TECHNICAL AND ECONOMIC CONSIDERATION FOR WATER DESALINATION BY REVERSE OSMOSIS

Y. Abdelaziz*, A. Karameldin*, S. Mekhamer*, and, N. Abdelmonem**

*Reactors Department, Nuclear Research Center, Atomic Energy Authority,
P.O.13759 Inshas- Cairo, Egypt - Fax. +202 4620778
**Chemical Engineering Department, Faculty of Engineering,
Cairo University, Cairo, Egypt

ABSTRACT

Product flow rate and salt rejection are the key performance parameters. They are mainly influenced by variable parameters such as feed pressure, feed temperature, and feed water salt concentration. The effect of feed temperature on membrane performance is the most important parameter. A seawater membrane FT30SW-2540 included in a test rig is used to perform the study. The membrane water permeability coefficient K_w is determined experimentally by the test rig measured parameters and compared with the projected manufacturer system analysis program (ROSA) for the same operating conditions. Besides, it correlated and presented with the different operating parameters. The results show that the permeate flux increases by increasing the feed pressure and/or increase the feed temperature. For the same system productivity, the increase in the feed water temperature leads to reduce the applied feed pressure. For such case the results also show that; an increase in the feed water temperature by one degree centigrade is associated with a reduction in applied feed pressure by 0.7 % to 1.35 %, a decrease in the membrane salt rejection of almost 1.4%, an increase of permeates flux from 1.11 % to 2.58 %, and a decrease of the specific energy consumption by an average value of 0.29 KW/1000 gal, according to the feed salt concentration and feed pressure. The results show that an increase in feed salt concentration of one gram per liter decreases permeate flux by an average value of 2.41% to 2.8 %, decreases the membrane salt rejection percentage by 0.06 to 0.16, decreases the membrane water permeability coefficient by 1.23%, and increases the specific energy consumption by an average value of 5.073 KW/1000 gal, according to the feed temperature. In addition, the membrane FT30SW-2540 water permeability coefficient is experimentally determined, compared with manufacturer, and correlated as a function of feed salt concentration, feed temperature, and feed pressure.

INTRODUCTION

RO membrane permitting only fresh water to pass through, separating salt at a higher feed pressure than the osmotic pressure of seawater by means of a high-pressure pump. The RO system design tends to save the pump power as well as increasing the system productivity. The experts and the system designer's regards to the RO feed preheating systems have two different opinions. The first group believes that the RO feed preheating increases the system productivity and/ or saves the process power consumption. Meanwhile, the second group believes that RO feed preheating neither increases the system productivity, nor increases the salt passage. In this respect, the author carried out an extensive work. In which the criteria of the feed preheating of the seawater RO system optimal operation is extensively studied concerning the leading element [1]. Moreover, a proposal of RO system rehabilitation is presented and analyzed [2]. It is worth mentioned that aforementioned works is carried out through the RO system projection to determine the permeability coefficients for water of the used membranes. In the present work, the conformation of the projected permeability coefficient for water is carried out experimentally to realize and confirm the aforementioned works in the field of co-generative systems study area. An experimental setup of small seawater RO system is equipped with appropriate measuring instruments is performed to measure the operating parameters, such as feed pressure, flow rate, temperature, and salt concentration, and system productivity. The corresponding projections are also performed.

THE EXPERIMENTAL LOOP

Small reverse osmosis unit is used to carry out this work. This experimental loop was constructed at the Heat Transfer and Desalination Laboratory, Reactor Department, Nuclear Research Center, Egyptian Atomic Energy Authority. Dissolved NaCl in tap water prepared the synthetic feed water, with similar concentrations as seawater for use in these experiments. A new membrane of a FILMTEC model FT30SW2540 membrane is installed to avoid the uncertainty of the membrane fouling. In such case the fouling factor is consumed equal to unity (FF = 1). The experimental rig front and side views are shown in Figure (1). The rig is equipped with accurate measuring instruments such as the digital pressure gage, temperature controller, and conductivity meter to measure the operating parameters. It is worth to mention that this small experimental rig can be helpful to obtain results that explaining the performance of the unit, which gives the insight of the best operation and control of the large RO units.

(a) rig side view **(b) rig front view**

Fig. (1) RO experimental rig

MEMBRANE PERFORMANCE

The membrane performance is affected by different operating parameters, which contribute in assigning the membrane flux and membrane salt rejection, such as applied feed pressure, feed temperature, and feed salt concentration.

1. The feed temperature

In the present study, the membrane FT30 SW 2540 will be considered [3]. Therefore, the membrane water permeability coefficient, (K_w) is determined from the Reverse Osmosis System Analysis program (ROSA) [4] at different operating feed temperature, feed salt concentration, and constant permeate flow. Figure (2a) depicts the membrane water permeability coefficient for water, (K_w) variations with the feed temperature at different feed-brine concentrations. This Figure shows that K_w slightly decreases by increasing the temperature. It increases by decreasing the feed-brine concentration.

