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Performance Evaluation of Multistage Flash (Msf) and Reverse Osmosis (Ro) Desalination Plants: Case Study (1) Process Description

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ABSTRACT: *This work is designed to evaluate and investigate the seawater desalination using multi stage flash (MSF) plant and Reverse Osmosis (RO) plants, which are located in Jeddah. The MSF unit consists of numerous basic components such as De-carbonator, Deaerator, Evaporator, and several systems such as product water system, these components and systemshave been discussed. The RO plant consists of numerous basic components or stages such as Pretreatment, High-pressure pump, Membrane assembly, Post-treatment, chemical dosing, and Sea Water Intake System, these components have been discussed. RO technology is the widespread for desalination,because of technology developmentswhich making construction costs of RO desalination plants have intensely reduced, creating this technology highly viable.The performance of desalination plant for RO unit and MSF unit is reported to evaluate the effect of main operating condition such as feed pressure and feed temperature on permeate product water. The result demonstrated that the permeate product water is depending on feed operating condition.*

Kay Wards: Multistage Flash (MSF); Reverse Osmosis (RO); Desalination; Plant

I. INTRODUCTION

The desalination technology is becomingasignificant process, where the main resources of potable water are not going to be talented to cover or meet all desires. Actually, fresh water are not been considered at the present time as a natural, self-renewable, low-cost resource, and easily accessible to all [1, 2]. According to potable water shortages, interest in using (brackish wateror seawater) desalination for producing fresh water is growing worldwide in the last decade. Thus, the desalination technologies for saline (brackish waterorseawater) have been progressed to face the requirements of potable water in the world. Attributable to the constraints of high relatively desalination costs, some countries cannothave the funds for these technologies as a water supplies.

Starting from the last decade and currently, desalination is considered in several countries as themainsupply of water resources [1-5]. desalination of seawater/ brackish water is applied for domestic uses in at least 120 countries around the world especially in the Gulf countries (Saudi Arabia, Oman, Kuwait, the Emirates, Bahrain, and Qatar). The Gulf countriesobtain more than 90% of their water from desalination.

Saline Water Conversion Corporation (SWCC) is a Saudi governmentinstitution dealing withdesalinationof sea waterand the production ofelectric power, and the delivery of freshwaterproduced for the various regions of the Kingdom of Saudi Arabiawhichis in a geographical area lackingfresh water thatdonot havenaturalsources suchas rivers and lakes[4].Withthe low amount ofrain orthe absence of it insome areas naturalresources in thekingdomare limited by somewells, pools and floods of rainwater which were notsufficient to meetthe necessaryrequirementsthrough the ages. As a result ofthe tremendous developmentand progressof civilization, economic, industrial and population growth, the demand fordrinkable waterhas increasedto a much higher rate than theavailablefrom natural sources. Making the attention goes towards thedesalination of sea water[5-10], especially as the Kingdom has two major resources for the sea water which they are thetwocoastsof the RedSeaandthe Arabian Gulf coast. The main technologies used to produce desalinated water in SWCC plants are Multistage Flash (MSF) and Reverse Osmosis (RO)[11-23].

Lately, RO technology is the widespread for water treatment particularly desalination. because of technology development of the RO system in the last decades, making construction costs of RO desalination plants have intensely reduced, creating this technology highly viable[7-12].RO membranes are found in a numerous of arrangements. The spiral-wound sheet and hollow fine fiber are the most commercially desired for desalting both brackish and seawater. the assembly of the membrane with pressure vessel (membrane housing) are depending on the producer and estimated salt content of the feed water. Membranes are highly sensitive towards chlorine, they get damaged easily by its effect. Only if more than the specific amount per a specific time got injected to the membrane[13-17]. Throughout the precedingyears, the operating costs of RO plants have been reduced because ofinvestments and evaluationsof new membranes,which have a high performance at low pressure, and the applying of energy recovery apparatussuch as turbines or pumps,which convert pressure drop to rotating energy.Generally, brackish water istreated bylow pressures membranes, while the energy recovery apparatusisapplied to the concentrate stream as it recycled from the membrane housing.

King AbdulAziz bin Abdul RahmanAl-Saud has begunthe idea ofdesalinationin the Kingdom when he unifiedthe country in 1348AH(1928), the establishment oftwointen ofdistillingsea water which were called later by "Alkendash" and that was made to help securethe needs ofconvoysof pilgrimsand Umrahandthe residents Jeddahfromdrinking water.The work for providing the region with drinkable water has continue over thepast yearswhich led to the establishment ofdesalination plantsto meet thegiant developmental needs which made the kingdom to become today as the world's largestproducerofdesalinatedwater.

The main objective ofSWCC is constrictingplants fordrinking water and later dual-purpose plants to produce water and power. likewise, SWCC madenumerousaccomplishments in field of seawater desalinationby making the safe requirements of potable water in the main cities over 30 plants, producing 3.5 million m^3 of water daily, and about 5000 MW of electricity. SWCC has increased the production rate of water due to increase in demand.

II. WATER DESALINATION TECHNOLOGIES

This section is dedicated to a literature survey of water desalination technologies. Thus, an analysis study for practical and applied articles concerning with desalination technologies will be covered. The most commercially important technologies are based on the multi-stage flash (MSF) distillation and reverse osmosis (RO) processes. Reverse Osmosis (RO) is a membrane separation process. While, multi-stage flash (MSF) distillation isa thermal desalination technology[24].This makes RO more attractive, as RO uses a semi-permeable membrane under elevated pressure to reject salts. Precisely, the RO desalination efficiency based on the nominated membrane [25,26 and 27].

