WATER TREATMENT OF COOLING TOWERS BLOWDOWN BY REVERSE OSMOSIS

Prof. Adil Al-Hemiri Ammar A. Beddai
Chemical Engineering Department - College of Engineering -University of Baghdad

ABSTRACT

An experimental investigation was conducted to study the effect of operating parameters on the permeable conductivity and product rate were studied for reverse osmosis process. The parameters studied were : - conductivity of feed water in the range of (1000-1500 μs/cm), pH in the range of (4-10) and operating pressure in the range of (3-6 bar).

The best operating conditions, which lead to good quantity and quality for water product, are: (1000 μs/cm) conductivity of feed water, (7) pH, and (6 bar) operating pressure. At these conditions the permeable conductivity is (52.905 μs/cm), and the product rate is (328.143 l/hr).

الخلاصة

تمت دراسة عوامل التشغيل التي تؤثر على النفاذية ونوعية الماء الناتج في عملية التنافذ العكسي وهذه العوامل كانت : موصلية الماء الداخل والاس الهيدروجيني والضغط التشغيلي النتائج دلت على ان الظروف التشغيلية التي تحقق كمية ونوعية عالية من الماء الناتج من عملية التنافذ العكسي هي: موصلية الماء الداخل (1000 μs/cm)، pH (7) والضغط التشغيلي(6 bar). عند هذه الظروف تكون موصلية الماء الناتج (52.905 μs/cm) وانتاجية الغشاء (328.143 l/h).

KEY WORDS

Reverse osmosis, Water treatment, Cooling tower blowdown.

INTRODUCTION

The transport of any species through the membrane is driven by a difference in chemical potential of that species across the membrane (Paul D. R., 1976). The driving forces are either from differences in pressure, concentration, electrical potential, or combination of these factors between the fluid phases across the membrane (C. N. Jayarajah, 1999).

Membranes that allow selected materials to pass, such as water or dissolved gases but prevent the passage of other materials such as dissolved minerals are referred to semi-permeable (SourirajanS., 1970, James M., 1985).

When a semi-permeable membrane separates fresh water and a salt solution, water will diffuse from the fresh waterside into the salt solution. This phenomenon is called osmosis. The semi-permeable membrane prevents the salt from migrating into the fresh waterside (Chabris A. H., 1989, M. E. Terril). The osmotic flow continues until a state of equilibrium is reached. Once equilibrium is attained the difference in fluid level becomes equal to what is known as osmotic pressure of the solution (Peter, 1997).When a pressure greater than the osmotic pressure is applied to concentrated solution, water flows from the concentrated to the dilute solution side. The flow of water through a semi-permeable membrane from the more concentrated solution into the dilute solution is called reverse osmosis.

Kimura and Sourirjan analysis (Beddaim A. A., 2002), which is based on a two-parameter model and the film theory proposed flux expressions for the solvent and solute reverse osmosis. By the action of mechanical pressure applied, both the solute and the water (solvent) tend to permeate the membrane, but because of the low value of the solute diffusivity in the membrane, a large part of solute must diffuse back to the bulk solution through the boundary layer. Concerning the rate at which the pure water permeate the membrane N_w, the equations that represent the diffusion of solvent and solute for diffusion-type membrane are as follows:

For the diffusion of solvent through the membrane.

$$N_w=(P_w/L_m)(DP-D_p)=A_w(DP-D_p) \quad (1)$$

$$P_w=(D_wC_wV_w)/(RT) \quad (2)$$

$$A_w=P_w/L_m \quad (3)$$

The equation representing the diffusion of the solute through the membrane is,

$$N_s=(D_sK_s/L_m)D_c=A_sD_c \quad (4)$$

When the solvent diffuses through the membrane, there is a build-up of solute that forms at the surface of the membrane. This solute build-up is called concentration polarization, b. It is defined as the ratio of the solute concentration at the membrane surface divided by the concentration in the concentrate. Concentration polarization decreases the solvent flux through the membrane and increases the solute flux. This is evident in the following equation:

$$D_p=BP_1-P_2 \quad (5)$$

$$N_s=A_s(c_{m1}-c_{m2}) \quad (6)$$

EXPERIMENTAL WORK

The selected membrane used is a polyamide 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 effect of feed conductivity, pH, and operating pressure on the permeable conductivity and product rate are investigated and analyzed by using the experimental design. Box – Wilson (Box &) central composite design is used to find a suitable relationship between the three independent variables and the observed response.

