STUDY OF THE FACTORS AFFECTING THE EFFICIENCY OF REVERSE OSMOSIS PROCESS

Talib A. Al-Saffar, Ahmed Faiq Hassan
Chemical Engineering Department – College of Engineering – University of Baghdad – Iraq

ABSTRACT

The present work aims to study factors affecting on performance of reverse osmosis process, which work at Dura power station. The effects of the operating pressure in the range of (4 – 6 bar), pH in the range of (5 – 9), and feed concentration in the range of (391.28 – 618.48 p.p.m) on the product rate and product solute concentration were studied for reverse osmosis pilot plant and NaCl – H_2O system.

The experimental design of Box – Wilson method was adopted to find a useful relationship between the three controllable variables and two responses (product rate and product solute concentration). The experimental data collected by this design is successively fitted to a second order polynomial mathematical model.

The best operating conditions which lead to good quantity and quality for water product are : 5 – 5.5 bar operating pressure, 5.8 – 6.2 pH, and 500 – 550 p.p.m feed solute concentration. At these conditions the product rate is 382 l/hr, the product solute concentration is 23.3 p.p.m, the conversion is 13.7%, and the rejection percentage is 95.3%.

The selected membrane used a polymeric membrane 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.

The results showed the effect of operating pressure has the greatest effect on the product rate among other variables. Also the effect of feed concentration has the greatest effect on the solute concentration in product among other variables.

INTRODUCTION

The membrane can be defined as a region of discontinuity interposed between two phases[1]. This statement implies that membranes can be gaseous, liquid or solid, or combinations of these phases. The separating of solutes through natural - origin membranes by the effect of pressure had been known for hundred years ago[2].

Membrane processes [3] can be broadly classified in two groups on the basis of the nature of the driving force employed in their operation. The more widely used membranes are those that rely on an imposed pressure gradient to force water through the membrane. The second type of membrane process uses an electrical potential gradient across the membrane to effect the selective migration of ions in a filtration process known as Electrodialysis.

A generic view of a membrane separation system is show in Figure (1). A feed solution is in contact with a membrane across which the solvent may pass preferentially with respect to some solute[4]. Membrane systems are unit processes that become a widely accepted for the demineralization of saline and other wastewater [5].

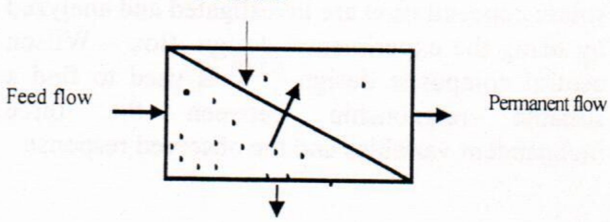

Figure (1) Schematic of membrane separation system. Solid dots represent Solute molecules.

Transport of fluid or solutes through membranes can occur by any of several different mechanisms, depending on the structure and nature of the membrane [6,7]. In all cases, transport of any species through the membrane is driven by a difference in chemical potential of that species across the membrane.

The driving forces may result from differences in pressure, concentration, electrical potential, or combination of these factors between the fluid phases on the upstream and downstream sides of the membrane [8,9].

The Permeation process is occurring in three steps. First, permeating species must enter the membrane, next, it passes through the membrane, and finally, it leaves from downstream surface. The pressure drop across the membrane works to open holes through which the permeating species can pass.

Reverse osmosis is used primarily prepare pure water from dilute aqueous solutions, though it could be used for purifying organic solvents. The main advantages of the process are that separation can take place at room temperature and there is no phase change [10,11].

The aim of this work is to study the effect of changing the pH value, concentration and the pressure of the feed water on the properties of the product water, and then predict the best operating condition for separation to a certain type of membrane.

EXPERIMENTAL WORK

Application of Box-Wilson Method to the Experiment

The effects of operating pressure, pH, and feed concentration on the product rate and product solute concentration are investigated and analyzed by using the experimental design. Box – Wilson central composite design [12,13] is used to find a suitable relationship between the three independent variables and the observed response.

Feed Preparation

Demineralized water, of 2 μS/cm conductivity, was used for making solutions of (391.28 – 618.48 p.p.m) sodium chloride concentration, Table (1) shows feed system concentration and their corresponding conductivities at 18 °C temperature.