2.1Desalination Costs

In the preceding years, desalination via Reverse osmosis (RO) has competitive effect on decreasing in the desalinate cost. Predominantly with reverse osmosis technology, desalination costs havechanged from high cost to economical, e.g., in 1994 the cost was over US$1/m3, but in these days it is about $0.50/m3 on average [3, 7]. Recently, RO is the potential competitor to the world leading desalination technology, multi stage flash desalination (MSF). RO is applied for Desalination led toconsume less energy than the other desalination technologies, Table (2) represents cost fig for desalting m^3 of potable water using different desalination technology.

Table 2: Desalination Costs ($/$m^3$ fresh water – multiply by 3.8 for $/1000 gal)

MSF	MEE	VC	Seawater RO	Brackish RO	Brackish ED	Reference
0.89	0.27-0.56		0.68			[25]
0.80	0.45		0.72-0.93			[26]
1.10-1.50	0.46-85	0.87-0.92	0.45-0.92	0.20-0.35		[28]
			1.50	0.37-0.70	0.58	[29]

From table 2 it was noticeably,not only that RO has animperative economic advantage for treating brackish water whereascost quotes for ED are not readily available. But also, RO has an economic advantage over other thermal technology such as MSF For desalination of seawater.

III. GENERAL DESCRIPTION OF SWCCPLANTS

SWCC have MSF and RO units to produce drinking water from Red seawater. The SWCC plantshave been designed to produce permeate minimum of 240,000 m^3/day (10,000m^3/hr.) of potable water from Redseawater via RO unit and 22,000 m^3/day from MSF unit. The total dissolved solid (TDS) of product water is designed to be less than 200 ppm. In the following section a process description forMSF and RO units are outlined.

1.1 Multi Stage Flash (MSF) plant

The MSF is consisting of basic components and systems as follow:

3.1.1 MSF Basic Components

The MSF is consisting of numerous basic components such as De-carbonator, Deaerator, Evaporator, Demisters, Brine Wires, Product Water Dampers, Product Water Trays, Heat Reject Section, Heat Recovery Section, Brine Heater, boiler and turbines.These components will be discussed as follow:

3.1.1.1 De-carbonator

the De-carbonator (D\C) is used to remove CO_2 from the makeup water after acid injection, as shown in Fig.1. Because CO2 is problematic as air since it reduced the heat transfer.

Figure (1): De-carbonator.

3.1.1.2 Deaerator

The deaerator is applied to remove oxygen and non-condensable Gases from makeup water, as shown in Fig.2. O_2 is very corrosive factor at any condition. the condensing tubes is protected inside stages by this way.

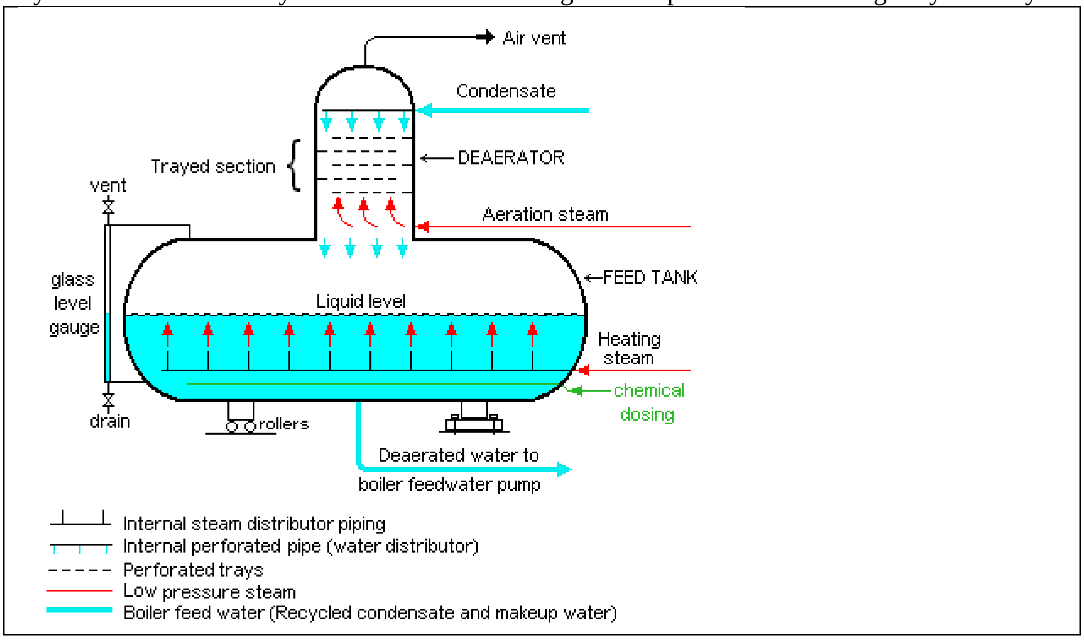

Figure (2): De-aerator schematic.

3.1.1.3 Evaporator

The evaporator contains many components the following components locate either inside or on the Evaporator (demisters, brine wires, product water trays and product water damper). The condensing tubes also locate in the top of the evaporator.

3.1.1.4 Demisters

Inside the evaporator; demisters locate. They prevent salt particles to carry over with vapors, because this salt increases the conductivity of product water.

3.1.1.5 Brine Wires

Brine Wires locate on the stage wall and they are used to control the following:

- Brine flow from one stage to another one.
- Brine level in the stages.
- Differential pressure between the stages.

3.1.1.6 Product Water Dampers

They also locate on the stage wall. They are used to control the following:

- Product water flow from one sage to another.
- Product water level in the stages.
- Differential pressure between the stages.

3.1.1.7 Product Water Trays

They are used to collect the condensate and transfer product water from stage 1 through the last stage.

3.1.1.8 Heat Reject Section

The stages 22, 23, and 24 are called "Heat rejects section" where the excess heatisrejected by heat exchanging between the cooling water tubes and the brine steam.

