Development of Desalination system using Reverse Osmosis

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Abstract: The present work are a theoretical and an experimental investigation based on the influence of the main operation parameters on the performance of the RO elements. The theoretical work is experiment is performed in order to measure the total dissolved salts, PH and conductivity of the permeate water when different temperatures and concentrations values for the Feed water. Combined between RO desalination system and heater system would improve the performance of the system as the results which is clarified under the temperature limits to prevent scaling and fouling deposition. Temperature of the feed water is the most noticeable environmental condition affecting the performance of RO systems. The general rule of thumb is to estimate productivity change at 3% per degree Celsius, °C change from the standard of 25 °C. There are equations to provide a more exact estimate of productivity. Pressure is approximated by direct proportionality to productivity. Temperature correction is an exponential function related to the membrane material.

Keywords: Desalination, thermal systems, membrane distillation, Energy consumption,permeate water.

Nomenclature:

T   Temperature, °C
C   Concentration of the salts, mg/l
K   Thermal conductivity, W/m.K
Cp   Specific heat, J/kg.K

Greek Symbols:

ρ Density, kg/m3
μ Dynamic viscosity, N.S/m2
ϑ kinematic viscosity
α Thermal diffusivity
θ constant heat flux or constant temperature
βvolumetric thermal expansion coefficient(equal to approximately 1/T, for ideal gases, where T is absolute temperature)
ω Vorticity
ψ Stream function

Subscript:

SEC   Specific Energy Consumption
ED   Energy device

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Introduction

Due to the membrane's sensitivity to corrosive and oxidizing environments, average membrane life is between 1 and 3 years. RO is used alone or with pre- and/or post-treatment equipment to meet a specified requirement for water quality.

Reverse osmosis is now used to treat hazardous waste as industrial processes have changed and environmental regulations become more stringent. One such application is the concentrating of metals in rinse water in the metal plating industry. A second application is the treatment of landfill

leachate and other liquids high in Total Dissolved Solids (TDS) and Volatile Organic Compounds (VOCs).

RO systems have limitations in plating because the metals have high oxidation potentials and the acid baths often have a pH of less than (2.5) or greater than (11). RO system alone cannot concentrate the metals in rinse water to the strength of the plating bath solution. An evaporator is required to reach necessary concentrations for reuse the plating bath [1]. The benefits to using reverse osmosis are waste reduction and/or concentration the waste for disposal.

Water is one of the prime elements responsible for life on earth perhaps fresh water is the most important natural resource for human survival and it is a human necessity. Food production, industrial productivity, energy production and the global economy are dependent on availability of water [4]. More than two-third of the earth's surface is covered with water about 1.4×10^9 km3 of water. Most of the available water is either present as seawater or icebergs in the Polar Regions. About 97% of the earth's water is salty and rest is fresh water. Less than 1% fresh water is within

human reach. Despite, technological progress, renewable fresh water reserves on earth will be only 0.3% of the world water. Agriculture uses two-third of available fresh water. The proportion of irrigated surface should increase by 1/3 in 2010 and by 50% in 2025. Both forms are not easily accessible for human use. Industrial and domestic water use increases at twice the rate of population increase. Water consumption increased sevenfold since 1900. In total, water demand doubles every 20-year. Fresh water resources are almost completely exhausted in many middle-east countries.

1.2 Desalination Systems

The most commonly used in practice are described. These systems are the multiple effect (ME), Multi-stage flash (MSF), vapor compression (VC), reverse osmosis (RO),the electrodialysis (ED) desalination systems, membrane distillation (MD) and finally, solar energy powered desalination systems. The most important features for each system is explained.

1.2.1 Multiple Effects (ME) Distillation

In MED, a series of evaporator effects produces water at progressively slightly lower pressures. Because water boils at

lower temperatures as pressure decreases, the water vapor of the first evaporator effect serves as the heating medium for the second evaporator effect, and so on. The more effects, the higher the performance ratio [4].

1.2.2 Multi Stage Flash (MSF) Distillation

Multi Stage Flash (MSF) Distillationwas the first commercial plants were commissioned in 1960 [5]. Seawater is pressurized and flashed in various chambers at lower pressures with a drastic reduction of the specific heat transfer[6].

1.2.3 Vapor Compression (VC) Distillation

(VC) process refers to a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapor. Since compression of the vapor increases both the pressure and temperature of the vapor, it is possible to use the latent heat rejected during condensation to generate additional vapor.VC is normally applied to a single effect and it takes place either by a high speed centrifugal compressor (mechanical vapor compression MVC) or by means of a steam ejector (thermal vapor vapour compression TVC) [7].

1.2.4 Reverse Osmosis (RO) Process

Reverse Osmosis (RO) Process is a process where in a relatively pure solvent is separated from a salt solution by using a semipermeable membrane by the application of hydrostatic pressure. In seawater desalination it commonly ranges from 55 to 68 bar [8]. Operating pressures for the purification of brackish water are lower due to the lower osmotic pressure caused by lower feed water salinity. Reverse osmosis process can separate not only ions and low molecular weight substances in the feed water, but also most impure matters such as bacteria and organic matters by the action of pressure difference across the membrane without any heat treatment and chemical addition.

1.2.5 Electro dialysis (ED) Process

Electro dialysis (ED) Process is a membrane process which upgrades brackish water (up to 10000 ppm) by the use of electrical energy to transfer ionized salts from the feed water through a membrane, leaving purified product water behind. The basic unit in the ED process consists of two metal electrodes (the cathode and the anode) separated by two ion-exchange membranes.

1.2.6 Membrane Distillation(MD)

Membrane Distillation (MD) is an emerging, thermally driven membrane separation process that utilizes a low-grade heat source to facilitate mass transport through a hydrophobic, micro porous membrane. The driving force for mass transfer is a vapor pressure gradient between a hot feed solution and a colder distillate; MD is capable of producing ultra-pure water; most likely at lower cost compared to conventional distillation processes. There are four unique configurations: direct contact MD (DCMD), vacuum MD (VMD), air gap MD (AGMD), and sweeping gas MD (SGMD).DCMD and AGMD are the most likely to be deployed as either pretreatment or post-treatment [9].

