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# Evaluation and Performance of Reverse Osmosis RO Process for brackish water Desalination

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**ABSTRACK:**

*The intent of the paper is to desalination of brackish water using Reverse Osmosis (RO). Reverse Osmosis (RO) is a separation technique that is appropriate for a wide range of applications, principally when salt and/or dissolved solids need to be removed from a solution consequently. Reverse Osmosis (RO) is a membrane based process technology to purify water by removing the dissolved solids from feed stream separating in permeate and reject stream for a large range of applications in domestic as well as industrial applications. This paper intend to provide an overall apparition of RO technology as an process for desalination of brackish water in different applications. Reverse Osmosis (RO) is a process that uses semipermeable spiral wound membranes to separate and remove dissolved solids, In the RO process, the permeate comes out along the surface of the RO membrane, while the concentrated brine flows axially through the RO membrane. Due to radial diffusion across the walls of the RO tubes (spiral and cylindrical), the permeate comes out and gets accumulated in the product tank. The axial flow stream goes as rejection or brine.*

***Key words:*** *Desalination, Brackish water, Reverse Osmosis (RO), semipermeable membranes,*

## 1. Introduction

Water is an important fundamental of life. Although two thirds of the earth's surface is covered by water in its assorted forms, there are not satisfactory, continuous and consistent sources of fresh drinking water available when and where needed for about three billion people around the world. Even the Naturally available potable water is often contaminated by human activity. Drinking water accessibility today, far from being pure may contain some hundreds of deadly chemicals. Add to that bacteria, viruses, organic and inorganic minerals, thereby giving rise to a chemical mixture that is unsuitable for human consumption. In the year 2000 alone, unsafe water humanity amounted to 80 million years of lost life [1,2].

Reverse osmosis (RO). The first technique for desalination is membrane separation technology such as RO, which was invented in 1959 and commercially produced in the mid-'60s. RO is a process in which both dissolved organics and salts are removed using a method different from distillation, ion exchange or activated carbon. The pressurized feed water flows across a membrane surface with a fraction of the feed permeating the membrane. The balance of feed sweeps parallel to the surface of the membrane to exit it without being filtered..[3-9]

The basic process of RO basically requires a pump, membrane pressure housing, membrane element(s) and plumbing connections. The number of membrane elements used in each desalination system is connected to the quantity of water produced by the system. There are many types of membranes, each categorized by a particular salt rejection. The pump is used to pressurize the feed water to create the RO effect and distribute the fresh water to storage. [10,11]

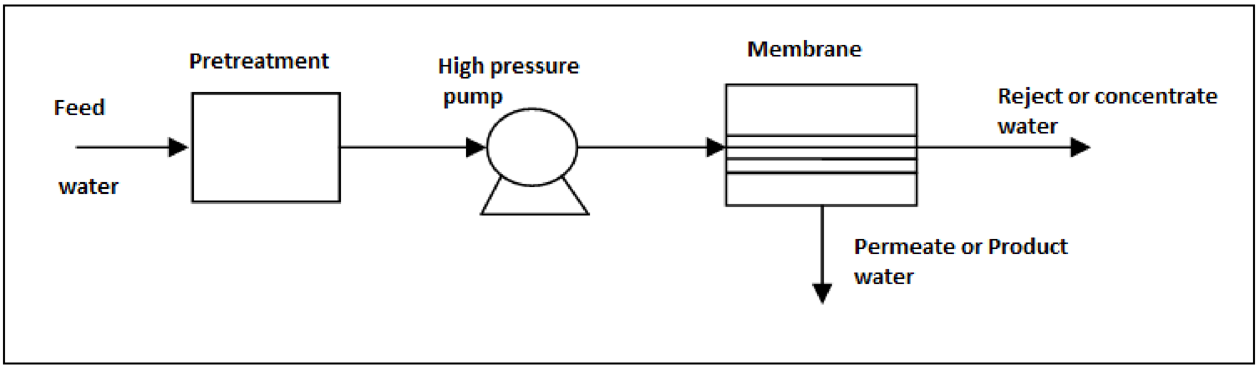


**Fig.1. Schematic Diagram of the RO Process [12]**

## 2.RO Membrane Performance

The performance of an RO membrane is defined by various parameters. The important parameters are defined as : Flow rate, Permeate flux, Salt rejection, Recovery rate, Differential pressure, Transmembrane pressure, [13-20]

### 2.1 Flow Rate:

In RO process there are three streams. The feed stream is separated by RO membrane into permeate and concentrate streams. Flow rates of these streams are usually expressed in cubic meters per hour ($m^3/h$) or in gallons per minute (gpm). Feed flow rate is defined as the rate of water entering the RO system. Permeate flow rate is defined as the rate of water passing through the RO membrane, and concentrate flow rate is defined as the rate of flow which has not passed through the RO membrane, and comes out from the RO system with rejected ions.