3.1.1.9 Heat Recovery Section

The stages from 1 to 21 are called "Heat recovery section." The heat is recovered there between the condensing tubes and the brine steam that comes from the box pipe.

❖ Heat Recovery Section (Condensing Tubes):

This is the main step in diesel process especially in the 'Heat recovery section"; the heat is exchanged between the brine and the condensing tubes or product the distillate. The heat is recovered by heat exchanging process. Because another source of energy like electric or steam might cost a lot higher. The heat recovery between the brine and the tubes is economical solution.The brine passes through around 5400 tubes. The tubes made of an alloy called ($CuNi_{10}Fe$), and they locate at the top of the stages.The stages of heat recovery section are arranged in 4 modules as the following:Module no. 1 contains of stages 1 to 6, Module no. 2 contains of stages 7 to 11, Module no. 3 contains of stages 12 to 16, and Module no. 4 contains of stages 17 to 21. Inlet temperature of the brine is around 40 ºC, and the pressure is 6 bar. The outlet temperature is 101 ºC, and the pressure is 3 bar.

❖ Heat Recovery Section (Box Pipe):

The brine enters to stage 1 of heat recover section at 110 ºC and 1 bar and completes the recycle. The temperature and the pressure reduces from one stage to another at certain rates. Until it reaches 40 ºC and 0.05 bar at stage 21 (the final stage of heat recovery). Then the brine goes to heat reject section.

3.1.1.10 Brine Heater

The main function of the brine heater is to heat the brine by heat exchanging between circulating brine and low pressure (L.P) steam. After the heat exchanging, brine temperaturewill increase from 100 °C to around 110 °C and steam will condense as product water.

3.1.2 **MSF systems**

The MSF is consisting of several systems such as seawater intake system, product water system,Brine Blow down System, Brine Recycle (B/R) System,Control Valves, Vacuum System, and Chemical Dosing System. these systems will be discussed as follow:

3.1.2.1 Seawater Intake System

This is the first stage that seawater come in through. Starts with 5 large pipes 12.5 m long under the sea with 1.5 m in diameter each. It takes the sea water into the pump house. Chlorine dosing system works to inject chlorine (sodium hypo-chloride) into the pipes to prevent fishes, bacteria and seaweed's that comes in with the seawater from entering. chlorine is being getting by electrolyzing seawater. There are 2 types of injection normal dosing during usual operation and shock dosing during emergency cases. Then the middle pipe divides to 2 pipes so the total can be 6 pipes that enters to 2 large sinks. At the end of each pipe there is a stop leg (stop gate) that stop sea water entry. Sea water go through 4 pipes for each sink. Every pipe passes through:

- Course bar screen: that is used to prevent large materials, mariners and jelly fishes. Because if that things enter to the pumps, they will be damaged.
- Traveler band screen: that is used to prevent sand, small fishes, and other small materials for the same reason.

Then sea water gets pulled by 13 pumps, as follow:

- Four diesel plant pumps 30,000 m3/hr each, 3 in service and 1 standby during normal operation.
- Four Power house pumps, 18,400 m3/hr each, 3 in service and 1 stand by during normal operation.
- Three Auxiliary cooling water pumps, 6,000 m3/hr each, 2 in service and 1 stand by.
- Two Firefighting pumps, 500 m3/hr each, one operates by diesel and one electrical.

Figure (3) represented the MSF process diagram.

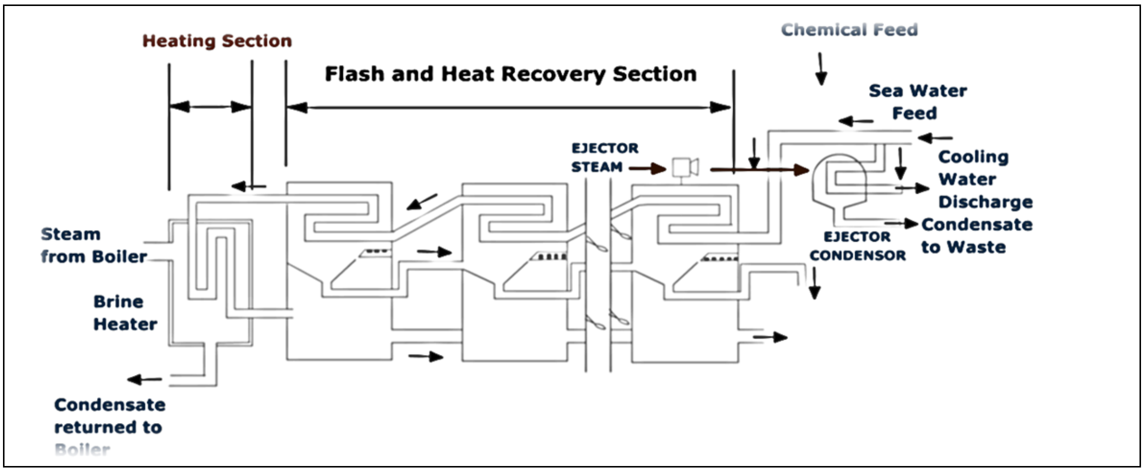

Figure (3): MSF process diagram

3.1.2.2 Product water (PW) system

- **PW pumps**

Two PW pumps are existing in MSF, their type is double stages vertical centrifugal pumps. One of them in service and other is stand by. The conductivityofPW is measured by using a quality gauge, the conductivity in micro Siemen / centi-meter.

- **PW header**

The PW header is the plant that send PW to the city after the chemicals treatment. The following chemicals are injected to the PW:

- NaOH: That isused to improve PH ofPW to give the PW good taste for human's consumption.
- Calcium hypochlorite[$Ca(ClO)_2$]: That is used to kill the microbes by the chlorine and the calcium is very important to humansfor strong bones. The healthy conductivity of the PW is less than 100 micro Siemen /centimeter.