Figure (2b) depicts the effect of feed temperature on the applied feed pressure for different feed salt concentration, and constant permeate flow. It is clear from Fig. (2) that the applied feed pressure decreases by the increase of the feed temperature for all feed salt concentrations. The results from running ROSA program clarifies that, for the membrane integrity point of view, any increase of feed temperature (T_f) by one degree centigrade, must corresponded to a decrease of the feed pressure (P_f) with a percentage of 1.348% to 0.695% according to the feed salt concentration of water, to maintain the same membrane permeate flux.

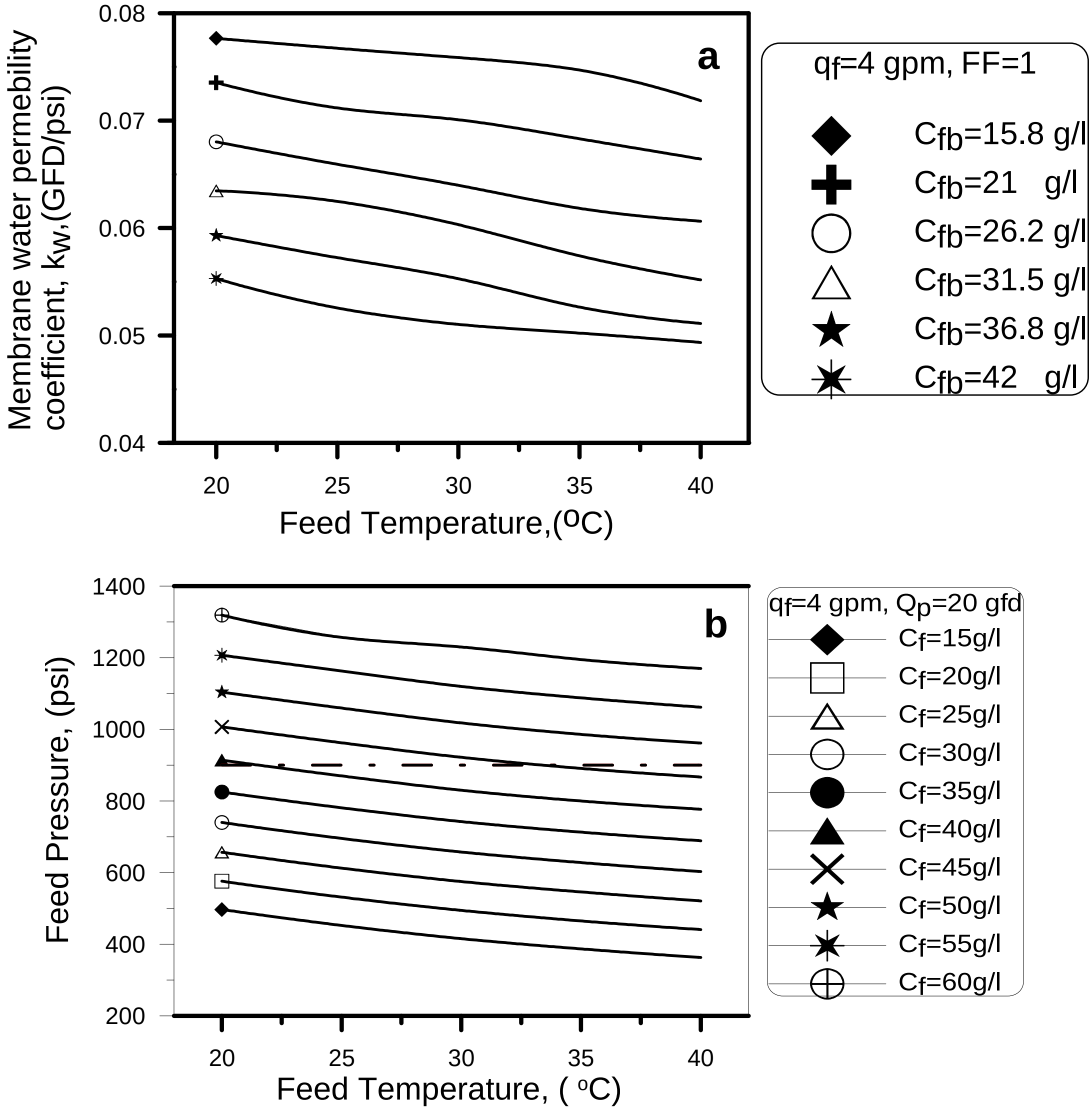

Fig. (2) Effect of feed temperature on FT30SW2540 permeability coefficient and feed pressure for different feed concentrations

Figure (3) depicts the effect of feed temperature on the permeate flux, salt rejection, and the permeator product recovery together at different feed salt concentrations and different feed pressures. It is worth mentioning that the broken lines in this Figure indicate the manufacture membrane operating productivity flux limitation.