### 2.2. Permeate Flux :

Permeate flux describes the quantity of permeate produced during membrane separation per unit of time and RO membrane area. The flux is measured in liters per square meters per hour (lmh) or in gallons per square feet per day (gfd).

The flux is defined by:

$$J_{V=}\frac{Q_P}{A} \qquad (1)$$

In which: Jv, permeate flux, A, area of the membrane, $Q_p$, permeate flow rate

2.3. Salt Rejection :

Salt rejection is a percentage which describes the amount of solute retained by the RO membrane. The retention is given by:

$$R = \left(1 - \frac{C_p}{C_{ave}}\right) \times 100 \qquad (2)$$

In which: R, rejection, $C_p$, permeate concentration, $C_f$, feed concentration $C_c$, concentrate concentration $C_{ave}$ is average feed concentration, which is calculated as follows.

$$C_{ave} = \frac{(C_f + C_c)}{2}$$

**2.4 Recovery Rate :**

The recovery rate is defined as the fraction of the feed flow which passes through the membrane. It is usually expressed in percentage.

$$Y = \frac{Q_p}{Q_f} \qquad (3)$$

In which: Y, recovery rate, $Q_p$, permeate flow rate, $Q_f$, feed flow rate

**2.5 Differential Pressure (Pressure Drop) :**

The pressure drop is the difference between the feed and concentrate pressure during water flow through one or more RO membrane elements. The pressure drop (dp) is defined by:

$$d_p = P_f - P_c \qquad (4)$$

In which: $P_f$, feed pressure, $P_c$, concentrate pressure

**2.6 Transmembrane Pressure :**

Transmembrane pressure (TMP or ΔP) is defined as the difference in pressure between the feed side and the permeate side of the membrane. This pressure is usually measured in bar or psi, and is the driving force for membrane separation and permeate production. In general, an increase in the transmembrane pressure increases the flux across the membrane.

The transmembrane pressure (TMP) is defined by:

$$TMP = \frac{P_f - P_c}{2} - P_p \qquad (5)$$

In which: $P_p$, permeate pressure, $P_f$, feed pressure, $P_c$, concentrate pressure

## 3.Materials and Methods

Reverse osmosis membrane model used for this work is AG 2540TM Brackish Water membrane . Membrane is purchased from Trinity technologies ltd. Mumbai (table 1) . Reverse osmosis set up for brackish water is preset with proper instrumentation like product flow indicator, reject flow indicator, feed pressure, total dissolved solids (TDS) indicator etc.

In the process of reverse osmosis, the feed is brackish water taken from borehole water collected from Airoli Navi Mumbai of TDS 4004.15 mg/l. and the whole feed is pre-treated before it passes to the hydrophilic membrane and the product water is collected for different time intervals at different operating pressure and feed flow rate of 200.00 L/hr( table 2 ), for the calculation of permeate flux performance and its efficiency.

**Table 1: Reverse Osmosis RO Membrane specifications**

| **Reverse Osmosis Membrane specifications** | **Characteristic** |
|---|---|
| Membrane model | AG 2540TM Brackish Water |
| Membrane material | Polyamide |
| Length | 40 inches |
| Active surface area | 2.7 $m^2$ |
| Maximum feed flow rate | 2.7 $m^3$/day |
| Maximum Pressure | 450 psi |
| Number of RO elements used | 2 |

**Table 2: Experimental operating parameter used in RO**

| Operating Parameter | Range |
|---|---|
| Feed pressure | 99 to 279 psi |
| Feed Temperature | 25 $^0$C |
| Feed flow rate | 200 L/hr |
| Osmotic pressure | 41.65 psi |