Table (1) Sodium Chloride Conductivity, at 18 °C

Conc. (ppm)	Cond. (μs/cm)
100	189
200	360
300	540
400	715
500	891
600	1063
700	1245

The Reverse Osmosis Pilot Plant

Figure (2) shows a schematic diagram of simple reverse osmosis unit, which work at Daura power station. This unit consists of feed tank, mixer, pump, conductivity meter and pH meter .Their specification are given somewhere [14].

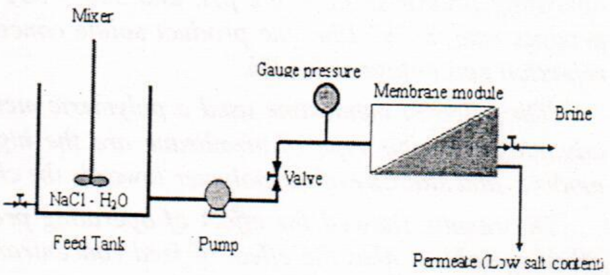

Fig. (2) Reverse Osmosis Pilot Plant

Experimental Procedure

Feed solution was prepared in the tank by dissolving the solid salt in 3 m^3 of demineralized water, then the out let valve of the feed tank was opened to let the solution fill the whole pipes of the system.

The pH of the feed solution was measured by the pH hand – held meter. It the same time the conductivities of the feed solution, reject solution and product solution were measured by the conductivity hand – held meter.

The change in value of pH of the feed solution by adding small quantity of 9.46 N HCl or 9.96 N NaOH depending on the value of pH decided.

The applied pressure was changed to pressures of (4 – 6 bar) by increasing the fraction of feed solution, which was inlet to the module. The flow rate of the product was recorded for each pressure value. The reject runs at 2400 l/hr which can be changed by means of a reject valve.

After recording the results, the solution was drained by means of a drain valve. The whole system was washed by pure demineralized water. Now, the system is ready for the next run.

RESULTS AND DISCUSSION

The Best Operating Conditions

The statistical analysis of the model are obtained as follows:

$$y_1 = 566.89 + 84.68\,X_1 - 133.03\,X_2 - 0.36\,X_3 + 9.11\,X_2^2 \quad (1)$$

$$y_2 = 60.94 - 2.42\,X_1 - 10.43\,X_2 + 0.02X_3 + 0.70\,X_2^2 + 8*10^{-6}\,X_3^2 \quad (2)$$

with correlation coefficients of 0.975, and 0.981 respectively. The best operating conditions, for the reverse osmosis unit which giving the lower values of the product salt concentration, and higher values of the product rate.

So the best operating conditions, for the reverse osmosis pilot plant is: X_1 (Operating pressure) = 5 - 5.5 bar, X_2 (pH) = 5.8 - 6.2, and X_3 (Feed solute concentration) = 500 - 550 p.p.m. These operating conditions, give the conversion between 10 to 15%.

Effect of Operating Pressure

Figures (3) and (4) show the effect of operating pressure on the product rate at different concentration of sodium chloride and pH respectively.

The relation between the operating pressure and product rate, which explained by these figures, is linear relationship. This relation was contingency with the equation:

$$N_B = A\,\{P - \{\pi(X_{A2}) - \pi(X_{A3})\}\} \quad (4)$$

As the applied pressure increased the product rate increased.

Effect of operating pressure on product solute concentration

The effect of operating pressure on product solute concentration is shown in Figures (5) and (6). The decrease in product solute concentration with increase in operating pressure might be due to a decrease in the average pore size on the membrane surface, and or increase in the preferential sorption of the membrane for pure water at higher-pressure [14].

Effect of operating pressure on rejection percentage

Figure (7) illustrate the effect of operating pressure on rejection percentage for sodium chloride.

The rejection percentage, is a combination factor between the solute concentration in feed and solute concentration in the product. It is calculated according to the following formula.

$$R\% = (C_F - C_p) / C_F * 10 \quad (4)$$

The decreasing of salt concentration will increase the rejection percentage and vice versa. The reason, which was discussed before for the effect of operating pressure on salt concentration, can be explain the increasing of rejection percentage with increase in operating pressure.