It is clear from Fig. (3a and d) that the permeate flux increases by the increase of feed temperature for the decrease of feed salt concentration (at constant feed pressure (600 psi)), and for the increase of feed pressure. The obtained results from the experimental work show that; an increase of feed temperature of one degree centigrade, leads to an increase of 2.58%, 2.39%, 2.19%, 1.25%, and 1.11% of permeate flux, corresponding to feed salt concentrations of 25 g/l, 30 g/l, 35 g/l, 40 g/l, and 45 g/l respectively, at feed pressure of 600 psi. Meanwhile, an increase by feed temperature of one degree centigrade, results in an increase of 1.43%, 1.95%, and

1.78% of permeate flux, corresponding to feed pressures of 600 psi, 700 psi, and 800 psi respectively, at feed salt concentration of 40 g/l.

It is clear from Figures (3b and e) that the permeator salt rejection decreases by the increase of the feed temperature, for different feed salt concentrations and feed pressure respectively. The obtained results from the experimental work demonstrates that; an increase of feed temperature of one degree centigrade, results in an average decrease for salt rejection of 1.4% at the feed pressure of 800 psi. Meanwhile, the salt rejection decreases by the increase of the feed salt concentrations, and the decrease of feed pressure.

Figures (3c and f) illustrate the effect of feed temperature on the permeator recovery, for different feed salt concentrations and feed pressure respectively. Figure (3c) illustrates that the permeator recovery increases by the increase of the feed temperature, and remarkably increase by the decrease of the feed salt concentrations.

Meanwhile, the permeator recovery increases by the increase of the feed temperature and feed pressure.

2. The feed pressure

Figure (4) depicts the effect of feed pressure on the permeate flux, salt rejection, and the permeator product recovery; together at different feed salt concentrations and constant feed temperature ($T_f = 25\ ^{O}C$). It is worth mentioning that the broken lines in this Figure indicate the manufacturer membrane operating limitations.