- **PW Demin plant**

PW is used there to supply the boilers. At the plant, PW is treated by Ion exchange to reduce the conductivity up to 0.3 micro Siemen /centimeterto keep boilers from harms.

- **PW changeover v/v.**

PW is dumped there if it has high conductivity (around 500 micro Siemen / centimeter. The valves of demin plant and PW dumper is arranged that one will be closed when the other is open.

3.1.2.3 Brine Blow down System

This system is very important to remove the concentrated brine from the plant. the brine passes through the stages; then there is an amount that will distillates as product water, this process causes increasing of the concentration ratio is:

The concentration ratio = $\frac{\text{Conductivity of B/R}}{\text{Conductivity of M.U.W}}$

Where: B/R = Brine Recycle

M.U.W = Make Up Water

The Concentration ratio should be 1.34 at maximum. If the concentration ratio rises; then the product water flow will decrease. After the brine recycle; the concentration of the brine will increase. The high concentration brine is removed, this process called Brine Blow Down system. The Blow Down pump pulls the high concentration brine from the bottom of stage 24.

3.1.2.3.1 Brine Recycle (B/R) System

This system isused to produce thedistillate water. We have 2 B/R pumps, both in service. They take the brine from stage 24 to 1. These pumps type is "double stages vertical centrifugal pumps". They are double stages to give the required pressure. The inlet pressure to stage 21 is around 6 bar. And the outlet pressure is 3 bar. If the pressure drops inside the condensing tubes; the brine will starts boiling, then the tubes well damage. And the ph of the inlet water is around 7.8.

3.1.2.4 Control Valves

It locates before stage 1 brine inlet, it used to protect the condensing tubes from any dropping in the pressure. Because if the pressure drops; then the brine will boilinside the tubes and damages them. It also controls the inlet temperature at the set point of 110 ºC. Because after this temperature the scales will form.

3.1.2.5 Vacuum System

The vacuumsystemis simply used to pull out the gasses from the deaerator and the stages. And the way for it to work is by using a High-Pressure Steam.High Pressure Steam (H.P) System is fed to the vacuum system units. It comes from the boiler at a pressure of 85 bar and a temperature of 510 ºC. In vacuum system, we have:

- Start Up Ejector (Hogger): The hogger is used to pull air and non-condensable gasses from the plant. When it starts the operating; it needs a pressure of 80 bar and a temperature of 500 ºC. At the end of the operating; the D/A pressure becomes 0.24 bar.
- Service Ejector: The service ejector is used to operate the vacuum system at the normal operating status. H.P steam is used for operating, the steam passes through reducing station (locates before the ejector inlet) to reduce the pressure to 12.5 bar and the temperature to 250 ºC.
- Barometric Condensers: For each vacuum unit, we have 3 condensers that used to condense the gasses that comes from the ejector or the hogger. The condensers have been provided in 3 different pressures.

3.1.2.6 Chemical Dosing System

❖ **Sulfuric Acid**

In seawater,thereissome solutes like $CaCO_3$, which forms soft scales on the tubes walls. If the scales forms, the heat exchanging rate will decrease, and the production of water will reduce. So we neutralize $CaCO_3$ by dosing acid to remove it from the make-up water. And the reaction will be as the following:

$CaCo_3 + H_2SO_4$ ==============➔ $CaSO_4 + H_2O + CO_2$

CaSO4 is produced, it makes hard scale at 120 C, but we don't reach this temperature. Our maximum temperature is 110 ºC in stage 1. $CaCO_4$ is blown down with the high concentration brine at stage 24.

❖ **Belgard EV-2000**

It's used to in same way as the H_2SO_4, they are both work as an anti-scale. theacidorBilgard are used. Belgard doesn'treact withthe solutes that causes scales. the solutes in the sea water exists as a positive and a negative ion (anions and cations), when a bond is initiating between a positive and a negative ion; scales appear. Belgard prevents the formation of the bonds. Belgard can be used up to a temperature of 112 ºC

❖ **Anti-Foam**

It's used to prevent the foam formation inside the stages. If the foam produced; product water will contaminate by the brine.

❖ **Sodium Sulphite ($NaSO_3$)**

$NaSO_3$ is injected into the make-up water to remove any Oxygen remaining in the make-up water after the D/A. the reaction is:

$2NaSO_3 + O_2$ ====➔ $2NaSO_4$

❖ **Sodium hydroxide (NaOH)**

Lime is injected into the product water to improve the ph value and to give a good taste for human consumption.

❖ **Calcium hypochlorite($Ca(ClO)_2$)**

It's injected to the product water to sterilize it and make it potable. The chlorine kills the microbes and the bacteria's. The calcium is important for human's body; to give strong bones.

3.1.2.7 Boilers

- The boiler contains many systems that works together for it to convert the water into steam successfully. Some of them are:

- Feed Water System:

The water required to convert to steam goes into multiple units. And goes under many operations.

A. Deaerator:

The deaerator has many benefits and roles. It removes the oxygen from the water by this reaction:

$N_2H_4 + O_2$ ====➔ $2H_2O + N_2$

Because the oxygen is a very corrosive material. it also gives a positive suction pressure to the Boiler Feed Pump that placed after it and it give heat to the water and raise the temperature from 37 to 127 ºC.

B. Boiler Feed Pump:

Its job is to raise the pressure of the water from 3.5 bar to 120 bar. This pump is huge and complicated it has auxiliary systems to help it out. The water goes through 6 stages throughout the process.

C. HP Heaters:

The HP heaters are two separate heaters in a row. Its job is to raise the temperature of the pressurized water from 127 ºC to 220 ºC.

D. Economizer:

It raises the temperature of the feed water by the flue gas that's generated by the combustion inside the boiler while it's leaving. Finally, the water goes inside the Drum of the boiler.