1.2.7 Solar Desalination

Solar energy can be directly utilized to produce fresh water [10] .The most efficient solar distillation system is the simple solar still which it consists of a basin coated with black paint to increase the absorptivity of solar radiation, covered with an inclined glass cover. The salt water flows to the basin in a shallow layer. The still may continue to work after the sunset as long as this temperature difference exist.

2.Literature Review

Desalination Technology is fasting growing with a greater number of installation around the world due to the capital cost and specific energy consumption (SEC) reduction. The spiral wound module is most popular among RO membrane modules.There is many studies and researches in development the separations properties of the RO membrane modules. But far fewer models have been developed to describe the whole membrane module.Senthilmurugan et al. [11] developed a steady-state model for the spiral wound module using a three-parameter nonlinear membrane transport model. Abbas [12] presented a semi-rigorous steady-state model for simulation and analysis of an industrial medium-scale brackish water RO plant based on spiral-wound membrane modules. Recently, Oh et al. [13] proposed a simplified simulation model based on the solution-diffusion theory and multiple fouling mechanisms to analyze the operation, optimization and performance of RO systems. Kaghazchi et al. [14] presented a semi-rigorous steady-state model to simulate and investigate the operation and performance of two industrial seawater RO plants based on spiral-wound membrane modules.

As mentioned by Marriott and Sorensen [15] developed a detailed mathematical model of a general membrane separation process from rigorous mass, momentum and energy balances and disregards some common assumptions due to the complex mechanism of flow through membrane module and lots of idealized assumptions, existing RO unit models are usually process specific and are only valid within a limited operating range. This work tries to study the dynamic characteristics and process operation aspects of an industrial large scaled RO desalination plant. The feasible steady-state and dynamic models of the membrane modules and RO plants presented in the literature are effectively combined to develop the overall process flow sheets for the industrial scale RO desalination process by using powerful commercial process design simulators. Simulation results of the steady-state and dynamic operating conditions of the proposed RO process flow sheet are compared to those shown in the literature.

Aim of the present work

In the present work the theoretical and experimental study of reverse osmosis is investigated. The operating parameter on RO system are feed water in, temperature of feed water inlet, input pressure of feed water, and the concentration of salt on feed water. Combined between RO desalination system and heater system would improve the performance of the system under the temperature limits to prevent scaling and fouling deposition. The main aim of the present work is the performance of reverse osmosis membrane. The water parameters are followed as a function of the running condition in order to follow the behavior of the membranes tested.

3. RO desalination system description

Reverse osmosis is a pressure-driven membrane process used to separate solute and solvent of the same order of molecular size. It is well known the most common application of RO unit is the separation of salt from water to obtain portable water. There are four types of membrane modules available in the marketplace: plate and frame, hollow-fiber, spiral-wound and tubular. Among these membrane modules, the spiral wound module occupies the largest market share due to its relative ease of cleaning, fabrication technology and very large surface area per unit volume.

3.1 Modeling of A Spiral wound module

In general, the following factors may directly affect the performance of RO desalination processes:

1. Effectiveness of the pre-treatment units.

2. Membrane: type, size and the number of modules used and their arrangement.

3. Rate and degree of fouling and cleaning ability.

4. Operating conditions such as feed pressure, temperature and permeate recovery.

5. Efficiency of pumps and energy recovery device.

In this study, the effectiveness of the pretreatment units is neglected. The spiral wound module with general property is used in the RO membrane module. To investigate the dynamic characteristics and process operation aspects of an industrial RO desalination plant, the steady-state and dynamic mathematical models for the membrane modules are developed below.

3.2 Model Assumptions

The main assumptions used for the RO model derivation include:

1. The solutiondiffusion model is valid for the transport mechanism of the solute and solvent through the membrane.

2. The RO membrane module is non-porous and is treated as a flat sheet with spacers.

3. The RO process is isothermal.

4. Osmosis pressure is proportional to the salt concentration and pressure drop in permeate side is negligible.

5. The film model theory and Fick's law for diffusion are applicable for calculating concentration polarization effect.

6. Diffusion coefficient is independent of solute concentration.

7. Mass transfer coefficient is constant for a given fluid condition.

3.3 Membrane Transport Modeling

The applied solution-diffusion model modified with the concentration polarization theory for analyzing the operation, optimization and performance of RO systems.

The following steady-state membrane transport equations can be derived. The solvent flux J_v, through the membrane is given by [11]

$$J_v = L_v(P_f - P_{Loss}) = L_v [P_f - (\Delta\pi + P_d)] \quad (1)$$

Where Lv is the solvent transport parameter, Pf is the feed pressure and P_{loss} is the pressure loss by osmosis pressure (bar) , $\Delta\pi$ and the pressure drop along a RO system Pd. Here, L_v, $\Delta\pi$ and P_d are expressed by [11]:

$$L_v = \frac{1}{\frac{1}{Le^{\frac{\alpha 1(T-273)}{273}} - \alpha 2Pf} + \eta R}\left(1 - \frac{As}{Am}\right)(2)$$

$$\Delta\pi = (C_m - C_p)RT(3)$$

$$P_d = \gamma_1 \left(\frac{Vv_z.d_h}{v}\right)^{\gamma_2}(4)$$

Where Lv_0 is the intrinsic solvent transport parameter (m/s), T is the temperature (k), η is the viscosity(m²/s), C is the resistance due to cake formation, As is the membrane area occupied by precipitation (m²), Am is the total membrane area (m²), and α_1 and $\propto_2$ are two contents(constant) for solvent transport. C_m and C_p are solute concentration at the membrane surface on the feed side and solute concentration on the permeate side (kg/m³), respectively. R is the ideal gas constant (kJ/kg.k). γ_1 and γ_2 are two contents(constant) for pressure drop along a RO system. v_z , d_h and v denote the feed solution velocity on the bulk solution side (m/s), hydraulic diameter (m) and kinematic viscosity, respectively.