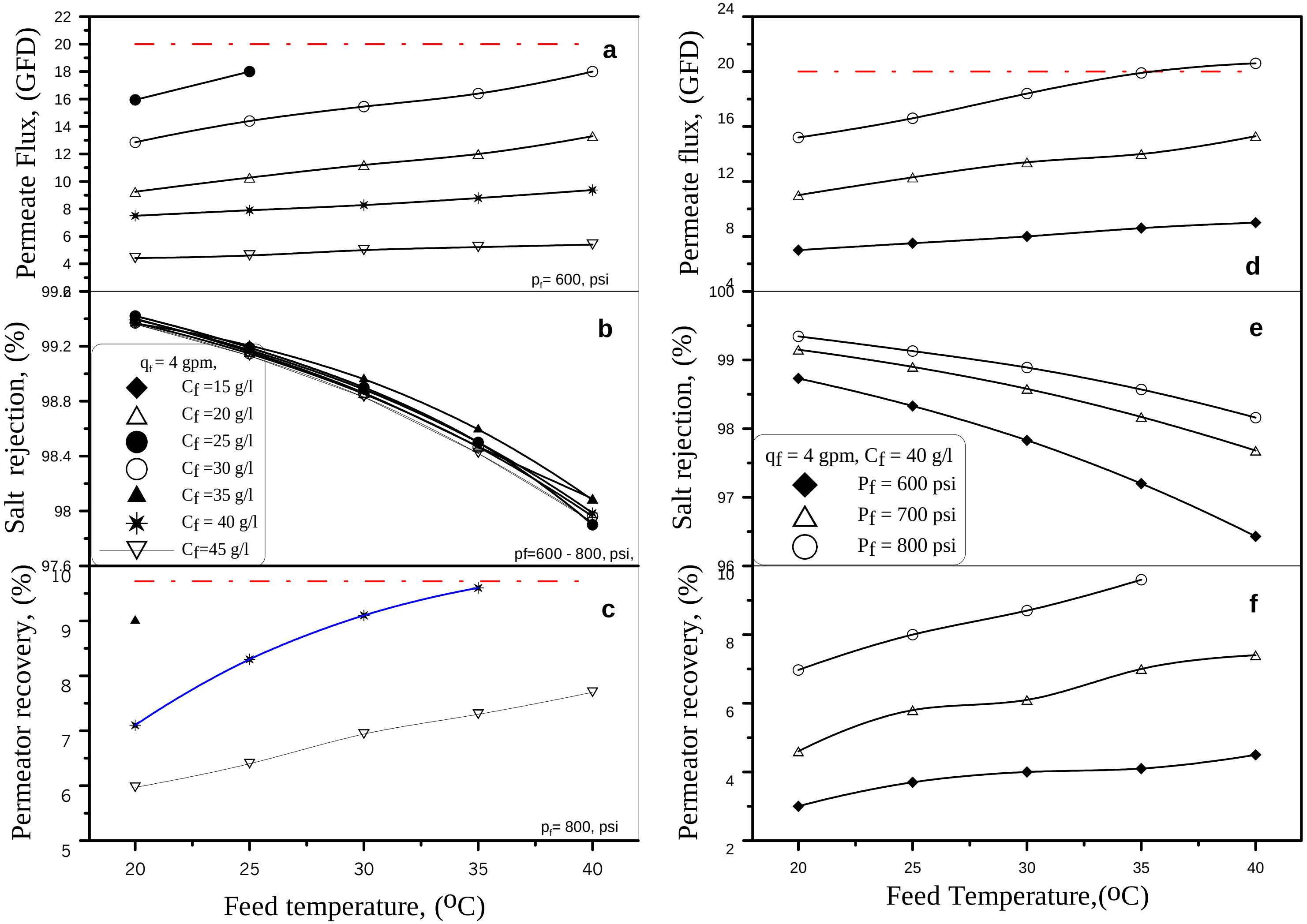

Fig. (3) Effect of feed temperature on permeates flux, salt rejection, and recovery

Figure (4a) illustrates the effect of feed pressure on the permeate flux at different feed salt concentrations. It is clear from the Figure that the permeate flux surprisingly increases by the increase of the feed pressure and by the decrease of the feed salt concentration. The same trend is indistinguishably observed in Fig. (4c), which depicts the permeator recovery variations with the feed pressure. Furthermore, the permeator salt rejection remarkably increases as the feed pressure increase, as shown in Fig. (4b).

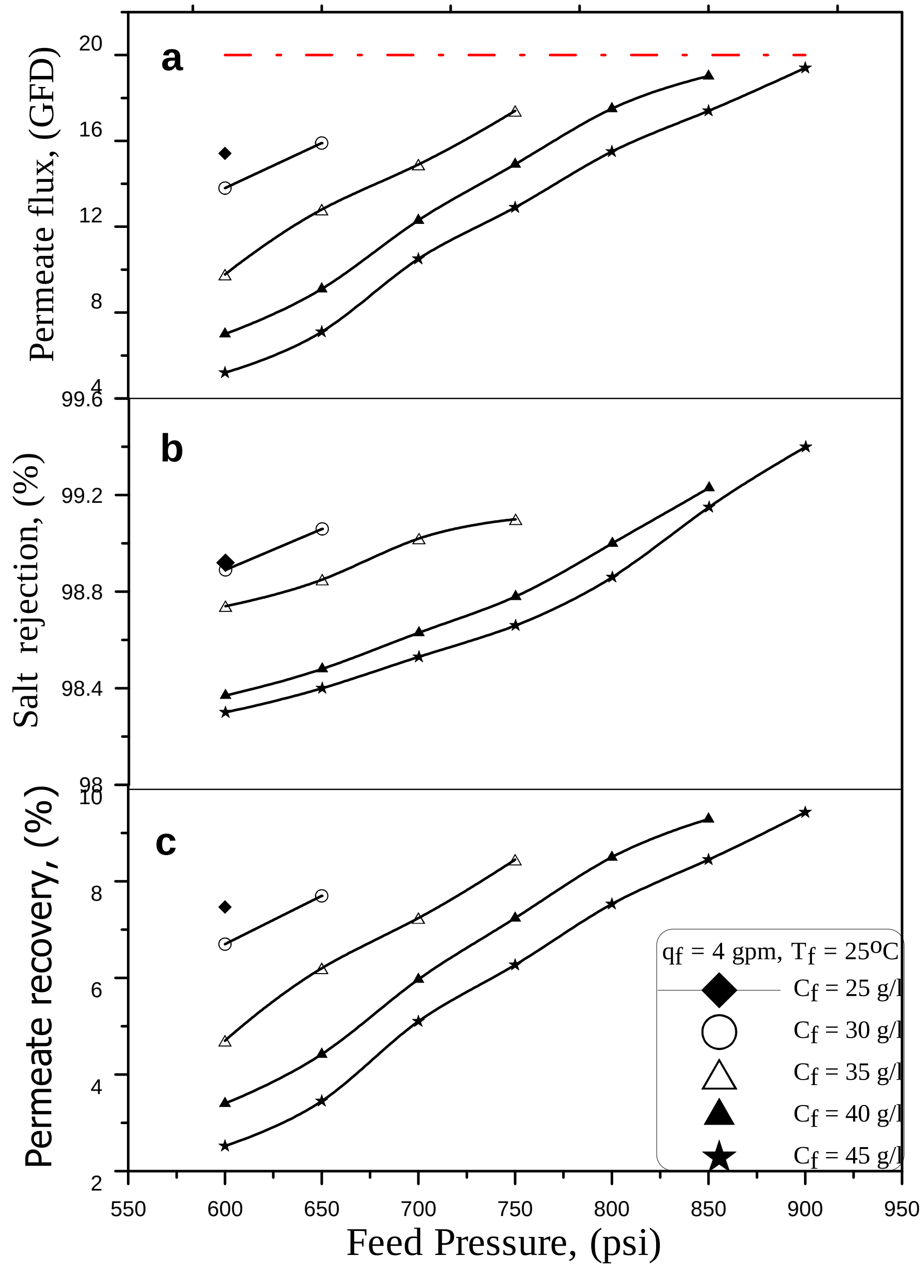

Fig. (4) Effect of feed pressure on permeate flux, salt rejection, and permeator recovery