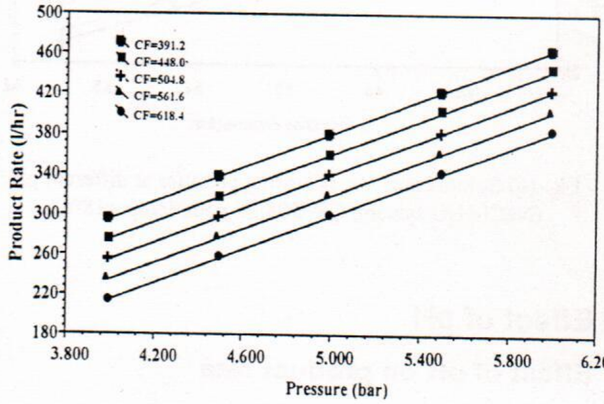

Fig. (3) Product rate vs. operating pressure at different feed concentration (NaCl-H_2O system, pH=6.0, Temp. = 18°C)

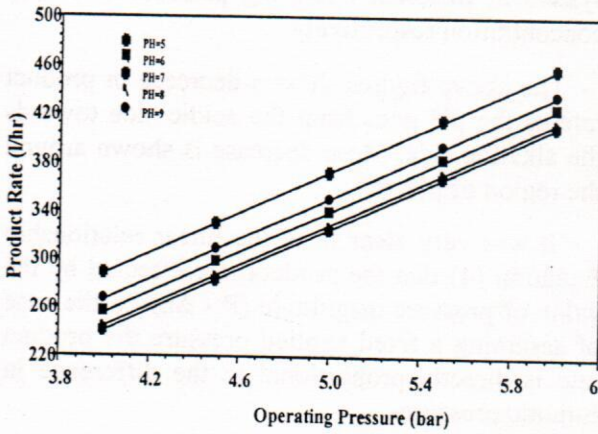

Fig. (4) Product rate vs. operating pressure at different pH (NaCl-H_2O) system, CF=504.88 ppm, temp. = 18°C)

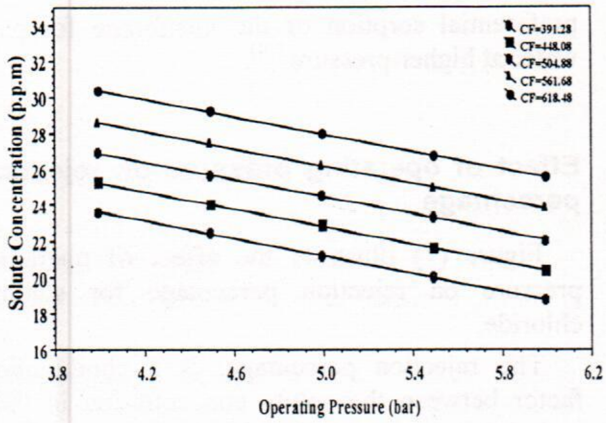

Fig. (5) Solute conc. vs. operating pressure at different feed concentration (NaCl-H_2O system, pH=6.0, temp. = 18°C)

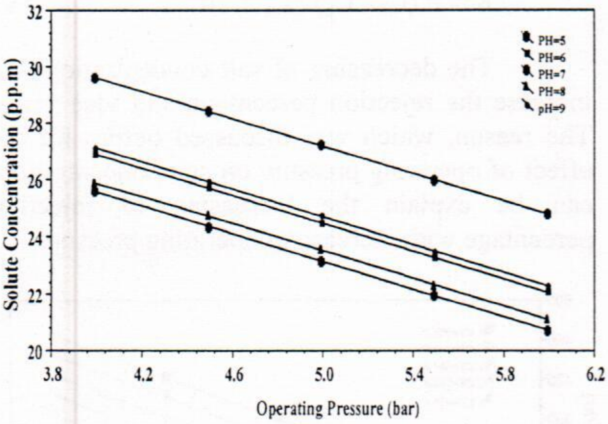

Fig. (6) Solute conc. Vs. operating pressure at different pH (NaCl-H_2O system, CF=504.88 ppm, temp.=18°C)

Effect of pH

Effect of pH on product rate

Figures (8) and (9) show the productivity change of the spiral wound module, type TFC, for various pH values of sodium chloride - water system at different operating pressure and feed concentration respectively.

The above figures show a decrease in product rate as the pH goes from the acidic side towards the alkaline side. More decrease is shown around the region of pH = 7.

It was very clear from the linear relationship Equation (4) that the product rate effected by the value of pressure magnitude ($P - \Delta\pi$). In the case of assuming a fixed applied pressure the product rate is directly proportional to the difference in osmotic pressure.

The concentration of solute difference across the membrane decrease in pH = 5, which led to a decrease in the osmotic pressure difference. Therefore, the value of the pressure magnitude ($P - \Delta\pi$) would be larger, this explains the increase in the product rate.