The solute flux, Js, through the membrane is given by

$$J_s = J_v.C_p = L_s(C_m - C_p)(5)$$

Where L_s is the solute transport parameter

$$L_s = L_{so}e^{\frac{\alpha 1(T-273)}{273}}(6)$$

where L_{so} is the intrinsic solute transport parameter and α_1 is contents for solute transport. Accumulation of the impermeable solutes on the membrane surface leads to the development of a concentration polarization layer which may be determined by the concentration polarization.

$$\phi = \frac{C_m - C_P}{C_b - C_p} = e^{J_v/h_m}(7)$$

Where C_b is the solute concentration in the bulk solution (kg/m³) and h_m is the mass transfer coefficient for the back diffusion of the solute (m/s), which is dependent upon fluid flow characteristics within the membrane channel.

$$h_m = \frac{D}{\delta} = \frac{Sh.D}{d_h}(8)$$

The mass transfer coefficient, h_m, is equal to the molecular diffusivity (D) of the solute (m²/s) divided by the thickness of the boundary layer δ)(Since we cannot measure δ directly, Sherwood number (Sh) correlations must be used. Sherwood number is calculated as;

$$Sh = \frac{h_m.L}{D}$$

Or

$$h_m = 0.5510 \left(\frac{v_z \cdot d_h}{v}\right)^{0.4} \left(\frac{v}{D}\right)^{0.17} \left(\frac{c_b}{\rho}\right)^{-0.77} \left(\frac{D}{d_h}\right)$$

Where ρ is the density (kg/m^3) and D is the solute diffusion coefficient.

Developed a two-dimension flow model to describe flow in the axial and spiral directions on both the feed and permeate sides. According to the schematic diagram of a flat membrane envelope shown in Figure (1), the following dynamic mass balance can be derived.

$$\frac{\partial Cb}{\partial t} = -\frac{\partial C}{\partial z} - \frac{1}{h}J_s = -\frac{\partial}{\partial z}\left(C_b v - D \frac{\partial C_b}{\partial z}\right) - \frac{J_s}{h} \quad (9)$$

Where C_b the solute molar flux in the axial direction and h is is the channel height on the feed side.

In this work, the effect of the solute molar flux in the spiral direction is neglected for simplifying above equation. On the other hand, the effect of the change in concentration due to the flux of solvent through the membrane is not considered in above equation. As mentioned by [16], above equation can be modified as

$$\frac{\partial Cb}{\partial t} = -\frac{\partial C}{\partial z} - \frac{1}{h}J_s - \frac{1}{h}J_y c_b$$
$$= -\frac{\partial}{\partial z}\left(C_b v - D \frac{\partial C_b}{\partial z}\right) - \frac{J_s}{h}$$
$$- \frac{1}{h}J_y c_b \quad (10)$$

Furthermore, the overall material balances for the feed and the permeate sides proposed by are given by

$$\frac{dv_z}{dz} = -\frac{J_v}{h} \quad (11)$$

$$\frac{dv_p}{dp} = \frac{J_v}{h_P} \quad (12)$$

Where v_p is the feed solution velocity on the permeate side and h_p is the channel height on the permeate side (m).
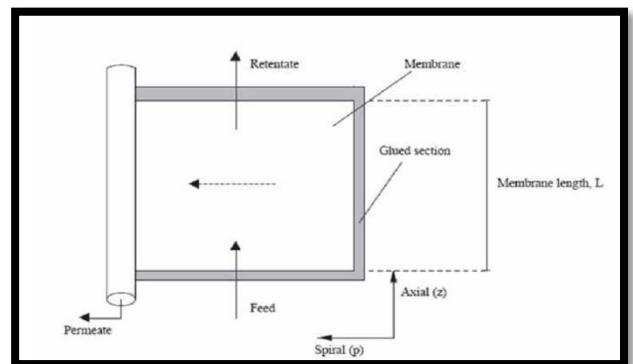

Fig. (1): Sketch of spiral module

3.4 Heat Transfer:

Temperature polarization coefficient(TPC) is used to quantify this phenomena as following:

$$TPC = \frac{T_{m1} - T_{m2}}{T_f - T_p}$$

Where T_{m1} is temperature at the membrane, T_{m2} is temperature at the other side of membrane, T_f is temperature at feed bulk solution and T_P is the temperature at the permeate water. The lower TPC value, the higher temperature polarization effect, and vice versa. The temperature polarization effect increases with increase in feed temperature [17]. The thermal boundary layers depend on fluid

properties, operation condition and hydrodynamic conditions [18]. Figure (2) shows below the cross section of RO membrane.

3.4.1 The heat flux from the feed bulk to the interface at the membrane side:

Can be described by [19 and 20]:

$$Q = (h_f + m^* . c_p)(T_f - T_{m1})$$

Where h_f is the film heat transfer coefficient (w/m².k), m∗ is the mass flux (kg/m².s), c_p is liquid specific heat capacity (kJ/kg.k).

3.4.2 The total heat transfer across the membrane:

It is the sum of the conductive heat transfer of the membrane material and membrane pores filled with air/gas which acts as a stagnant film. This heat flux is described by:

$$Q = \frac{k_m}{d}(T_{m1} - T_{m2})$$

$$k_m = \varepsilon . k_a + (1 - \varepsilon) k_s$$

Where k_m is effective thermal conductivity of the membrane (solid material and air in the pores) (w/m.k), d is the membrane thickness (m), ε is the membrane porosity, k_a is the thermal conductivity of the air and k_s is thermal conductivity of the solid material (w/m.k).

3.4.3 The total heat transfer from the membrane and the permeate water side is:

$$Q = h_f(T_{m2} - T_p)$$

Where Q total heat transfer (w/m²) and h_f is the heat transfer coefficient inside the film flow.

3.5 Mass Transfer:

Mass transport of a volatile species occurs in threesteps [18]:

1. Mass transport from the bulk feed solution to the seed membrane surface.
2. Mass transport through the membrane pores.
3. Mass transport from the membrane surface to permeate bulk liquid, the mass transported through the membrane is affected by diffusion through the pores [19].

3.5.1 Mass transport from the bulk feed solution to the seed membrane surface.

Considering only water; contain dissolved solids, the concentration of the solute at the membrane surface becomes higher than the one in the feed bulk due to mass transfer across the membrane. When the concentration of the solute increases; a concentration layer is formed on membrane

surface reducing the flux as it constitutes a resistance to mass transfer. Concentration polarization coefficient (CPC) is used to quantify this resistance within the concentration layer [18]. It is defined as:

$$CPC = \frac{C_m}{C_f}$$

Where C_m is the concentration at the membrane and C_f is the concentration at feed bulk.