3. The feed salt concentration

Figure (5) depicts the effect of feed salt concentrations on the permeate flux, salt rejection, and the permeator product recovery; together for different feed temperature and constant feed pressure (600 psi). The broken lines in the figure indicate the manufacturer maximum operating permeate flux.

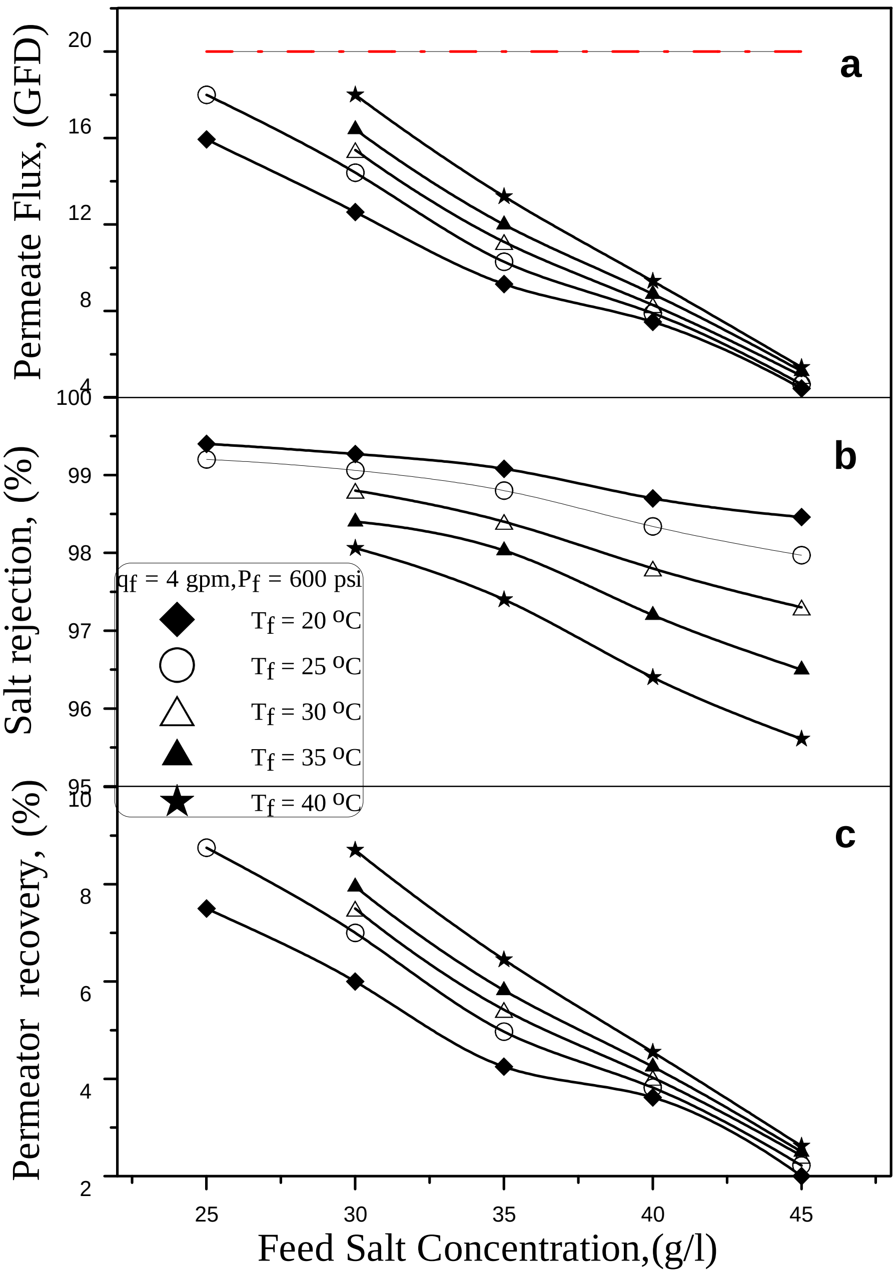

Fig. (5) Effect of feed salt concentrations on permeate flux, salt rejection, and recovery

Figure (5a) illustrates the effect of feed salt concentration on the permeate flux at different feed temperature. It is clear from Fig. (5a) that the permeate flux decreases by the increase of the feed salt concentration and by the decrease of the feed temperature. Any increase in ($C_{f)}$ value with one g/l decreases the permeate flux by an average value of 2.41% to 2.8 % according to the feed temperature, for a constant feed pressure (P_f = 600 psi). The same trend is indistinguishably observed in Fig. (5c), which depicts the permeator recovery variations with the feed concentrations.