In order to design the experiments, the operating range of the variable is first specified, thus:

Conductivity of Feed Water	=1000 – 1500 μs/cm
pH	=4 – 10
Operating Pressure	=3 – 6 bar

The reverse osmosis unit, at Al- Dora power station was used to carry out the experiments of the present work. This unit consists of a feed tank (3 m^3 in capacity) containing an electric mixer (1500 r.p.m). The fluid is pumped by a centrifugal pump delivering 30 m^3/hr at 7 bar.

The spiral wound unit employed has the following characteristics

Type	=	TFC - 8822HR
Membrane length	=	93.5 cm
Membrane width	=	105 cm
Half of channel height	=	0.055 cm
No. of membrane	=	34
Total Membrane area	=	333795 cm^2
Conversion	=	10 – 15 %
Salt rejection	=	96 – 98 %

The concentration and acidity were measured using a conductivity meter (Type: WTW, LM8) and a pH meter (Type: WTW, pH 340), both of German manufacture.

Experimental Procedure

The raw water is pumped from the feed tank by the pump to pass through the RO unit. The pH of the feed solution and the conductivities of the feed, reject and product solutions were measured. The pH of the feed solution was varied by adding small quantity of 10 N HCl or 10 N NaOH according to the desired value of pH. The applied pressure was varied between 3 and 6 bar by increasing the fraction of feed solution. The flow rate of the product and reject were recorded for each pressure value employed.

After recording the result, the solution was drained by means of a drain valve. The whole system was washed by pure demineralized water to prepare the system for the next run.

DISCUSSIONS

The best operating conditions, for the reverse osmosis unit giving the lower values of the permeable conductivity and higher values of the product rate are:

Conductivity of Feed Water =1000 μs/cm
pH =7
Operating Pressure = 6 bar

These results are not surprising since the operating pressure applied was the maximum available in the unit(6 bar), thus giving rise to the highest permeation driving force. A value of pH equal to 7 indicates the absence of acidic and alkaline ions. And, finally the conductivity of feed water is the lowest employed and that should results in better product quality.

However the effect of the various variables at other conditions is discussed in details below showing the behavior of the unit throughout the range of operation.(Beddai, A. A., 2002)

Effect of Studied Variables on Permeable Conductivity

The effect of studied variables (i.e., conductivity of feed water, pH and operating pressure) on the permeable conductivity are as shown in **Figs. (1) to (3).**

Fig. (1) represents the interaction between conductivity and pH. The decreasing of pH from 7 to 6 shows a slight increase in the solute permeability and this increase will be larger as the pH is lowered to 4. An increase in solute permeability has been noticed when the pH increased from 7 to 8 and 10, but 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 ion H^+. Thus 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 explain the reason of the high permeability in the acidic side if compared by the alkaline side. The electrical charge equilibrium will vary according to the concentration of the ions on both sides of the membrane. The permeable conductivity essentially increases with the increase in the feed conductivity. A higher salt conductivity in the feed inlet increases the salt flux as indicated in equation (6) and increases the osmotic pressure as well. This will reduce the water flux in accordance with equation (1).

Fig. (2) represents the interaction between operating pressure and PH. Equation (1) shows that the product rate is directly proportional to the pressure drop across the membrane. Since the product – side pressure is constant, it follows that the product rate is a direct function of the feed pressure. However, there is an indirect effect of pressure on the salt conductivity of the product rate. If the pressure is reduced, less water permeates the membrane while the salt flux stays constant. Thus, there is more salt per unit volume of product water. Conversely, if the pressure increases, more water permeate the membrane, yet the same amount of salt transfer occurs, and there will be less salt per unit volume of water.

Fig. (3) shows the interaction between operating pressure and conductivity. The permeable conductivity decreased with increase in operating pressure and decrease in the feed conductivity. The reason. which was discussed before for the effect of operating pressure and conductivity on permeable conductivity, can explain the decreasing of permeable conductivity with increase in operating pressure and decrease in the feed conductivity.