## 4.Result and discussion

### 4.1 Effect of feed pressure on osmotic pressure

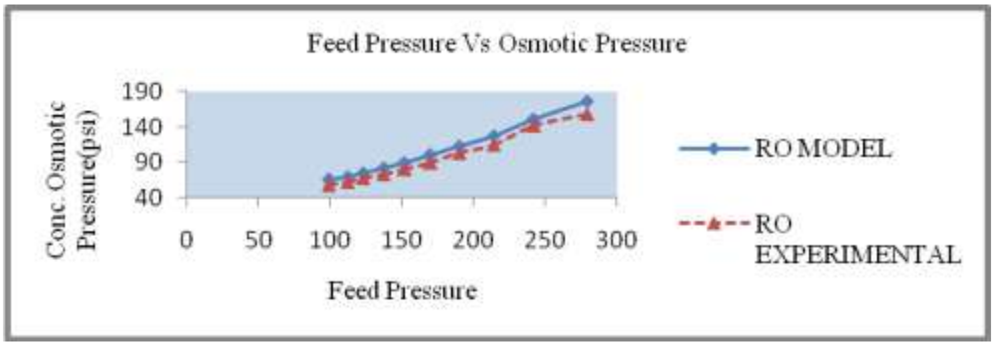


Fig 1. Effect of feed pressure on osmotic pressure ( Feed temperature 25$^0$C , feed flow rate 200 L/hr ), feed TDS 4004.15 mg/l , feed pH 7.50. )

The model results of the RO process were presented and was compared with the different experimental data. Fig. 1 represents the mathematical model predict and exponential behaviour of the RO Osmotic pressure as a function of feed pressure . The Osmotic pressure was calculated . Such model also supported by an experimental data. The feed pressure was varied from 99 psi to 279 psi. at the constant other operating parameters like feed flow rate of 200L/hr , feed temperature of 25 $^0$C and feed TDS 4004.15 mg/l. OF pH 7.50 It can be observed that increasing feed pressure was varied from 99 psi to 279 psi leads to about 170% rise in osmotic pressure .This may be due to The vapor pressure of a solution is increased by increasing the pressure on it. The osmotic pressure is the liquid *pressure* under which the vapor *pressure* of the solution is equal to the vapor pressure *of* the pure solvent. Fig. 1 shown that the mathematical model is better in predicting osmotic pressure . The maximum and minimum record percentage error in the RO between the model and experimental data are 10.20 % and 5.90 % respectively.

### 4.2 Effect of feed pressure on % salt rejection

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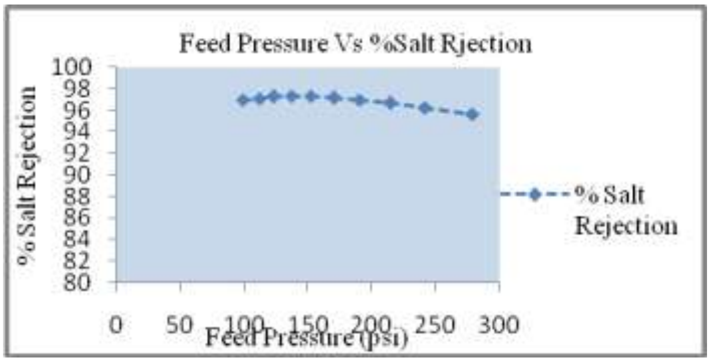


Fig 2. Effect of feed pressure on % salt rejection. (Feed temperature 25 $^{0}$C , feed flow rate 200 L/hr , , feed TDS 4004.15 mg/l , feed pH 7.50. )

The % Salt Rejection was measured for varied feed pressure from 99 psi to 279 psi. at the constant other operating parameters like feed flow rate of 200.0 L/hr , feed temperature of 25 $^{0}$C and feed TDS 4004.15 mg/l. Of pH 7.50 it was found that % salt rejection slightly decreases with feed water pressure in RO membranes. This may be due to that the Reverse Osmosis technology involves application of pressure to the feed water stream to overcome the natural osmotic pressure. Pressure in excess of the osmotic pressure is applied to the concentrated solution and the flow of water is reversed. A portion of the feed water (concentrated solution) is forced through the membrane to emerge as purified product water of the dilute solution side . for the constant feed conditions, increase in feed pressure results into increased recovery ( i.e ratio of permeate / feed flow) and concentration factor ( i.e a factor by which TDS of the concentrate stream increased from feed TDS). This phenomenon results into decrease in rejection efficiency as membrane tends to handle higher feed TDS.

$$\text{Net feed TDS} = \frac{\text{Original TDS ( before entering membrane system)} + \text{Concentrate TDS}}{2}$$

So every time, feed pressure increased to increase the recovery, concentrate TDS is increased and subsequently Net Feed TDS to membrane is increased. This causes increase in the permeate TDS.

fig 2 shows the Effect of feed pressure on % salt rejection .% salt rejection starts decreasing at the pressure of 190 psi.