Figure (5b) depicts that the effect of feed salt concentration on the permeator salt rejection at different feed temperature. It is clear from the experimental work that the salt rejection percentage of the permeator decreases by the increase of the feed salt concentrations and by the increase of the feed temperature. The average decrease in the salt rejection percentage of the permeator is 0.06 to 0.16, according to the feed temperature.

Figure (6) depicts the effect of feed salt concentration on the membrane water permeability coefficient k_w at different feed temperature. It is clearly observed from this figure that as the membrane water permeability coefficient k_w considerably decrease by the feed salt concentration increase with an average decrease value of 1.23% per one gram per liter feed salt concentration increase.

Figures (6 a and b) illustrate the effect of feed salt concentration on the membrane water permeability coefficient k_w at different feed temperature obtained from the experimental data and from the Reverse Osmosis System Analysis program (ROSA [4]) respectively, at different feed temperature. These figures show that the permeability coefficient k_w decreases by the increase of the feed salt concentration. Meanwhile, it is slightly decrease by the increase of the feed temperature. It is observed from these figures, that the permeability coefficient of a feed temperature at 20 ^oC has slightly elevated value than the rest of the feed temperatures. This may attribute to the effect of temperature correction factor, which has a value less than unity at this feed temperature. The relationship between K_w, feed temperature, feed pressure and feed salt concentration obtained from the experimental data is correlated as in the following equation;

$$K_w = (0.4675 - 0.136761*\beta*\pi_{fb})*(0.3702 - 0.179744*T_f)$$

where; K_w = permeability coefficient, gfd/psi

β = concentration polarization factor

π_{fb} = average feed-brine osmotic pressure, psi

T_f = feed temperature, ^oC

This equation demonstrates that the membrane permeability coefficient for water K_w decreases by increase of feed temperature and increases of feed salt concentration.