Effect of pH on product solute concentration

The TFC membrane can operate over a pH range of 5 to 9. Figures (10) and (11), show that the salt passage is increased away from the region of pH around 7, in both alkali and acidic sides.

The runs of the sodium chloride system were started using feed pH equal to 7. The decreasing of pH from 7 to 6 shows a slight increase in the solute permeability, and this increase will be larger if the pH lowered to 5.

An increase in solute permeability has been noticed when the pH increased from 7 to 8 and 9, but the increasing of solute permeability in the acidic side is larger than that in the alkaline side.

The decreasing of pH means the increasing of the concentration of hydrogen Ion, H^-, while the increasing of pH is a result of increasing of hydroxide Ion OH^-. The molecular weight of hydroxide Ion is much larger than H^+. According to the pore side theory for membranes the permeation of hydrogen Ion with small molecular weight (i.e. small Ion size) is larger than the hydroxide Ion, and this can be explain the reason of the high permeability in the acidic side if compared by the alkaline side [2].

The electrical charge equilibrium will be varied according to the concentration of the Ions on both sides of the membrane.

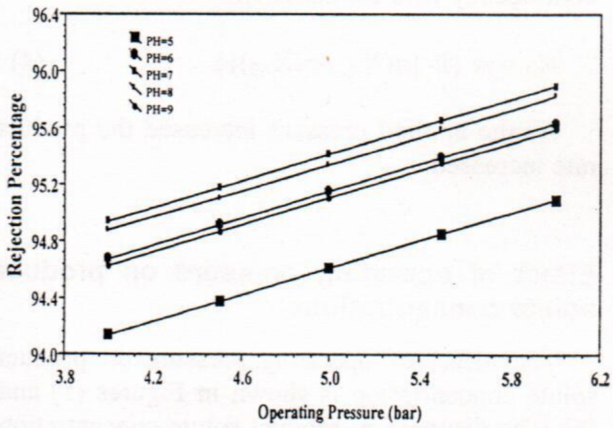

Fig. (7) Rejection percentage vs. operating pressure at different pH (NaCl-H_2O system, CF-504.88 ppm, temp.= 18°C)

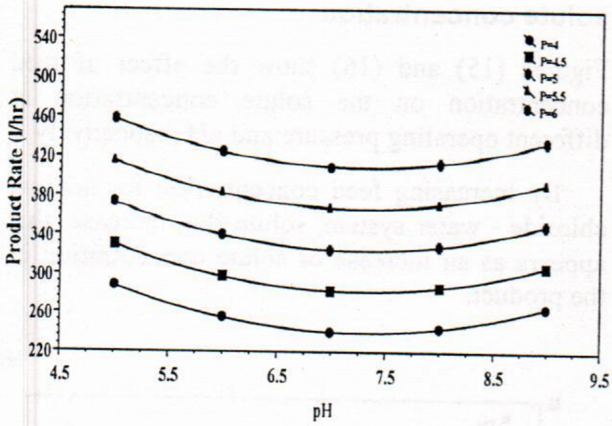

Fig. (8) Product rate vs. pH at different operating pressures ($NaCl$-H_2O system, CF=504.88 ppm, temp.=18°C)

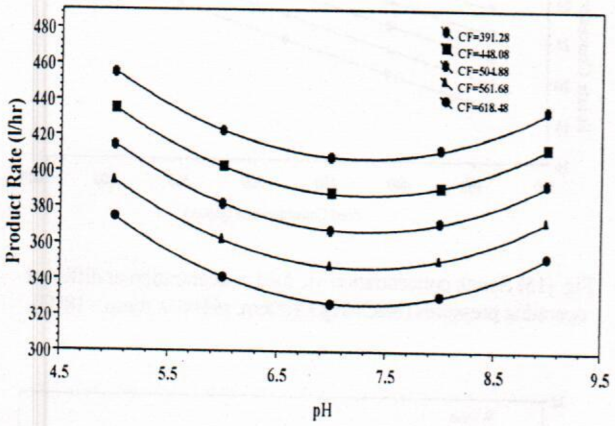

Fig. (9) Product rate vs. pH at different feed concentrations ($NaCl$-H_2O system, P=5.5 bar, temp. =18°C)

