ...2$$

Where C_f is the concentration of a specific component in the feed solution to the membrane process and C_p is the concentration of the same specific component in the cleaned discharge stream leaving the membrane system [12]. Rejections varied considerably for the different solutes, and rejections of ionizable organics were greatly dependent on degree of dissociation; nonionized and hydrophobic solutes were found to be strongly sorbed by the membranes and exhibited poor rejection. In reverse osmosis, a high rejection of total dissolved solids (TDS) is important.

Concentration Factor

Concentration factor (CF) is the ratio of the feed quantity (or feed stream) over the concentrate quantity (or concentrate stream). It can be calculated from the following equation;

$$CF = \frac{C_c}{C_f} \qquad ...3$$

Where C_c is the concentration of the solute (dissolved species) or solid in the concentrate or reject stream. The dependence of the concentration factor on operating conditions and water composition is why manufacturers want to have a water analysis before they give membrane system quotes [13].

Experimental Work

The reverse osmosis Industrial unit works at Al-Daura power station. This unit employs the TFC modules using spiral - wound polyamide membranes. Figure 1 shows a schematic diagram of reverse osmosis industrial unit. Table 1, shows the specifications of the plant.

Table 1 The Specifications of the Reverse Osmosis Industrial Unit.

Rated capacity	Recovery	Feed Rate	Permeator	Stage	Vessels	Permeators per vessel	Feed pressure norm/max
27 m^3/hr	75 %	36 m^3/hr	TFC - 8822 HR	3	6	4	20/40

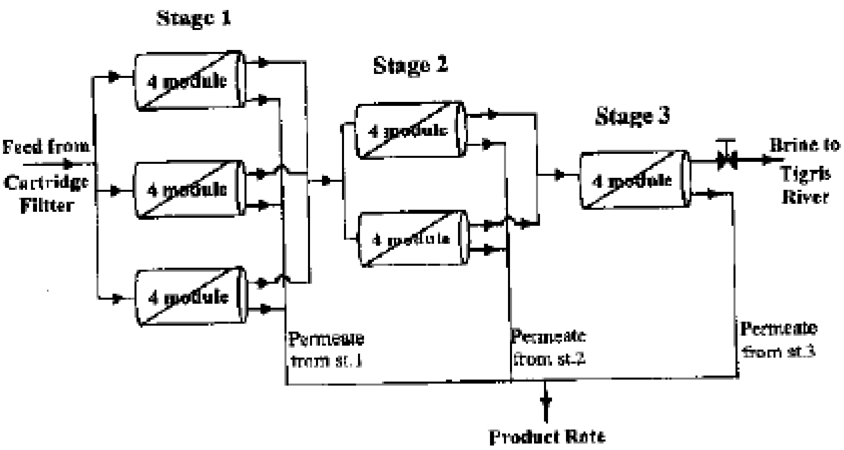

Figure 1 Schematic Diagram of Reverse Osmosis Industrial Unit.

In reverse osmosis unit, the water flowing from the activated carbon filters to the reverse osmosis plant is blended with a hardness stabilizer (sodium hexa meta phosphate) in order to avoid precipitations, and with hydrochloric acid to reduce the pH value.

To increase the yield (conversion factor), the osmosis plant is controlled in third stages. The total brine stream from the first stage is the feed for the second stage, the brine from the second stage is the feed for the third stage, and the concentrate from the third stage is discharged as waste water into the Tigris River. The permeate collected from the three stages is advanced to the osmo water storage tank. Various equipment such as temperature recorders, pH meter, TDS meter, flow meters, pressure gauges, etc. are also inclusive for monitoring and controlling the reverse osmosis system in operation.

Periodic cleaning of the membrane surface is required to maintain high water transfer efficiency.

Results and Discussion

The recovery percent from reverse osmosis unit are plotted vs. time, as shown in Figure 2. It can be easily observed that the recovery (or product rate) from reverse osmosis unit decrease with increase in operating time. The product rate of a reverse osmosis system decrease as fouling occurs, because the foulants on the membrane surface retard the back diffusion of the salt into the bulk solution to cause concentration polarization at the membrane surface. The increase in concentration polarization causes a decrease in the product rate and an increase in the operating pressure (Figure 3). This can be explaining the decreasing of product rate and increasing of the operating pressure with increase operating time. But after cleaning of membranes the product rate will increase and the pressure will decrease.

The membrane cleaning process is required when salt passage increased, product water flow rates decline and the module bank pressure drop increased.

Figure 4 shows the effect of operating time on rejection percent for reverse osmosis industrial unit. The increase in concentration polarization causes an increase in the salt passage. This reason can be explain the increase solute concentration with increase in operating time. The decrease of salt concentration will increase the rejection percentage and vice versa. Also after the cleaning, the salt passage decreasing through the membranes, consequently the rejection percent increases.