- Combustion Air and Flue Gas System:

Air from the atmosphere is pulled into the Forced Draft fan and blown into the boiler, at a controlled rate depending on boiler load.

A. Air Preheater
For good combustion the air needs heating before entering the furnace. This heater raises the temperature of the air from 35 ºC to 65 ºC via steam.

B. Ljunstrom Heater (LJ Heater)
The air is passed through a rotating drum, that's filled with metal plates which the air passes between. The plates are rotated into flue gas leaving the boiler, which heats the plates. They then rotate into the air flow which cools the plates and heats the incoming air. And this process is a generative air heater.

C. Wind box
The hot air enters the wind box and its entry to the furnace is controlled by dampers at the burners.

D. The flue gas line and treatment
We need to get rid of the generated flue gas from the combustion. But we first going to benefit from its temperature. So, first it's going to be used in the super heaters to heat up the steam. The super heaters are mainly three headers: Low Temperature Super Heater (LTSH), Intermediate Temperature Super Heater (ITSH) and High Temperature Super Heater (HTSH).

The flue gas goes first to the LTSH then the ITSH then to the Attemperator which controls the temperature before going to the HTSH and keeps it within the metal limits of the super heaters. Then the flue gas goes to the economizer and heats up the incoming feed water. After that it passes through the gas side of the LJ heater and then enters to the electronic sulpherization precipitator (ESP). An electrostatic precipitator, or ESP, is one method for removing particulate matter from flue gas which in our case is the silver. Then 60% of the flue gas goes to the FGD and the rest goes straight to the chimney. The FGD wash the flue gas with the sea water to reduce the releasing of the silver in the air. Then the leaving gas of the FGD returns to the 40% and gets dissipated to the atmosphere.

- **Boiler parts and its way of work**

▪ The water enters the steam drum from the economizer. As the water enters the stem drum the pressure reduces to about 97 bar from 120 bar and the temperature rises to about 300 ºC. the internal feed line nozzles point down the water to something calls the down comers which takes the water to the bottom wall header so it won't affect level in the drum. From the bottom header the water rises in the rises tubes placed in the furnace wall back to the drum. Because the water in the walls is less dense the water in the down comers force it to go back in the drum and this is the natural circulation. It's used to keep the walls cool.

▪ The drum is the place where the water and the steam separates from each other by a cyclone move. And the drum is the perfect place to dose some chemicals in the boiler.

▪ The chemicals of the boiler are:

1. Sodium Phosphate (Na_3PO_4) to remove the hard scale.

$2Na_3PO_4 + 3CaSO_4$ ====➔$3Na_2SO_4+Ca_3PO_{42}$

2. Sodium Hydroxide (NaOH)

It's a special dosing only in the startup. Its job is to raise the value of the ph in the boiler to make it between (8.7 and 9.5) which is the acceptable range in the boiler.

▪ These products leave the drum in a stream calls Continuous Blow Down.

▪ The single boiler contains 12 Burner. 4 in each elevator or level. All the 12 burners use the same heavy fuel oil for combustion. But the down 4 or the first level's burners also use diesel which is only used in the startup process as an igniter. Because it ignites faster and it has a lower heat which is better used as a warm up.

▪ There are five boilers in Jeddah 4. Each one of them produces a steam flow equals 600 T/hr with a temperature of 510 ºC and a pressure of 85 bar.

3.1.2.8 Turbines
There are five turbines in Jeddah 4. The produced steam from the boilers goes into the turbines. Each turbine can produce up to 118 MW at a rate of 3600 RPM. First and second extractors from the turbines goes to the HP heaters located before the economizer. And the third extractor with a pressure of 1.5 bar and a temperature of 125 ºC goes to the diesel section, to the brine heater to be more exact.

3.2 Reverse Osmosis(RO) plant
RO plant system is designed of the following basic components or stages: Pretreatment, High-pressure pump, Membrane assembly,Post-treatment, chemical dosing, and Sea Water Intake System. Schematic of RO plantwas shown in Fig.4.

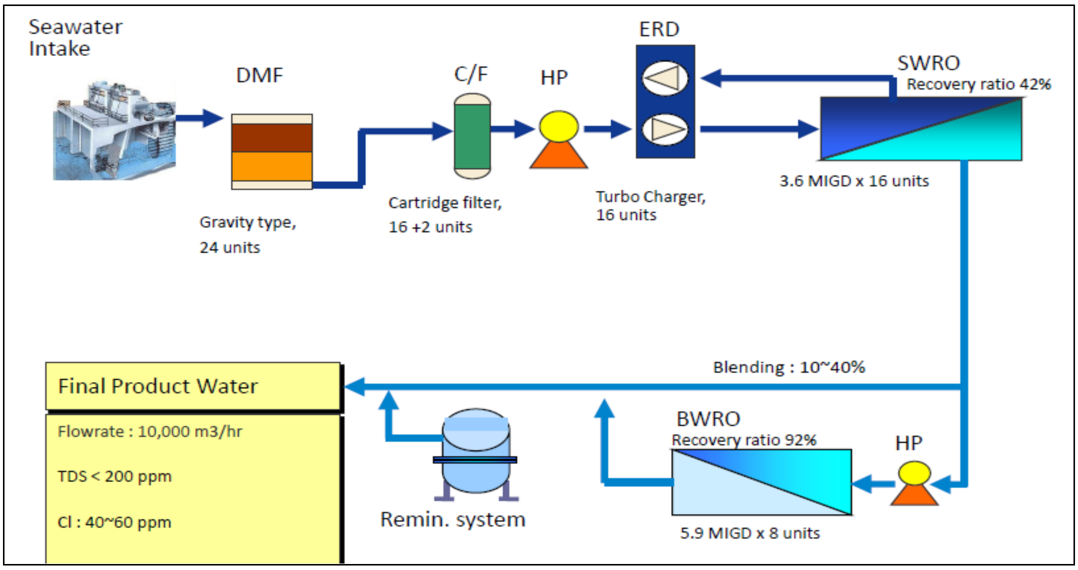

Figure (4): RO plant Schematic.