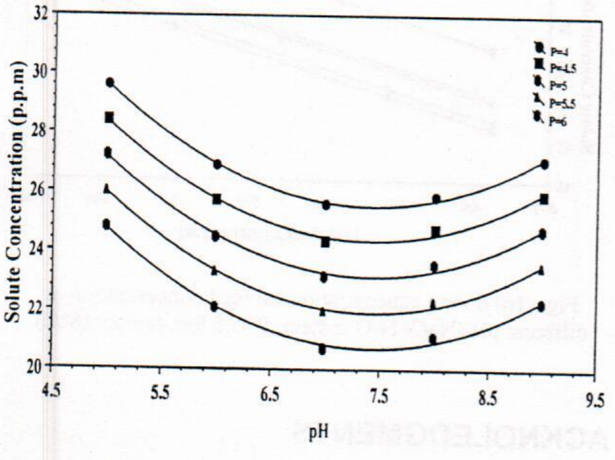

Fig. (10) Solute concentration vs. pH at different operating pressures ($NaCl$-H_2O system, CF=504.88 ppm, temp.=18°C)

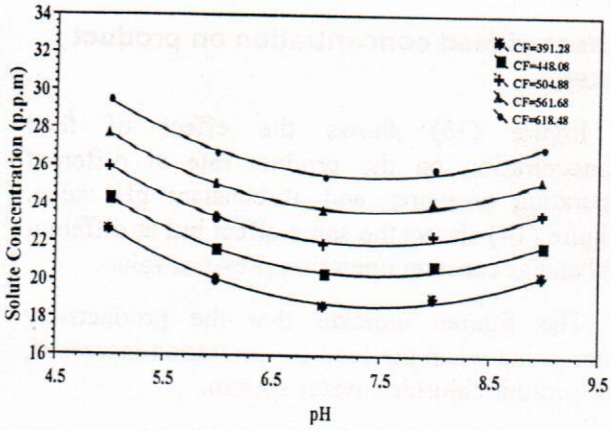

Fig. (11) Solute concentration vs. pH at different feed concentration ($NaCl$-H_2O system, P=5.5 bar, temp.=18°C)

Effect of pH on rejection percentage

Figure (12) illustrate the effect of pH on rejection percentage for sodium chloride. The above figures indicate that the maximum rejection percentage can be achieved in the region of pH around 7.

The reason which was discussed before for the effect of pH on product solute concentration can be explain the decreasing of rejection percentage in both sides of acidic or alkaline regions.

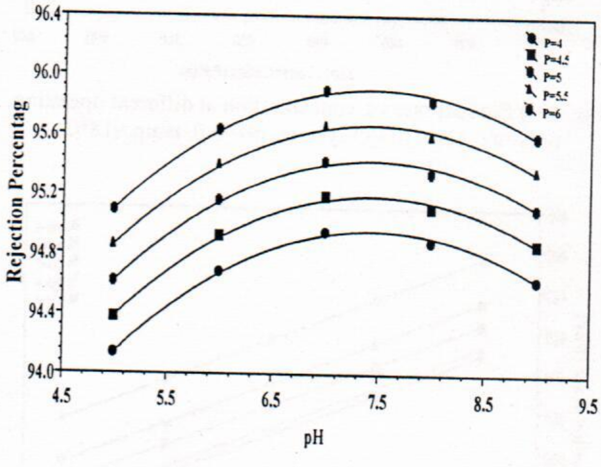

Fig. (12) Rejection percentage vs. pH at different operating pressures ($NaCl$-H_2O system, temp.=18°C, CF=504.88 ppm)

Effect of Feed Concentration

Effect of feed concentration on product rate

Figure (13) shows the effect of feed concentration on the product rate at different operating pressures and at constant pH value. Figure (14) shows the same effect but at different pH and at constant operating pressure value.

The figures indicate that the productivity decreasing when the feed concentration increased, for sodium chloride - water system.

The possibility of fouling inside the pores of membrane would be larger in case of the concentrated solution flowing, this fouling could be acting in two ways. First, blockage a number of pores completely or partly, so the flow would be decreased, and the second decrease the voidage which increased the osmotic pressure across the membrane and that also would be decreased the product rate.