**4.3 Effect of feed pressure on Energy**

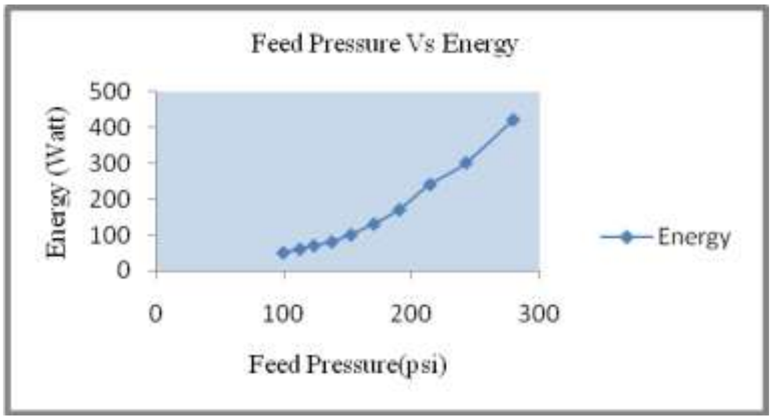


Fig 3. Effect of feed pressure on Energy (Feed temperature $25^0$ C , feed flow rate 200 L/hr ,), feed TDS 4004.15 mg/l , feed pH 7.50.)

The effect of feed pressure on the energy consumption was measured as shown in fig 3 .for varied feed pressure from 99 psi to 279 psi. at the constant other operating parameters like feed flow rate of 200L/hr , feed temperature of 25 $^0$C and feed TDS 4004.15 mg/l. OF pH 7.50 it was observed from that the energy consumption increases with feed pressure in RO process the energy consumption increases leads to 740 % . This was due to more power required for pumping the feed at higher pressure.

#### 4.4 Effect of feed pressure on concentrate conductivity and TDS

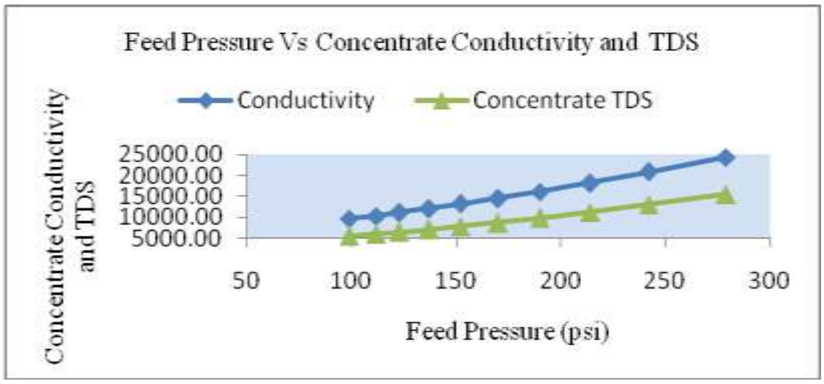


Fig 4. Effect of feed pressure on concentrate conductivity and TDS ( Feed temperature $25^0$C , feed flow rate 200 L/hr ,feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50. )

The effect of feed pressure on concentrate conductivity and TDS was measured as shown in fig 4. Keeping others parameter constant as feed temperature $25^0$C, feed flow rate 200 L/h, feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50 . the increase in the concentrate conductivity and TDS was measured ,the concentrate conductivity increases leads to 151 % and concentrate TDS increases leads to 175 %

respectively . This is typically due to the higher feed water pressure as higher will be the osmotic pressure . The feed water concentration increases, and % rejection of RO membrane declines keeping other parameters such as feed water temperature, feed flow rate constant. For the constant feed conditions, increase in feed pressure results into increased recovery ( i.e ratio of permeate / feed flow) and concentration factor ( i.e a factor by which TDS of the concentrate stream increased from feed TDS). This phenomenon results into decrease in rejection efficiency as membrane tends to handle higher feed TDS.