3.2.1 Pretreatment

Pretreatment stage is significant in RO and plays a vital role for removing suspended solids from water,consequently salt precipitation or microorganism growth does not appear on the membrane surface. Generally, the pretreatment process is formed ofa fine filtration and the addition of acid or other chemicals to prevent precipitation.Pretreatment consists of the following components:

- **Stop Gates:**

Located after the water intake and the before the Sea Water Pumps. Its job is to close to protect the plant and its parts from any sudden threat if needed or when there is a periodic maintenance happening.

- **Course bar screen:**

Located after the first line of the stop gates. Its job is to prevent large materials, mariners and jelly fishes from entering the plant. Because if those obstacles entered inside the pumps, they will damage it.

- **Traveler band screen:**

Located right after the Bar screens. Its job is to prevent sand, small fishes and other small obstacles from passing through with the water and entering the plant.

- **Sea water Pumps:**

Located after the second line of the stop gates and before the Dual Media Filtration (DMF). They are 4 pumps 13800 V each. Its job is to push the water from the holding tank after the stop gates to the DMF cells.

- **Dual Media Filtration (DMF):**

It's a 3 layers filter. It consists of coal, sand and gravel. Its Located after the Sea pumps. Its job is to pass the water through a porous for the physical removal of suspended solids and/or turbidity. There may be contaminants in the water added via contact with earth elements that leads to dissolved impurities or particulates or manmade such as wastewater, chemicals, fats, oil, grease.

- **Clear well:**

It's used as a storage for filtered water after DMF and before the cartridge filter with large quantity.

- **Cartridge Filter:**

Cartridge Filters are part of the fine filtration system. This system is used as an additional safety measure against the possible presence of suspended particles of size larger than 10 micron in the seawater. Purpose of cartridge filter is to removal of finer suspended impurities of 10 microns and larger size from the filtered water pumped from the filtered water clear well by 3 filtered water pumps that raise the pressure of the passing water to 3.5 bars, before being supplied to RO train. Providing a dumping facility of filtered water until the quality of water reaches to the permissive value to feed to RO Trains.

3.2.2 High-pressure pump(HP)

HP Supplies the pressure desirable to allow the water to penetrate the membrane and prevent the salts to pass. For brackish water, the required pressure varieties from 17 to 27 bar while for seawater from 54 to 80 bar with the support of the turbo charge. In the present case for the red seawater the needed pressure is about 41 bar. this value is calculated by multiplying the conductivity of the red sea with the value of 0.0007 (a constant factor), so $58000 \times 0.0007 \approx 41$ bar which is the needed pressure, so start the production of the pure water.

3.2.3 Membrane assembly

Membrane assembly is designed of a pressure vessel and a membrane that allows the feed water to be permitthrough membrane. In our case, the RO planthas 16 units. Each unit consists of 226 vessels. And inside each vessel are 2 membranes. Each membrane has ability to permitpotable water and prevent permeation of salts.

3.2.4 Post-treatment

Post-treatment process is appliedto remove gases such as hydrogen sulfide and adjusting the pH number of the product waterby dosing some chemicals as Calcium Hypochlorite.

3.2.5 Chemical Dosing through RO Plant

❖ **Sulfuric Acid (H_2SO_4)**

- Preventing scaling in Pipes and RO membranes.
- Increasing the efficiency of the coagulant for Ferric Chloride; causes a better filtration efficiency. The injection of H_2SO_4 as follow:

a. Point 1 Before the DMF inlet.

b. Point 2 Before Cartridge Filter inlet.

❖ **Ferric Chloride ($FeCl_3$)**

- Coagulating the suspended impurities in seawater
- Ensuring an efficient filtration as the seawater passes through the DMF bed of materials.

❖ **Polymer**

- Helping:to enhance the effect of coagulant (ferric chloride).
- It's used when the SDI goes over the normal numbers.

❖ **Sodium Bisulfite**

Providing the de-chlorination to protect the membranes.

❖ **Sodium Hypochlorite**

Purifying the intake water by vanishing, bacteria and seaweed's that comes with sea water.

❖ **Calcium Hypochlorite**

Purifying the product water.

❖ **Caustic Soda**

Washing chemical for the 2^{nd} pass membrane.

❖ **Citric Acid**

Washing chemical for the 1^{st} pass membrane. It prevents the Iron Oxide fouling.

❖ **Ammonia**

Washing chemical for the 1^{st} pass membrane. It prevents the Iron Oxide fouling.

3.2.6 Sea Water Intake System

This is the first stage that sea water come in through.Starts with 2 large pipes with 2.4m in diameter and 27000 m^3/hr in capacity. Takes sea water into the pump house. Chlorine dosing system works to inject chlorine (sodium hypochloride) into the pipes to kill fishes, bacteria and seaweed's that come in sea water. There are 2 types of injection: Normal dosing during usual operation and Shock dosing during emergency cases.

IV. RESULTS

4.1. MSFunit

4.2.7 Mass Balance

The feed Red seawater for MSF desalination unit is 2810 m^3/h. The desalination process is from stage 24 to stage 1.

Figure (5): Mass balance and energy balance.