The molar flux of the water through the concentration layer is defined by [18]

$$J_w = c_{molar}.h_m.\ln(\frac{C_f}{C_m})$$

Where C_{molar} is the bulk total molar concentration, h_m is the mass transfer coefficient

3.5.2 Mass transport through the membrane.

The mass transfer mechanism is governed by three mechanisms: Knudsen diffusion, Poiseuille flow, and molecular diffusion or combination between them, and the dusty-gas module is used as a general model describing the mass transport through the membrane generally [18]. In general, the mass flux is described by the following relation.

$$m^* = K\Delta P$$

Where K is membrane permeability and ΔP is the difference pressure across the membrane.

One can solve the above equation and get the Sherwood number as;

$$Sh = \frac{h_m.L}{D}$$

Where L is the membrane total length in meter
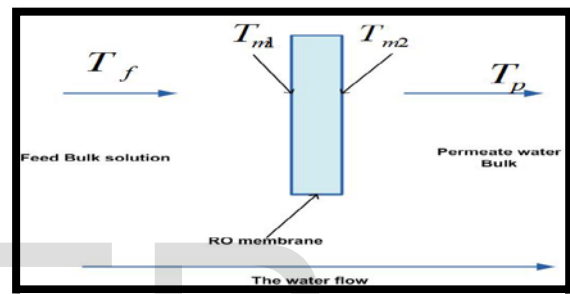
Fig. (2): Cross section of RO membrane

4. Experimental setup

The present study includes a hybrid system of a small size reverse osmosis desalination plant and heating system. The experimental is worked under nominal operating conditions.

The effecting parameters are pressure, temperature and salinity. The operating parameters is 12 bar for the operating pressure, 25.4°C for the temperature and 0.26 to 10 ppt for the feed water salinity.

4.1 System description:

The reverse osmosis desalination system figure (3) consists of a mixing tank, a feed

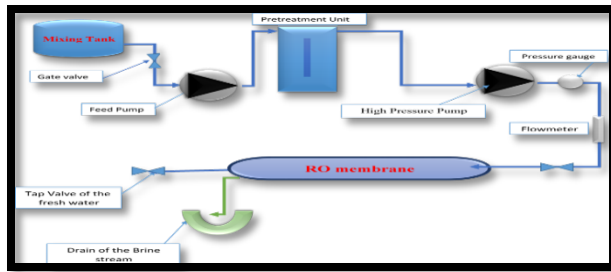water pump, a pretreatment system, a high-pressure pump and RO membrane.

Fig. (3): Simplified schematic diagram of the conventional RO system.

4.1.1 Feed water tank

The feed water tank is a black polyethylene tank with a capacity of 0.21 m³, in which the salinity is prepared.

4.1.2 Feed pump:

The feed water pump drives the feed water from the mixing tank to the pretreatment system. The technical characteristics of the motor pump are shown in table (1).

4.1.3 Pretreatment system:

The pretreatment system consists of three stages: stage (1) sediment filter (5 μm) for the removal particles, sediments and suspended solids, stage (2) granular activated carbon (1 μm) absorbed chlorine,
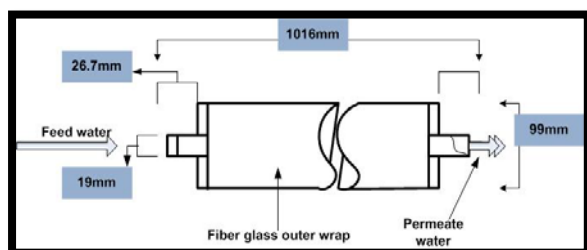
Fig. (4): Schematic of the RO membrane

dissolved gases, bad taste and odours disinfection by product, stage (3) post carbon filter provides the final polish by absorbing, remaining impurities and

Technical Data of a Single Stage Centrifugal Pump	
MOC	F42, F46 & HT200 -CNP pumps
Flow range (Q)	0.32 − 0.50 M3/hr.
Delivery head: Max.	50 M Head
Medium temperature	20°C -120°C
Voltage	220V

improving the final taste.

4.1.4 High-pressure pump:

After pretreatment, the feed water passes to the main RO pump. The technical specifications of the high-pressure pump are shown in table (2).

4.1.5. Membranes:

The reverse osmosis system consists of one spiral wound module), figure (4) shows the

Membrane type	Spiral-wound thin film composite
Active area	7.6 m²
Model	BW30-4040
Maximum operating pressure	15.5 bar
Product water flow rate	9.1 l/d
Minimum salt rejection	99.5 %
Recovery rate	15 %

Membrane type	Polyamide Thin film composite
Maximum operation pressure	41 bar(600psi)
Maximum feed flow rate	3.6m³/h (16gpm)
Maximum pressure drop	1 bar (15 psi)
pH range, continuous operation	2-11
pH range, short term cleaning	1-12
Maximum feed silt density index	SDI 5

Schematic of the RO membrane element. The membrane is the heart of any RO desalination system. It separates the feed water stream into two output streams: low salinity product water and high salinity concentrate. Tables (3) and (4) show the RO membrane specifications and the operation limits of RO membrane module respectively.

Table (1): Technical characteristics of the feed water pump

Table (2): Technical specifications of the high-pressure

Table (3): RO membrane specifications

Table (4): Operations limits for RO membrane BW30-4040

4.1.6 System of the Instrumentation:

The RO system is initially provided with measuring instruments shown in table (5).

Table (5): Basic instrumentation of the RO unit

Equipment	Position
Pressure gauge	Inlet of the high pressure pump
Flow meter	Outlet of the feed water line
PH gauge	Measure the concentrate line and permeate water line and also the conductivity
TDS / conductivity meter	

4.2 Experimental Setup and Procedure

Pump type	high-pressure pump
Model	Pentair Water/Italy S.r.l
Type	RMY90SA2 V18
Horse power	1.5 hp
Current / Voltage	6.9 A / 230 V
Rated flow rate	$0.6 - 3.5$ m³/h
Pressure	25 bar
Rated speed	2785 rpm

The mixing tank (volume 0.21m³) is connected with pipes (diameter 0.75 inch) then it is connected with the feed pump, then the pretreatment system, then the high pressure pump before it is connected with RO membrane, pressure gauge and

flowmeter is put to measure the operation parameters. All the inlet pipes are the same (dia. 0.75 inch).Outlet product water pipe with diameter 0.5 inch and brine water pipe also the same and then it is connected each other with tap valve. Figure (5) shows the small RO desalination system.