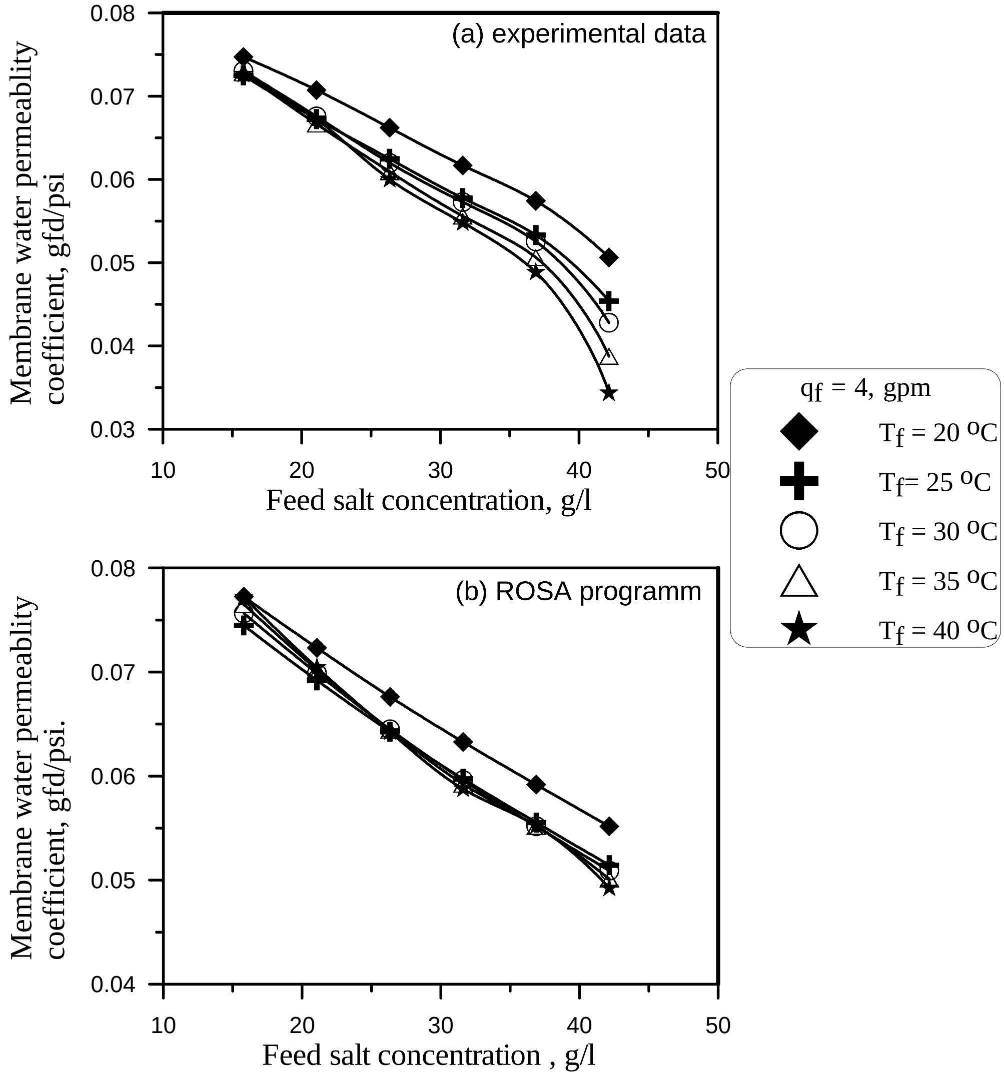

Fig. (6) The variations of the permeator water permeability coefficient with the feed salt concentration

Figure (7) shows the comparisons of water permeability coefficients variations of experimental data and ROSA 6 program [4], with the feed salt concentration at each individual feed water temperature. Figures (7 a, b, c, d, and e) depict the differences of the membrane permeability coefficient for water obtained from experimental data and ROSA 6 program, at different feed salt concentrations. It is observed from Figs. (7 a, b, c, d, and e) that the variations of experimental data and ROSA 6 program at the feed salt concentration of 42 g/l is slightly deviated for the experimental data from ROSA 6 program, which may attributed to the limitation of the flow meter in this range of low permeate flow rate. The rest feed salt concentrations ranges between the experimental data and ROSA 6 program, have tiny differences. The membrane permeability coefficient for water k_w obtained from ROSA 6 program is deviated from that obtained experimentally by a value less than 5.48 %.

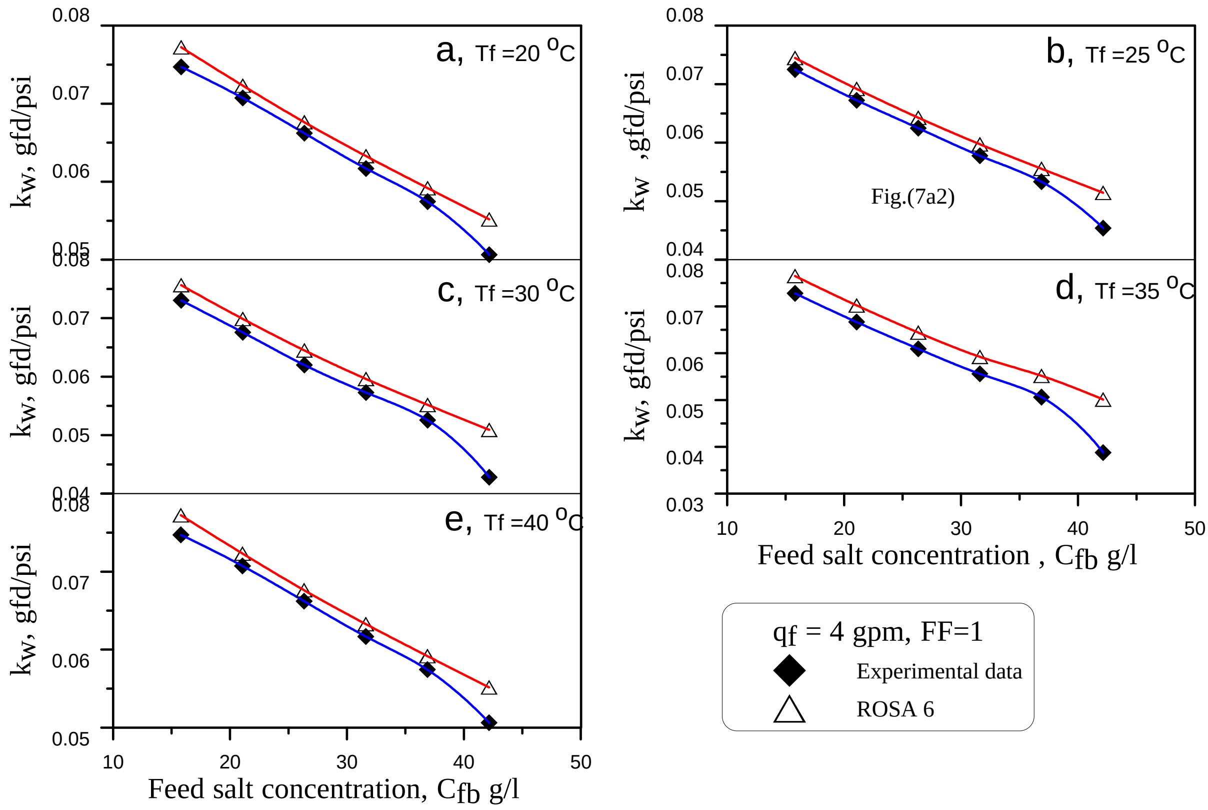

Fig. (7) Comparison between the permeator permeability coefficients obtained from experimental data and ROSA program