Fig.5 shows the inputs and outputs for MSF desalination process. The equations for mass balance and energy balance was determined as follow:

- Mass balance:

$$\dot{m}_{feed\ water} = \dot{m}_{product\ \ water} + \dot{m}_{blow\ -down\ water} \qquad (1)$$

$$2810\ m3/h = 917\ m3/h + 2000\ m3/h$$

$$2810\ m3/h = 2917\ m3/h$$

Sometimes the mass balance value is unreasonable because of the losses in the plant like: Feed water leak (flanges, traps, drains, vents), Level change (reading error), Instrumentation difference, and Dead stage.

- Energy balance:

$$\dot{m}_{steam}\ (\Delta h) = \dot{m}_{produ\ ct\ water}\left(h_{product\ \ water} - h_{feed}\right) + \dot{m}_{blow\ down}\left(h_{blow\ down} - h_{feed}\right) \qquad (2)$$

$h_{product\ \ water}$ At 38°C = 150.81 KJ/kg

$h_{blow\ down}$ At 40 °C = 167.53 KJ/kg

h_{feed} At 35 °C = 146.64 KJ/kg

$$\dot{m}_{steam}\ (\Delta h) = 91.7 * 10^4\frac{kg}{h} * (150.81 - 146.64) + 20 * 10^5\frac{kg}{h}(167.53 - 146.64)$$

$$\dot{m}_{steam}\ (\Delta h) = 45603890\ KJ/h$$

4.3.8 Performance of MSF unit.

The performance of MSF unit is measured for studying the effect of main operating condition such as Vacuum Pressure and feed temperature on permeate water. The obtained data is represented in Figs. (6,7).

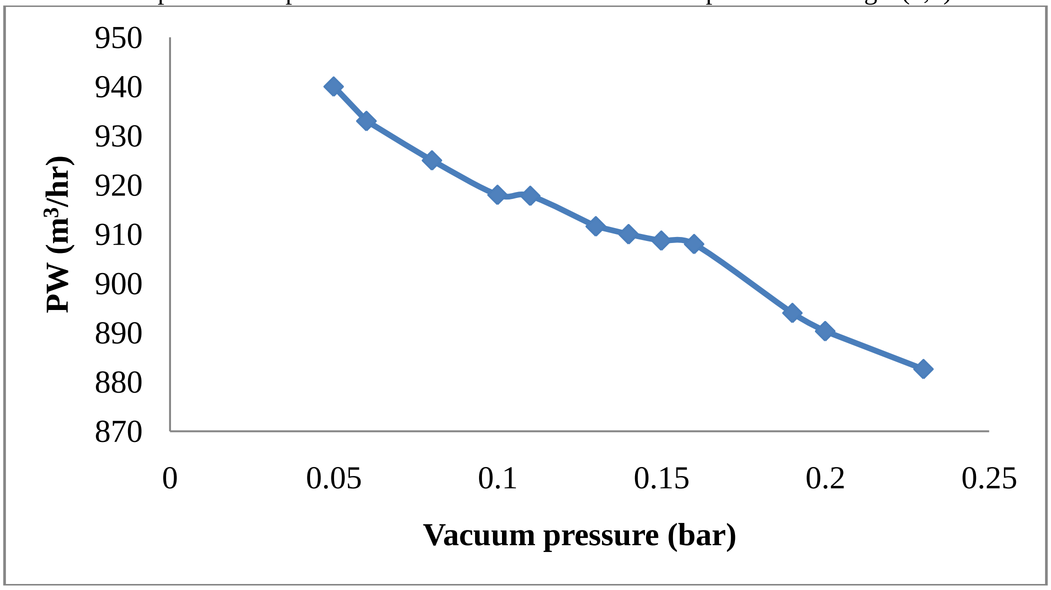

Fig. (6): The relationship between Vacuum Pressure and product water in MSF.

Fig.6 shows the relationship between Vacuum Pressure(VP) and PW in MSF station. It seems that there is aninverse relationship between VPand PW, the increase in VP leads accordingly to decrease in PW [30]. This could be resorted to the decrease in vaporization at stage 24.

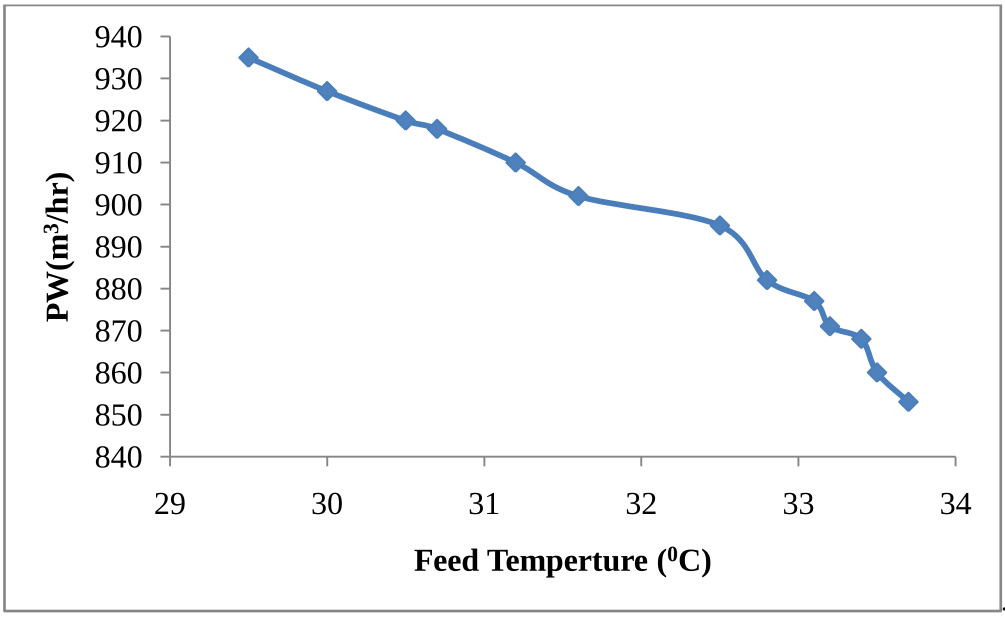

Fig. (7): The relationship between feed temperature(FT) and product water in MSF.