- **Steps of the procedure**

1. Prepare the Salinity of the Feed water.

2. Measure pH, TDS, Conductivity, Pressure and temperature of the Feed water before operation.

3. Operate the RO system and at this moment check the valves and pipes leakages. After sure that there is no leakage.

4. After ten minutes take a sample from outlet (permeate water and brine water and

    Keep it out side.

5. Repair the fourth step for 5 times.

6. When the one hour complete, start to take the measurement of (TDS, pH and conductivity) of the six samples and record it.

7. Changing the Feed water the TDS and repetition the fourth, fifth and sixth steps for the new values.

Note:Flashing the RO membrane before every new case.

- **The Measurement Instruments**

1. A pressure gauge is an instrument that uses to measure pressure of the fluid inside tube. The accuracy of the Bourdon gauge is equal to (±0.4%).

2. Flow meter is device that measure the amount of liquid that passes through pipe. Flow meter accumulates a fixed volume of fluid and then count the number of times the volume is filled to measure flow.

3. A pH meter is an electronic device used for measuring the pH (acidity or alkalinity) of a liquid. The range (2.0 to 16.0 pH), resolution(0.1/0.01 pH), accuracy (±0.1 / ±0.01 pH), PH calibration automatic (1or 2 point with 2 sets of memorized buffers (pH 4.01/7.01/10.01 or 4.01/6.86/9.18) and dimensions (175.5 x 39 x 23 mm).

4. Total dissolved solids and conductivity meter measures the conductivity and total dissolved solids (TDS) in water including salts, metals and minerals. It is essential tool to check water purity of Reverse Osmosis (RO) systems. Range (0.00 to 20.00 mS/cm / 0.00 to 10.00 PPt), resolution (0.01 mS/cm / 1 PPt), Accurcy(±2% f.s. (EC/TDS)), TDS calibration (automatic, 1 point12.88 mS/cm, 6.44 PPt or 9.02 PPt) and the dimensions(175.5 x 39 x 23 mm).
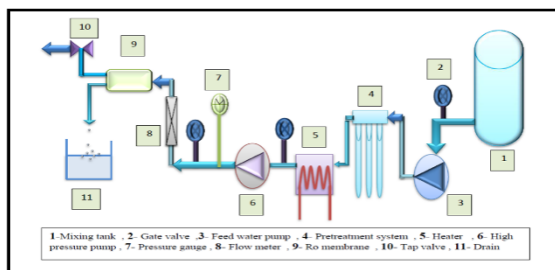

Fig. (5): Flowchart of RO desalination system combined with Heater

4.3 Data Reduction

- **Mass balance**

$$m_T = m_1 + m_2$$

Where m_T, m_1, m_2 are masses of the feed water, permeate water and the brine water respectively. Figure (6) shows schematic of the RO membrane process.
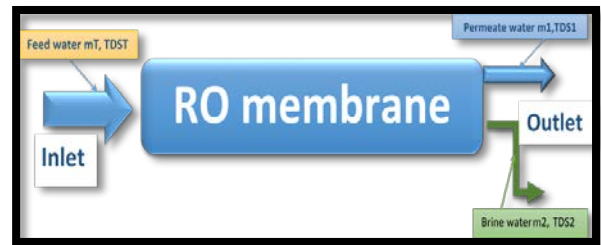
Fig. (6): Schematic of the RO membrane process

- **Concentration**

$$m_T.TDS_T = m_1.TDS_1 + m_2.TDS_2$$

$$m_1 = m_T - m_2$$

Where TDS_T, TDS_1, TDS_2 are total dissolved solids of the feed water, the permeate water and the brine water respectively.

$$m_T.TDS_T = (m_T - m_2).TDS_1 + m_2.TDS_2$$

$$m_T.TDS_T - m_T.TDS_1 = m_2.(TDS_2 - TDS_1)$$

$$\frac{m_2}{m_T} = \frac{TDS_T - TDS_1}{TDS_2 - TDS_1}$$

$$\frac{m_1}{m_T} = 1 - \frac{m_2}{m_T}$$

4.4 Mass Transfer

The mass transfer inside the membrane due to the concentration of feed water and the product is used as;

$$m^= = -D\frac{\partial C}{\partial X}$$

$$m^= = \frac{m_1}{A}$$

Where $m^=$ is the mass flux (kg/m².s), D is the diffusivity, C is the inlet or the outlet

concentration, dx is the width equal (0.099 m), m_1 is the mass of permeate water (kg/s) and A is the area of the RO membrane (m²).

4.5 Concentration polarization coefficient (CPC)

The concentration polarization coefficient (CPC) is used to quantify this resistance within the concentration layer [25]. It is defined as:

$$CPC = \frac{C_m}{C_f}$$

Where C_m is the concentration at the membrane side of the feed and C_f is the concentration at feed bulk.

4.6 Temperature polarization coefficient (TPC)

The influence of this thermal layer in the feed channel is referred to as temperature polarization effect. Temperature polarization coefficient (TPC) is used to quantify these phenomena as following:

$$TPC = \frac{T_{m1} - T_{m2}}{T_f - T_p}$$

Where T_{m1} is temperature at the membrane, T_{m2} is temperature at other side of membrane, T_f is temperature at feed bulk solution and T_p is the temperature at the permeate waterside. The lower TPC value, the higher temperature polarization effect, and vice versa.

5. Results and Discussion

The reverse osmosis system is operated under
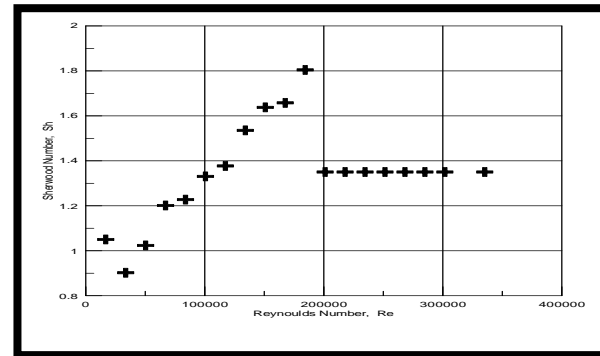
various operating parameters values. Salinity, pH value of the feed water and it influences on the performance of RO elements.