Effect of Studied Variables on Product Rate

The effect of studied variables (i.e., conductivity of feed water, PH, and operating pressure) on the product rate are as shown in **Figs. (4) to (6).**

Fig. (4) represent the interaction between conductivity and pH. The product rate essentially decreases with the increase in the feed conductivity. The latter effect is simply due to increase in feed conductivity. Therefore, the water flux is decreased in accordance with equation (1).

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 of a number of pores completely or partly, so that the flow would be decreased, and the second the decrease in the voidage which increases the osmotic pressure across the membrane and that also would decrease the product rate.

The above figure shows 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 is very clear from the linear relationship equation (1) that the product rate is effected by the value of pressure magnitude ($DP-D_p$). 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 at around pH=4, which led to a decrease in the osmotic pressure difference. Therefore, the value of the pressure magnitude ($DP-D_p$) would be larger, this explains the increase in the product rate.

Fig. (5) shows the interaction between operating pressure and pH. The relation between the operating pressure and product rate, which is explained by this figure, is linear relationship. This relation is in consistence with equation (1). As the applied pressure increased the product rate increased.

Fig. (6) shows the interaction between operating pressure and conductivity. The decreasing of operating pressure and increasing conductivity will decrease the product rate and vice versa. The reason, which was discussed above for the effect of operating pressure and conductivity on product rate, can explain the increasing of product rate with increase in operating pressure and decrease in conductivity.

CONCLUSIONS

1- The three variables : conductivity of feed water, pH, and operating pressure effect the permeable in the order:

Conductivity of feed water > operating pressure > pH

And the effect of the experimental variables on the product rate is in the order:

Operating pressure > conductivity of feed water > pH

2- The best operating conditions are :- conductivity of feed water = 1000 μs/cm , pH = 7 and operating pressure = 6 bar. At these conditions the permeable conductivity is (52.905 μs/cm) and the product rate is (328.143).

3- The productivity decreases when the pH goes from the acidic side towards the alkaline side.

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NOMENCLATURE

Symbol	Definitions	units
A_w	Solvent permeability constant	$kg/s.m^2.atm$
A_s	Solute permeability constant	m/s
B	Concentration polarization	-
c_{m1}	Concentration of solute in adjustment to the membrane face (high pressure side)	kg/m^3
c_{m2}	Concentration of solute in adjustment to the membrane face (low pressure side)	kg/m^3
C_w	Mean concentration of solvent in membrane	kg/m^3
D_c	Concentration difference across the membrane	kg/m^3
DP	Hydrostatic pressure difference across membrane	atm
D_p	Osmotic pressure difference across membrane	atm
D_s	Diffusivity of solute in membrane	m^2/s
D_w	Diffusivity of solvent in membrane	m^2/s
K_s	Concentration of solute in membrane/concentration of solute in solution	-
L_b	Boundary layer thickness	m
L_m	Membrane thickness	m
N_s	Solute flux	$kg/s.m^2$
N_w	Solvent flux	$kg/s.m^2$
P_1	Osmotic pressure of feed solution	atm
P_2	Osmotic pressure of product solution	atm
P_W	Solvent membrane permeability	kg/s m atm
R	Universal gas constant =0.082057	m^3 atm/kg mol ^0K
T	Absolute temperature	^0K
V_w	Molar volume of solvent	m^3/kg mol