As the operating time of reverse osmosis unit increases, the concentration factor (CF) (or reject concentration) will decrease. This is shown in Figure 5. The increasing of time means the increasing of salt concentration in permeate and decreasing of product rate, which led to an increase in the reject concentration. The increasing of reject concentration will increase the concentration factor (Equation 3).

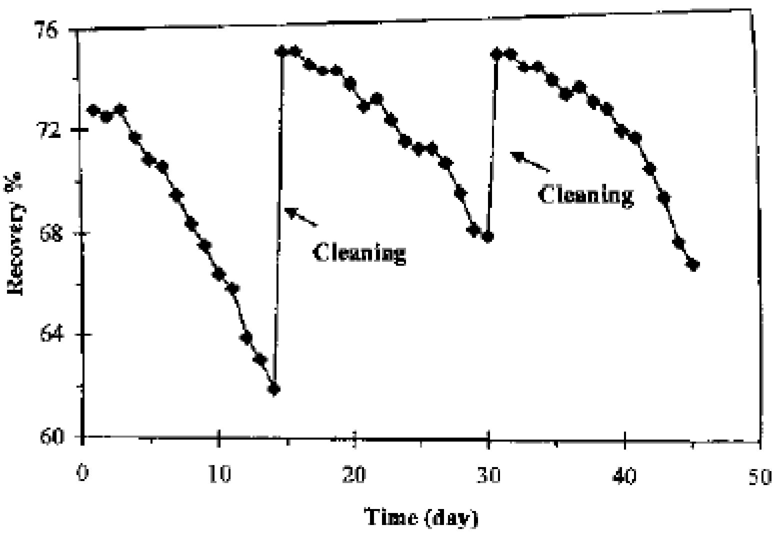

Figure 2 Effect of Operating Time on Recovery Percentage (C_f =550 – 560 mg/L, Q_f = 36 m^3/hr and T=23 – 25 °C).

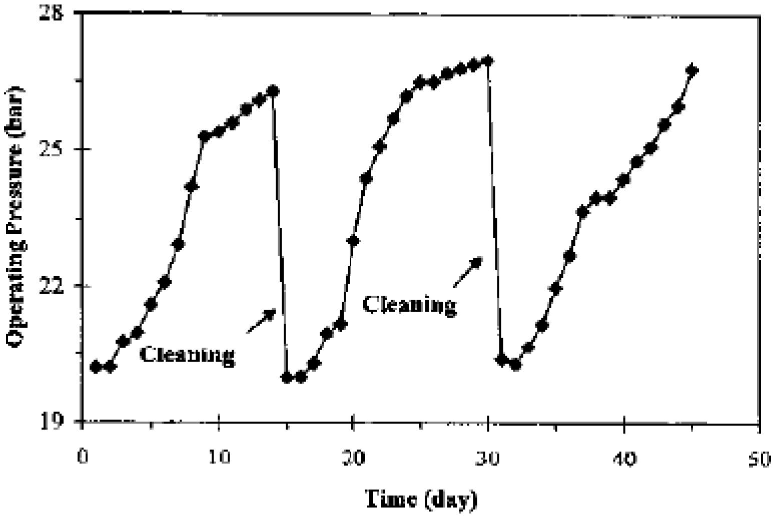

Figure 3 Effect of Operating Time on Operating Pressure (C_f =550 – 560 mg/L, Q_f = 36 m^3/hr and T=23 – 25 °C).

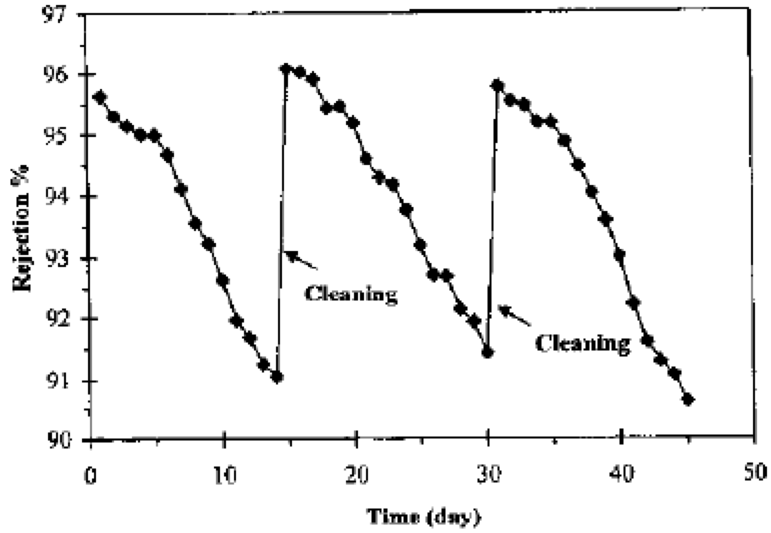

Figure 4 Effect of Operating Time on Rejection Percent (C_f =550 – 560 mg/L, Q_f =36 m^3/hr and T=23 – 25 °C).