Fig.7 shows the relationship between FT and PW in MSF station. It is clear that there is ainverse relationship between FT and PW, the increase in FT leads accordingly to decrease in PW. That is because the condensation decreases at stage 24 when the heat rejection high.

4.4 Performance of RO unit

The performance of RO unit is detectedtostudy the effect of main operating condition such as feed operatingpressure and feed temperature on permeate water. The observed data is plotted in Figs. (8,9).The RO Design Parameters are:

- Seawater Temperature 26-35 ℃, TDS 43,300 ppm, Feed flow rate 604,300 m3/day.
- Permeate or product flow 240,000 m3/day(680 m3/hr. each train), Product TDS < 200 ppm, Number of trains: First pass 16 trains, Second pass 8 trains.
- Conversion rate: First pass 42 %, Second pass 92 %.

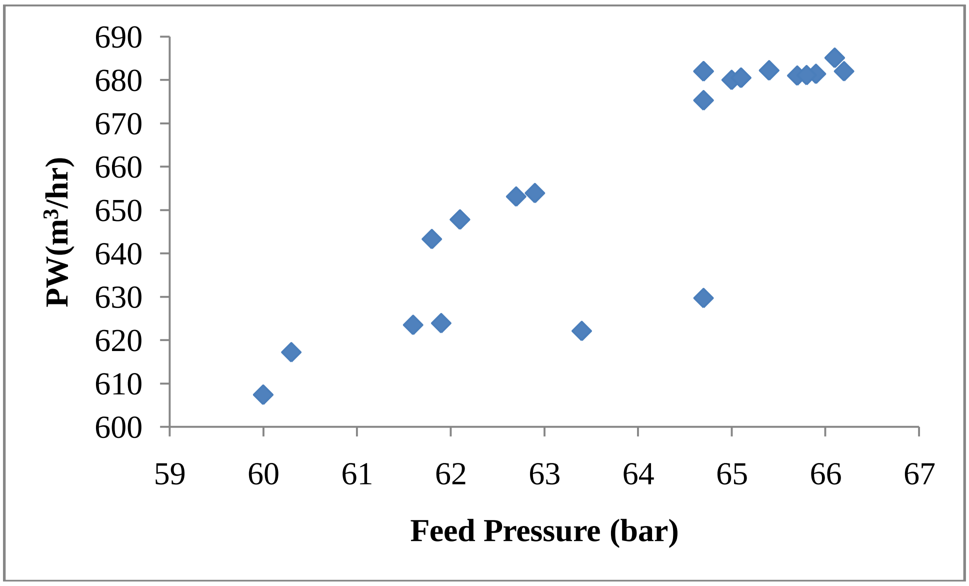

Fig. (8): The relationship between feed pressure(P) and product water in RO for each train.

From the fig.8 which represents the relationship between P and PW,it appears that there is a proportional relationship between P and PW, the increase in P leads accordingly to increase in PW taking into consideration the recovery must not exceed 42%.

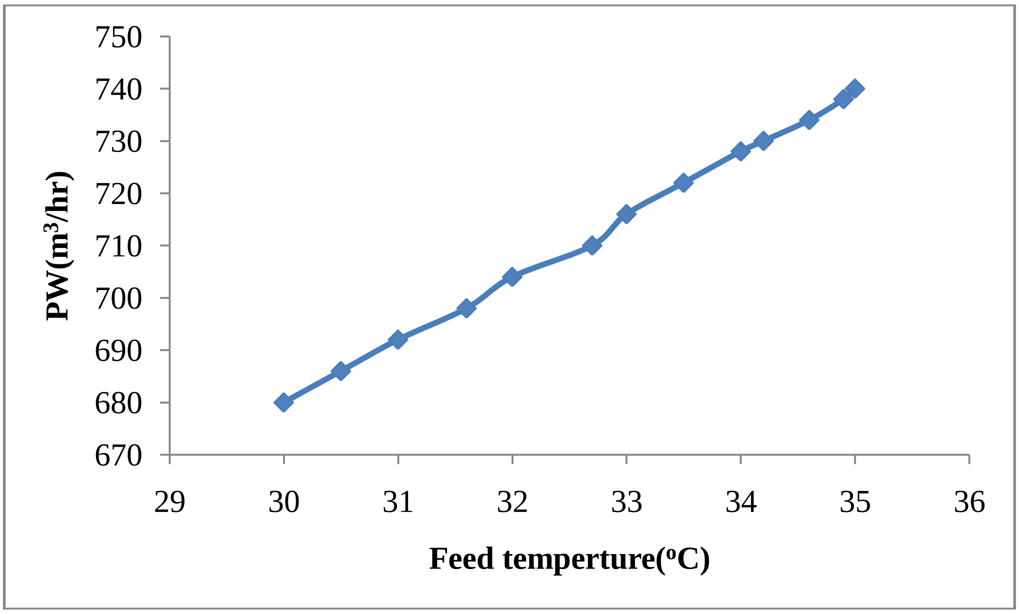

Figure (9): The relationship between feed temperature and product water in RO for each train.

Fig.9 shows the relationship between FT and PW in RO station. It obvious that there is a proportional relationship between FT and PW, the increase in FT leads accordingly to increase in PW [30]. This could be resorted to the increase in water movement activity.

V. CONCLUSION

In this study, the performance of a multistage flash (MSF) and a reverse osmosis (RO) plant is investigated of Saline Water Conversion Corporation (SWCC) in Jeddah, Saudi Arabia. The major components of the system are described as well as the pre-and post-water treatment processes of the plants. The main findings of this work are that the production of permeate water is dependent on the feed operating conditions.

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