**4.5 Effect of feed pressure on average flux**

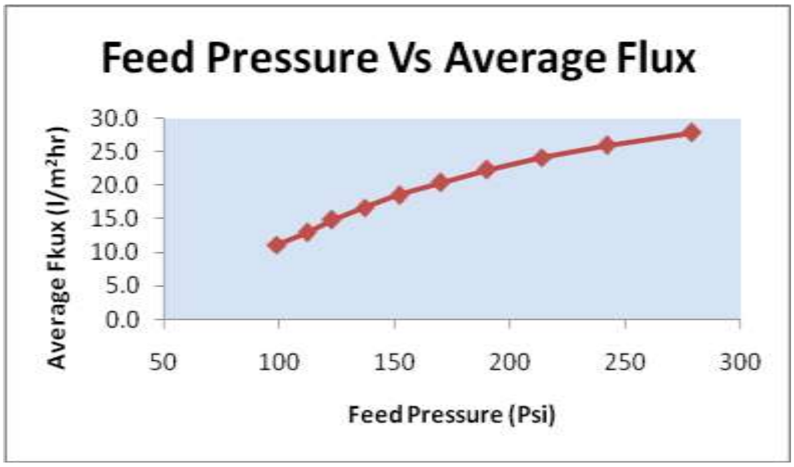


Fig 5. Effect of feed pressure on average flux . ( Feed temperature 25$^0$C , feed flow rate 200 L/hr ,feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50. )

The effect of feed pressure on average flux was measured and shown in fig 5. Keeping others parameter constant as feed temperature 25$^0$C, feed flow rate 200 L/hr, feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50 the average flux increases from 11.1 l/m$^2$hr to 27.9 l/m$^2$hr As operating pressure increases, more permeate water is produced .

**4.6 Effect of feed pressure on % recovery**

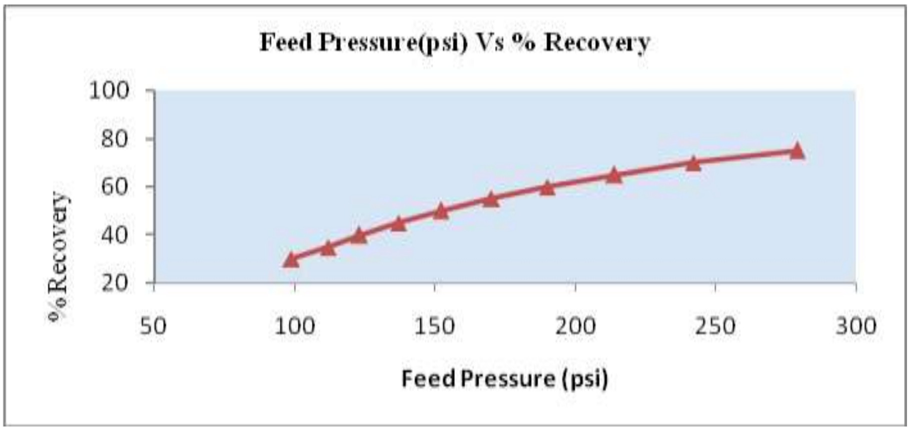


Fig 6. Effect of feed pressure on % recovery ( Feed temperature $25^0$C , feed flow rate 200 L/hr ,feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50. )

The effect of feed pressure on % recovery was measured with increase in feed pressure from 99 psi to 279 psi as shown in fig 6 keeping other operating parameter constant as feed temperature $25^0$C, feed flow rate 200 L/hr, feed conductivity 7019.00 (µS/cm), feed TDS 4004.15 mg/l , feed pH 7.50 reverse osmosis occurs when the natural osmotic flow between a dilute solution and a concentrated solution is reversed through application of feed water pressure. If percentage recovery is increased the salts in the residual feed become more concentrated and the natural osmotic pressure will increase until it is as high as the applied feed pressure. This can negate the driving effect of feed pressure; slowing or halting the reverse osmosis process and causing permeate flux and salt rejection to decrease and even stop.

## 5.Concussions

The paper presents the work carried out on Reverse Osmosis membrane during the course of the work. Presented are results for the performance of polyamide membrane The performance of Reverse Osmosis for desalination of brackish water by using a spiral wound polyamide membrane is presented experimentally. The RO permeate flux were increased with increasing the feed pressure , 99.0 psi to 279.0 psi and feed flow rate 200.0 L/hr. with osmatic pressure of 41.65 psi Brackish water used is taken as borehole water collected from Airoli Navi Mumbai of TDS 4004.15 mg/l. The optimum operating parameters of RO process was found at a pressure 190. psi with 60% recovery as further increasing the pressure there is increase in energy and the process will be uneconomical.

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