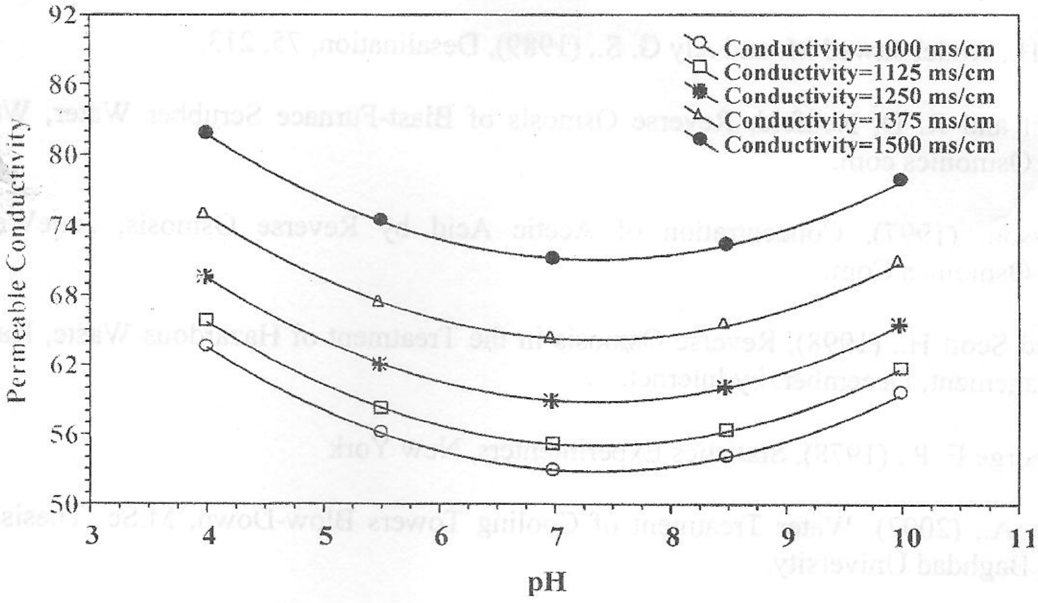

Fig. (1) Effect of pH on Permeable Conductivity at different Conductivity at an Operating Pressure of (5.5 bar)

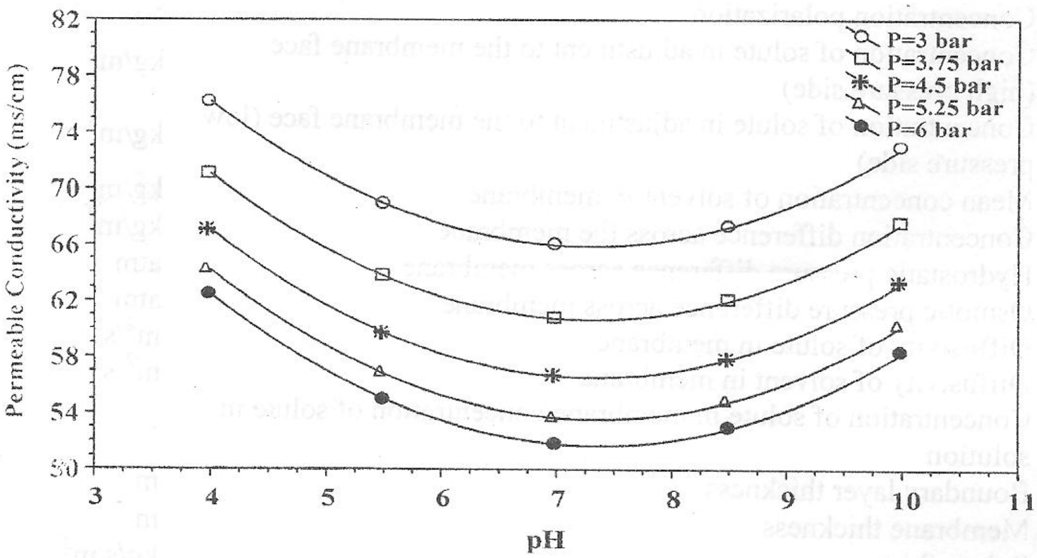

Fig. (2) Effect of pH on Permeable Conductivity at different Operating Pressure at a Conductivity of (1000 μs/cm)