5.1 Theoretical Results

As shown in Figure (8), permeate flow rate is seen to decrease with increasing feed concentration at different feed water temperature. In Figure (9) permeate flow rate is seen to increase with increasing feed pressure atdifferent feed water temperature.
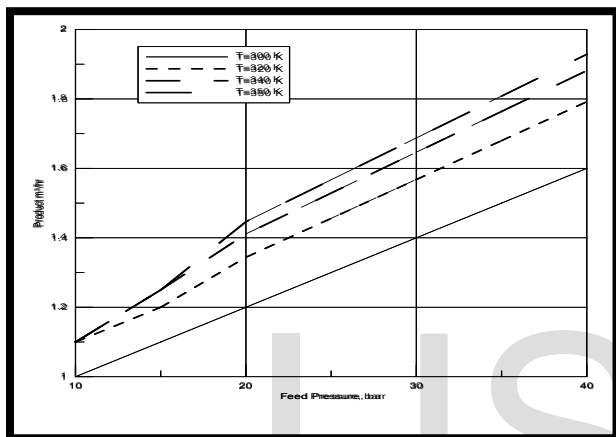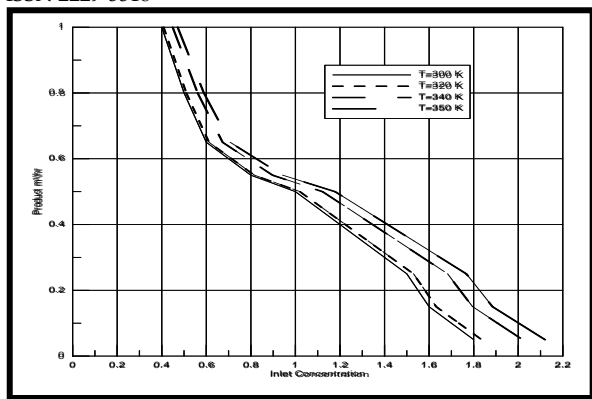
Fig. (9): The flow rate of product vs inlet feed
pressure at different temperature

Figure（10）shows the Sherwood number versus Reynolds number.Sherwood number increasing at increasing Re which limit in Re=20000, then Sh Decreases with Re increases due to formation of scaling in the pressurized of RO membrane surface.

Figure（11）shows Concentration versus time at Reynolds number. Concentration increases at time increases and the high value of concentration is in Re=800, due to formation of scaling in the pressurized of RO membrane surface.

Figure（12）shows Applied Pressure versus time at Reynolds number. Applied pressure increases at time increases and the high value of concentration is in Re=2000, due to formation of scaling in the pressurized of RO membrane surface.

5.2The Experimental Results:

Fig. (10): Sherwood number vs. Reynolds number

Fig. (12): Applied Pressure verses time at Reynolds number

Fig. (11): Concentration vs. time at Reynolds number

In the section, there are two parts; first the feed water temperature and the pressure are constant, second the feed water temperature is not constant until the pressure is still constant. The feed water is

changed in ninth values of salinity, pH and conductivity. These cases measure and record at every ten minutes to see the difference in the salinity, conductivity and pH values.

The Brackish water used from the Laboratory water source and then changed in its salinity. Table (6) shows the specifications of the water source and in the ninth cases.

Table (6): The specifications of the water source and in the ninth cases.

NO.	Water source	T. °C	pH	TDS ppt	Conductivity μs
1	Water source region		8.9	0.18	0.37
2	Case 1		8.1	0.26	0.52
3	Case 2		8.6	0.66	1.33
4	Case 3	25.4	8.2	2.56	5.11
5	Case 4		8	3.21	6.38
6	Case 5		8	4.82	9.70
7	Case 6		7.2	5.17	10.34
8	Case 7		7.7	8.34	16.68
9	Case 8		8.1	8.76	17.52
10	Case 9		7.6	10	20

From figure (13) the property of water is constant at start (time=0.0 s) and the change with time. Figure (13-a) the change of TDS.increases for brine with time but the TDS. permeate decreases with time due to the effect of RO membrane. Figure (13-b) the change of PH decreases for brine with time but the PH permeate increases with time due to the effect of RO membrane. Figure (13-c) the change of conductivity increases for brine with time but the conductivity permeate decreases with time
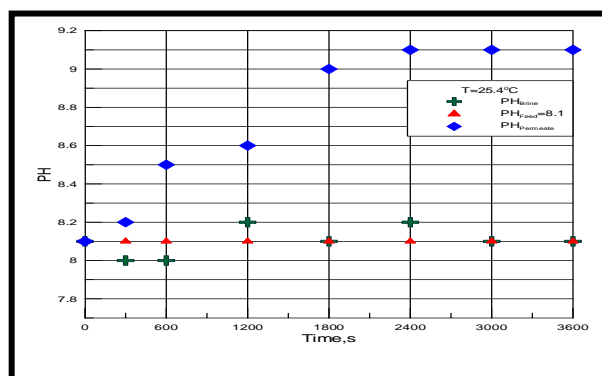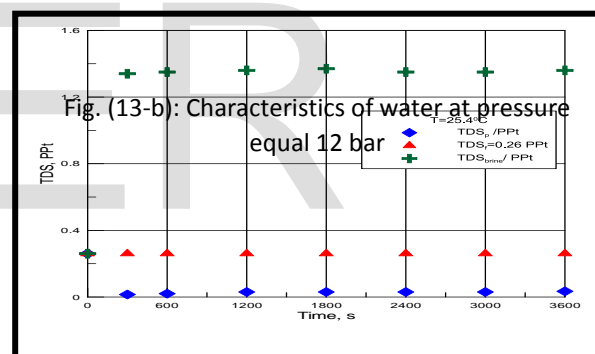

due to the effect of RO membrane.