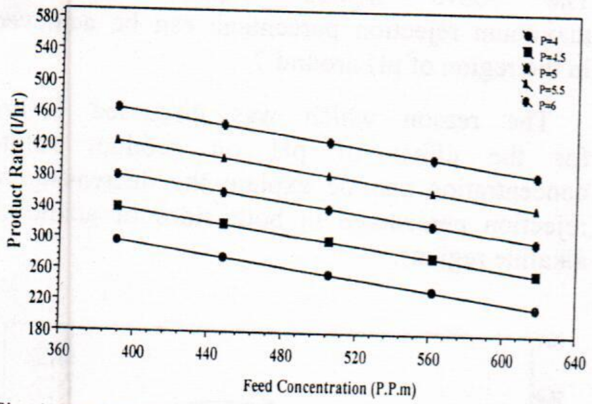

Fig. (13) Product rate vs. concentration at different operating pressures ($NaCl-H_2O$ system, pH=6.0, temp.=18°C)

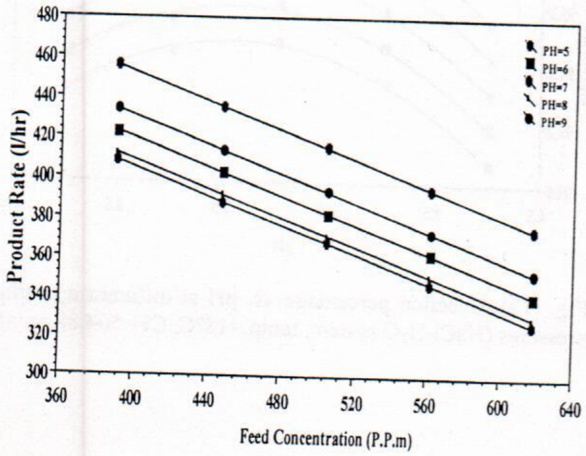

Fig. (14) Product rate vs. feed concentration at different pH ($NaCl-H_2O$ system, p=5.5 bar, temp.=18°C)

Effect of feed concentration on product solute concentration

Figures (15) and (16) show the effect of feed concentration on the solute concentration at different operating pressure and pH respectively.

By increasing feed concentration for sodium chloride - water system, solute flux increase, this appears as an increase of solute concentration in the product.

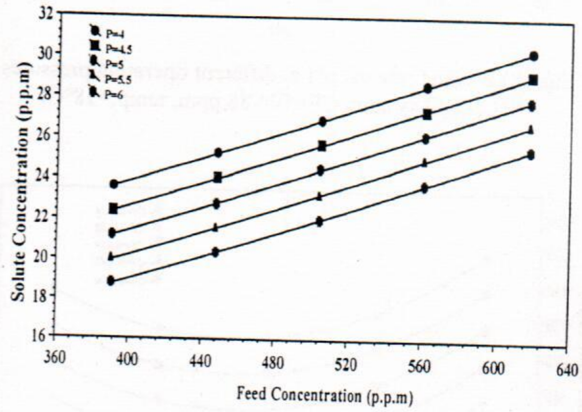

Fig. (15) Solute concentration vs. feed concentration at different operating pressures ($NaCl-H_2O$ system, pH=6.0, temp.=18°C)

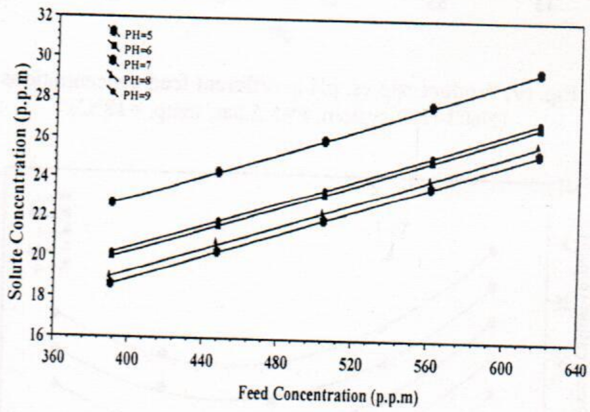

Fig. (16) Solute concentration vs. feed concentration at different pH ($NaCl-H_2O$ system, P=5.5 bar, temp.=18°C)

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NOMENCLATURE

A Pure water Permeability Constant. [gmol $H_2O.bar^{-1}$ $m^{-2}.sec^{-1}$]
C_F Feed Solute Concentration. [p.p.m]
C_p Product Solute Concentration. [p.p.m]
N_B Solvent Flux Through Membrane [$gmol.m^2. sec^{-1}$]
P Pressure [bar]
R Rejection Percentage
X_1 Operating Pressure. [bar]
X_2 pH Feed
X_3 Feed Solute Concentration. [p.p.m]
X_{A2} Solute Mole Fraction in the Membrane.
X_{A3} Solute Mole Fraction in the Product Solution.
y_1 Calculated Value of the Response (Product Rate)
y_2 Calculated Value of the Response (Product Solute Conc.)

Greek Symbols

π Osmotic Pressure. [bar]

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