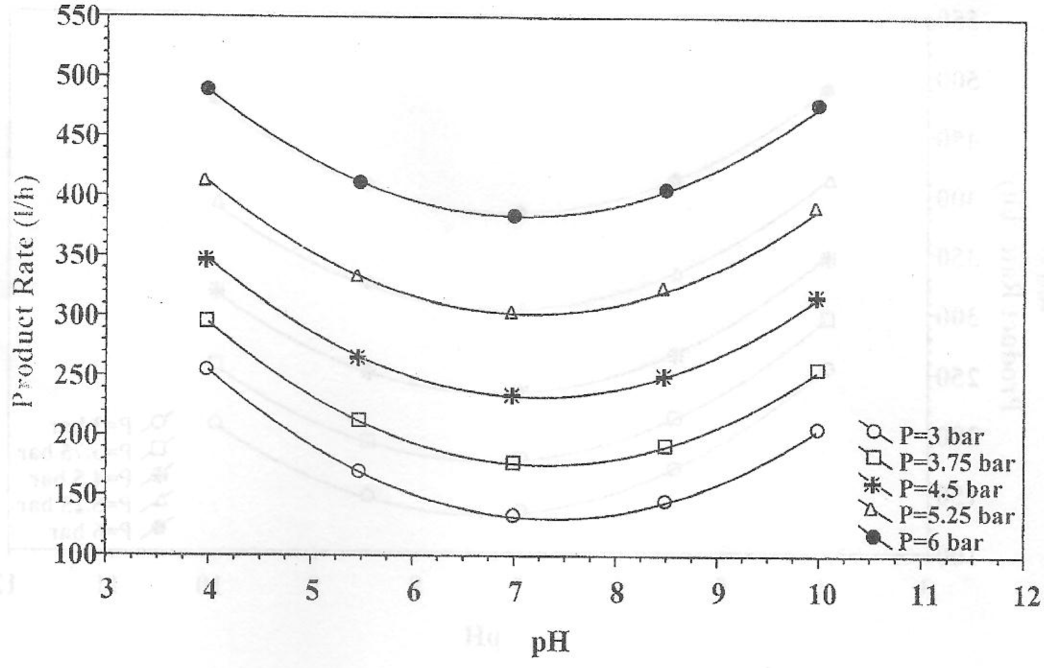

Fig. (3) Effect of conductivity on permeable Conductivity at different Operating Pressure at a pH of (7)

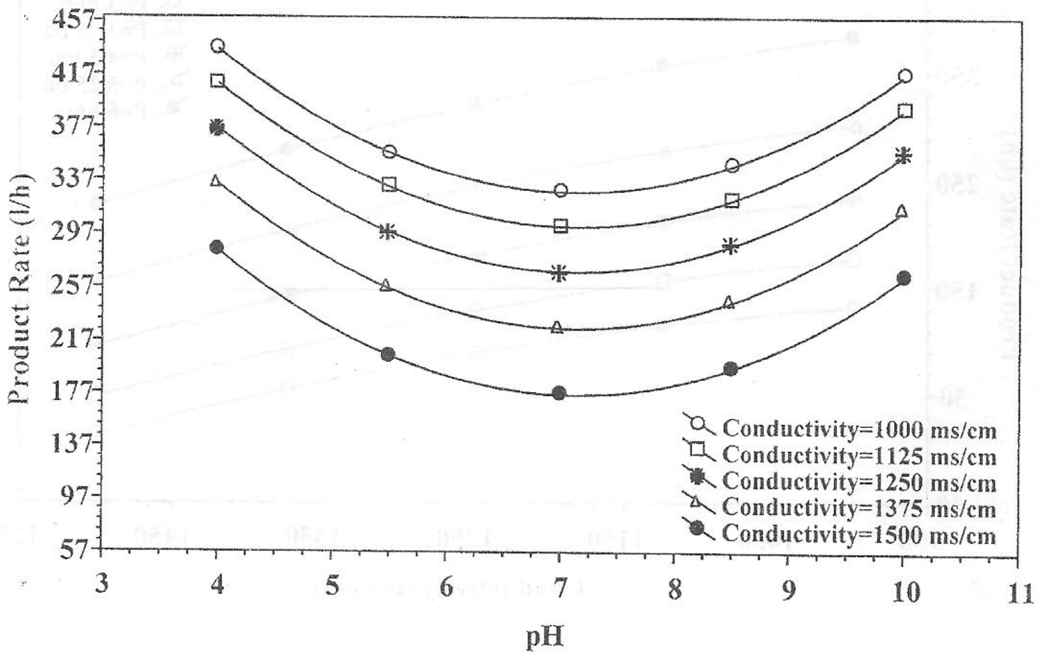

Fig. (4) Effect of pH on Product Rate at different Conductivity at an Operating Pressure (5.5 bar)