Fig. (13-b): Characteristics of water at pressure equal 12 bar

Fig. (13-a): Total dissolved solids vs. time for feed, permeate and brine water at P=12 bar

Fig. (13-c) conductivity verses time for feed, permeate and brine at p=12bar

5.2.1 The Performance of the RO desalination system

5.2.1.1 Effect of Feed water salinity on permeate water

At the operation pressure equal（12 bar）and the temperature equal（25.4°C）with
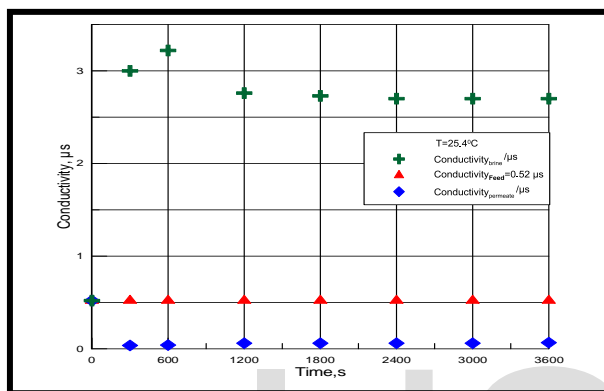
various feed water TDS. values.

Figure（14）shows the effect of the TDS.of the feed water on TDS.of permeate water with the time. In general TDS. of the feed water takes the maximum value then decreases with time when the water passes the RO membrane due to the RO membrane separate the salts to water.
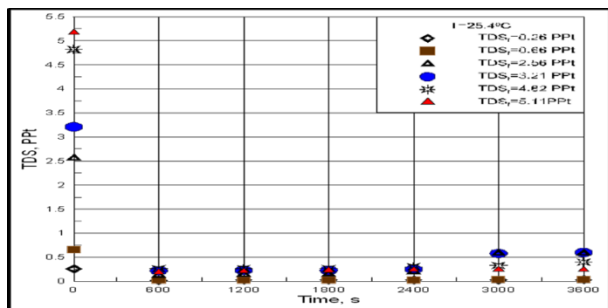

Fig.（14）: The effect of the feed water salinity on

5.2.1.2 Effect of feed water pH

At the operation pressure equal（12 bar）and the temperature equal（25.4°C）with various feed water pH values.

Figure（15）shows the effect of the pH of the feed water on pH of permeate water with the time. In general the pH of the feed water takes the minimum value and then

increases with time when the water passes the RO membrane due to the RO membrane separate the salts to water.
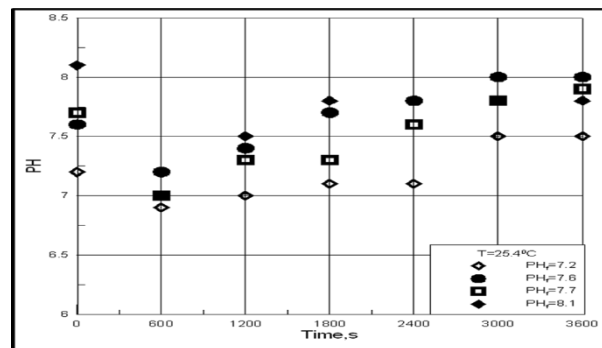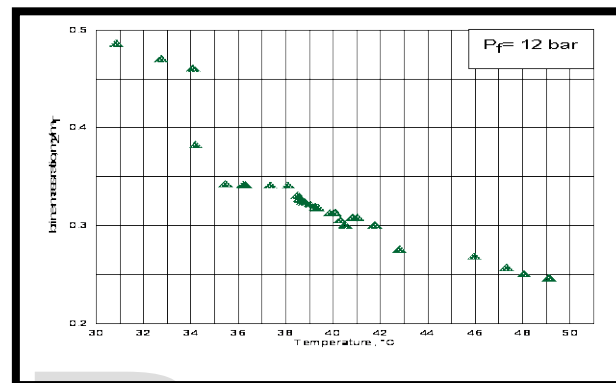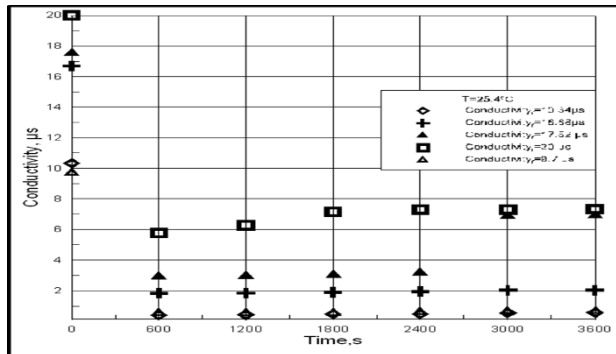

Fig.（15）: The effect of the feed water pH on permeate water pH with time

5.2.1.3 Effect of Feed water conductivity

At the operation pressure equal（12 bar）and the temperature equal（25.4°C）with various feed water conductivity values.

Figure （16） shows the effect of the conductivity of the feed water on conductivity of the permeate water with the time. In general the conductivity of the feed water

takes the maximum value and then decreases when the water passes the RO membrane due to the RO membrane separate the salts to water.

5.2.1.4 Effect of Feed water temperature

In the experimental work, at the operation pressure equal （12 bar）, the changes through used various values of water

Fig. (16): The effect of the feed water conductivity on permeate water conductivity with time

temperature which is influenced also on the performance of RO desalination system.

Figure （17） shows the mass ratio of the brine to the feed water versus the feed water temperature at the operation pressure equal （12 bar）. The mass ratio of the brine water to the feed water decreases with the temperature increasing.

Figure （18） shows the mass ratio of

Fig. (18): the mass ratio of permeate water versus the

permeate water versus the feed water temperature at the operation pressure equal （12 bar）.The mass ratio of permeate water to the feed water increases with the temperature   increasing.
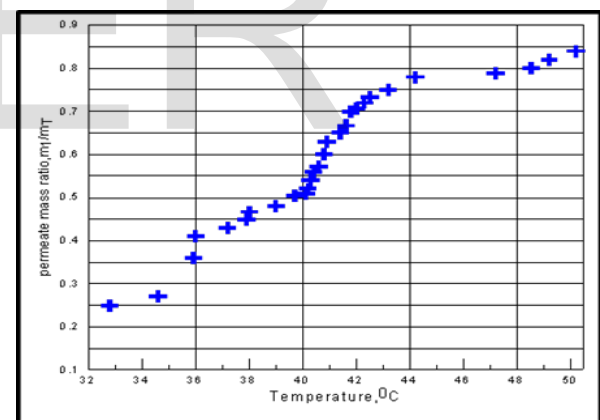
RO membrane prevents salts to pass through it but with large time and the increasing of temperature, the salts accumulate in the pressurized RO membrane surface which is called scaling, makes some of salts pass through the RO membrane and this effect on the quality and quantity of product water. It makes understanding principle of that there must temperature limit to prevent salts pass the RO membrane.