EFFECT OF OPERATING PARAMETERS ON WATER UNIT COSTS

Desalinated water cost is one of the main parameters used in selecting specific desalination technology. Capital and operating costs are the two main parameters used in cost estimates for any desalting process. Unit product cost is affected by several design and operational variables: Salinity and quality of feed water, plant capacity, site conditions, qualified labor, energy, and plant life and amortization. From an operational and economical point of view, one of the most important design features of RO seawater plant is the feed pump energy consumption per unit volume of permeate produced (i.e. specific energy consumption). Figure (8) depicts the effect of the feed temperature and feed salt concentration on the product specific power consumption. It is clear from Fig. (8a) that the specific energy consumption decreases as the feed temperature increases almost by an average value of 0.29 KW/1000 gal per one-degree centigrade. Meanwhile, it is considerably increases by the increase of the feed salt concentration by an average value of 5.073 KW/1000 gal per one-degree centigrade. The recent result confirmed with the author findings [2, 5].

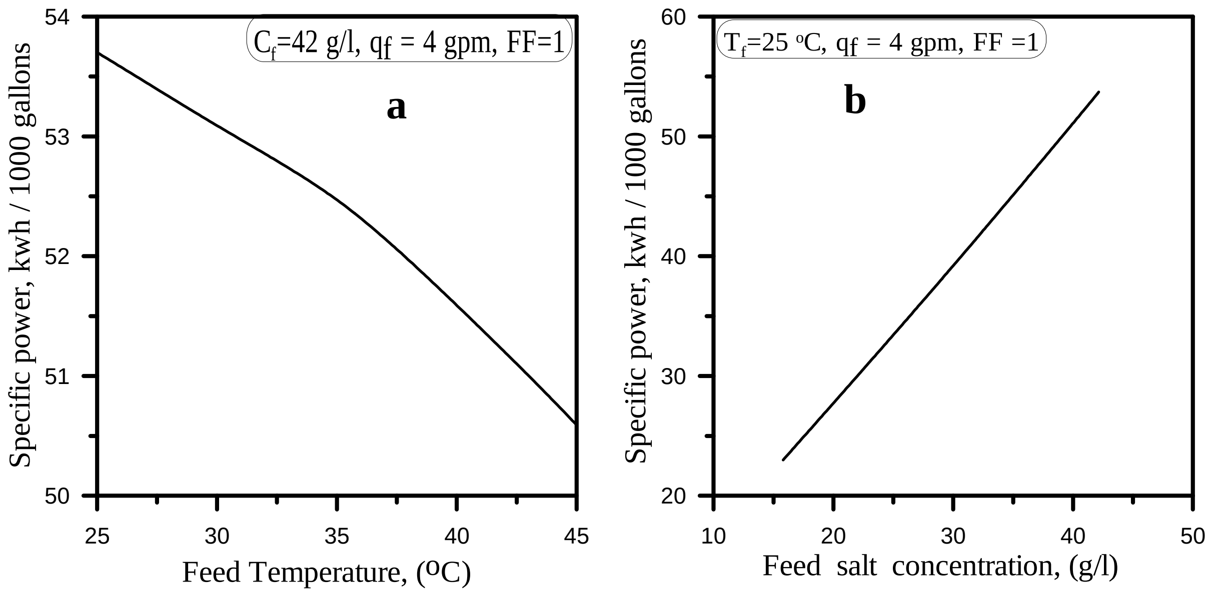

Fig. (8) Effect of the feed temperature and salt concentration on the permeate specific energy consumption

CONCLUSIONS

1. An increase one degree centigrade of the feed water temperature leads to:
    a. A reduction of applied feed pressure from 0.7 % to 1.35 % according to the feed salt concentration, to maintain the same membrane permeates flux.
    b. An increase of permeates flux from 1.11 % to 2.58 % according to the feed salt concentration and feed pressure.
    c. A decrease in the membrane salt rejection of almost 1.4%
    d. A decrease of the specific energy consumption by an average value of 0.29 KW/1000 gal, at the same feed salt concentration.
2. An increase in feed salt concentration of one gram per liter (C_f) leads to:
    a. A decrease of the permeate flux value equal to from flux by an average value of 2.41% to 2.8 % according to the feed temperature.
    b. An average decrease of the permeator the salt rejection percentage of 0.06 to 0.16, according to the feed temperature.
    c. A decrease in the membrane water permeability coefficient with an average value of 1.23%
    d. An increase in the specific energy consumption of an average value of 5.073 KW/1000 gal.
3. The membrane FT30SW-2540 water permeability coefficient is experimentally determined and correlated as a function of feed salt concentration, feed temperature, and feed pressure.
4. Extensive studies are needed for different membrane types for different manufacturers to explore membranes characteristics and adaptation for co-generative systems.

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