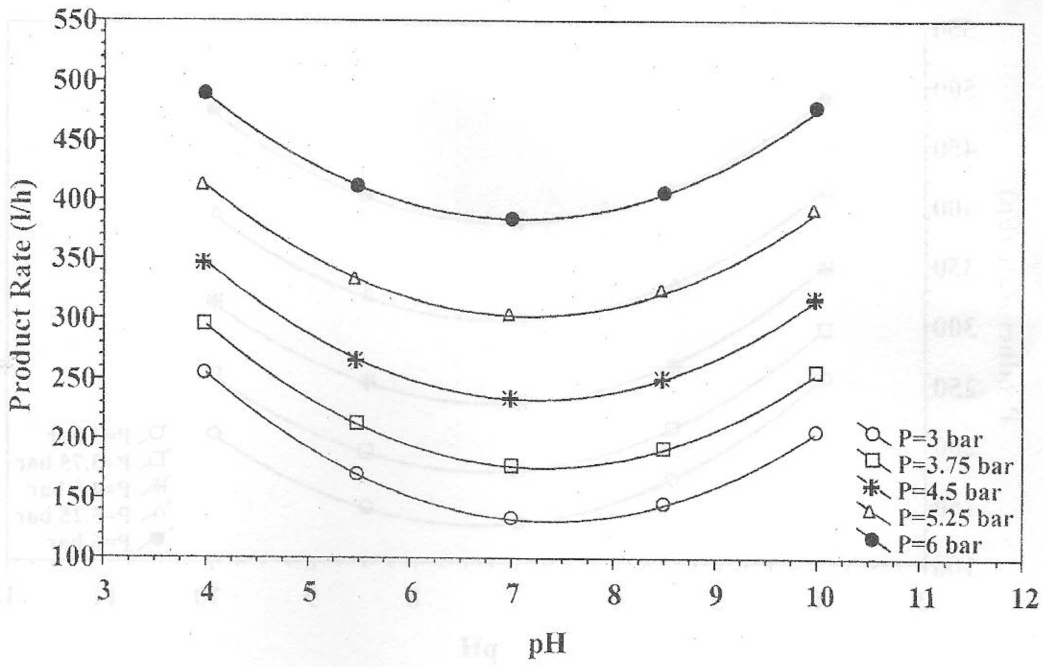

Fig. (5) Effect of pH on Product Rate at different Operating Pressure at a Conductivity of (1000 μs/cm)

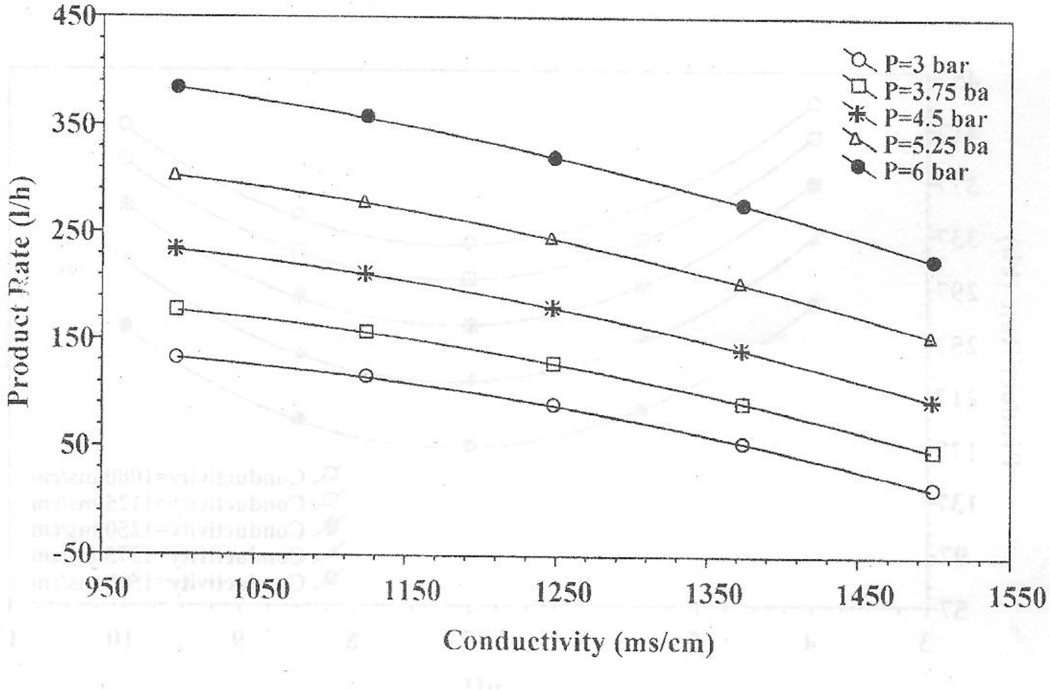

Fig. (6) Effect of Conductivity on Product Rate at different Operating Pressure at a pH of (7)