5.2.1.5 Performance of RO system in Diffusivity

Diffusivity is defined as the ratio between the mass transport by across the element RO, and its down with concentration gradient.

Figure (19) shows the diffusivity of permeate versus the feed water temperature.

Diffusivity of permeate decreases with the increasing of the feed water temperature.

For increasing inlet temperature that leads to the increasing of concentration and that will decrease the diffusivity of permeate.
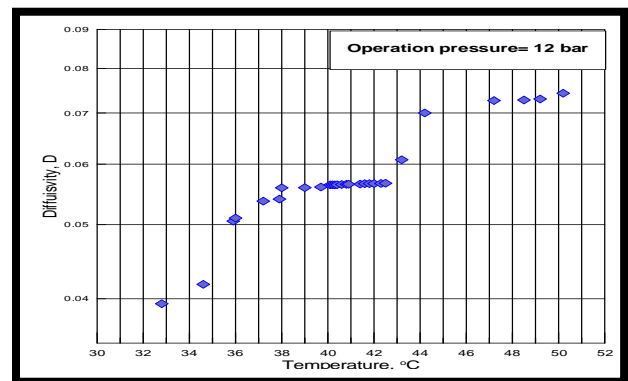

Figure (20) shows the diffusivity of the brine water versus the feed water temperature.

Diffusivity of the brine water increases when the feed water temperature increases with very limit range.Increasing temperature lead to increasing concentration and that will increase the diffusivity of brine water

fig (19) Diffusivity of permeate versus feed water temperature

because the salt message will be increasing and the salt rejection decreases.
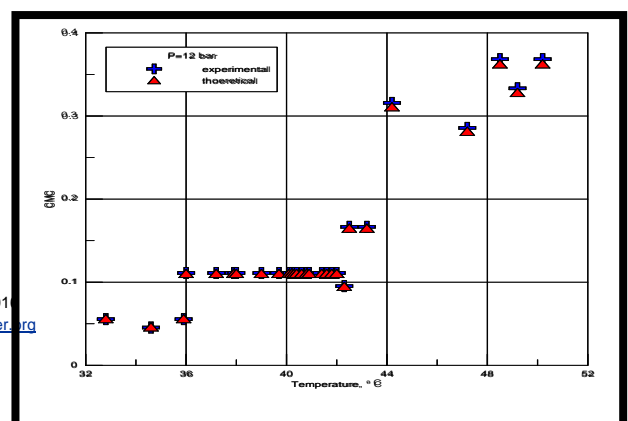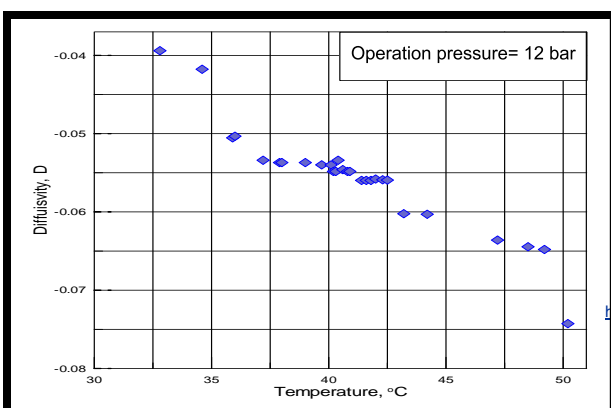
5.3 comparisons between Theoretical and Experimental Results

.The membrane performance parameters have been estimated for the experimental data of present work, and the results clearly

Fig. (20) Diffusivity of the brine vs. the feed water temperature

show that the present theoretical model predicts the data, and the estimated membrane parameters remain constant for a variety of operating conditions. Figure (21) shows the comparisons between the theoretical and Experimental results.

5.4 comparisons between present and previous work

Figure (22) shows a comparison between

Fig. (22) Sherwood number from RO membranes
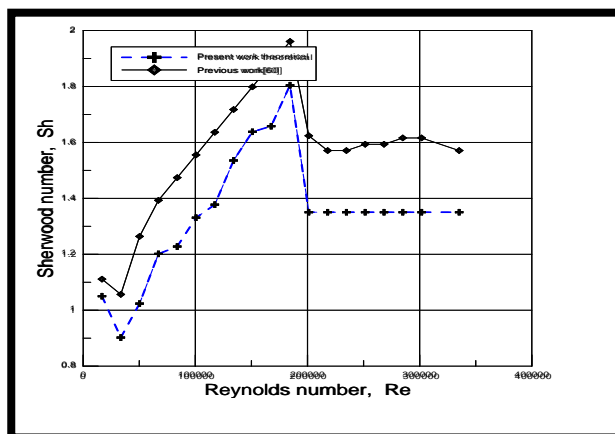
theoretical and previous work [19], for relation between Sherwood number and Reynolds number of permeate this figure

show the Sherwood number of permeate increases with Reynolds number but then it decreases due to the fouling outside the ROmembrane and the outlet concentration increases, the theoretical results have a lower than previous results, but have the same trend.

Conclusions

From the present work the following conclusions can be drawn

1. Applied pressure and solution temperature have positive impact on permeate flux from RO membranes. But it was inversely related to concentration and pH.

2. The separation of salt and permeate flux were mainly dependent on the concentration of the feed solution.

3. The permeate flux increased with increasing flow rate; for high feed flow rates it seemed to reach its maximum values asymptotically.

4. It was found that the order of effect of the operating variables on the removal of RO membranes was in the following sequence: $T > pH > P > TDS$.

5.   The initial concentration and initial volume of the solution played an important role in determining the flux and the concentration in permeate.

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