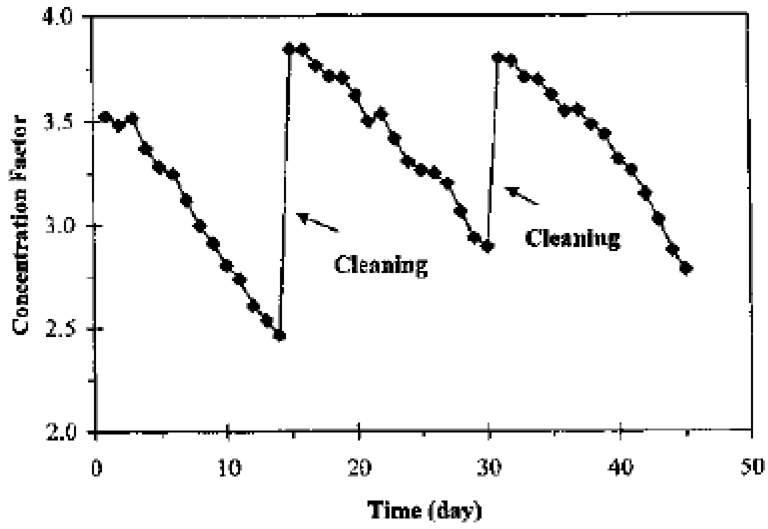

Figure 5 Effect of Operating Time on Concentration Factor (C_f =550 – 560 mg/L, Q_f = 36 m^3/hr and T=23 – 25 °C).

Conclusions

1. The recovery percent, rejection percent and concentration factor of the thin film composite membrane decreases with the operating time.
2. The mean reason for flux decline is due to membrane fouling with time (during 45 day).
3. Maximum recovery percentage is 75% at P = 20 bar, Q_F = 36 m^3/hr, C_F = 550 – 560 mg/L and T = 24 °C.
4. Maximum salt rejection percentage is 96% at P = 20 bar, Q_F = 36 m^3/hr, C_F = 550 – 560 mg/L and T = 24 °C.
5. Membrane compaction phenomenon was not apparent.

Acknowledgment

The author wish to thank the staff of water treatment department in Dura power station, especially engineers Wiaam K. Hassan and Janet L. Zozan, and the supervisor of the department Mr. Sabah Challoub.

Nomenclature

Symbol	Definition	Units
C_c	Reject concentration	mg/L
C_f	Feed solute concentration	mg/L
CF	Concentration factor	
C_p	Product solute concentration	mg/L
P	Pressure	bar
Q_f	Feed flow rate	m^3/hr
Q_p	Product flow rate	m^3/hr
R	Rejection percentage	
T	Temperature	°C

References

1. Ahmed F.H., "Study of The Factors Affecting The Efficiency of Reverse Osmosis Process", M.Sc. thesis, Baghdad University, (2000).
2. Baker R. W., "Membrane Technology and Applications", John Wiley & Sons, (2004).
3. Sourirajan S., "Reverse osmosis", Academic, New York, 1970.
4. Nicolaisen B., "Desalination", 153,355, (2002).
5. El-Dessouky H.T. and Ettouney H.M., "Fundamentals of Salt Water Desalination", Department of Chemical Engineering, College of Engineering and Petroleum, Kuwait University: Elsevier, Amsterdam, (2002).
6. Kenneth I.N., "Evaluation of Membrane Filters Experiment at Gaddvik Drinking Water Plant, Luleå", M.Sc. Thesis, Luleå University of Technology, (2007).

7. Khawla A. M., "Modeling, Simulation, and Optimization of Large-Scale Commercial Desalination Plants", Ph.D. thesis, State University, (1998).

8. Durham B., Bourbigot M.M., and Pankratz T., "Desalination", 138, 83, (2001).

9. Hoon H., and Jae-Hong K., "Journal of Membrane Science", 286, 269, (2006).

10. Ozaki H., and Huafang, L., "Water Research", 36,123, (2002).

11. Bertelsen, http://www.osmonics.com/products/Page831.htm, (2005).

12. Kaup E.C., and Roe, Inc., "Chemical Engineering", 80, 46, April (1973).

13. ZENON Environmental Inc., "Development of an Advanced Transverse Flow Nanofiltration Membrane Process for High Performance Desalination", Water Treatment Techuology Report No. 9, June, (1995).