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# Evaluating Membrane Technology for Drinking Water Production in Comparison with Conventional Processes.

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# Evaluating Membrane Technology for Drinking Water Production in Comparison with Conventional Processes

# تقييم تكنولوجيا الاغشية في انتاج مياه الشرب بالمقارنة بالطرق التقليدية

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## Abstract

This paper discusses the performance and characteristics of desalination membranes used in treatment of water for potable use. In this study, The Desalination Economic Evaluation Program (DEEP) is a spreadsheet tool originally developed for the IAEA by General Atomics and later expanded in scope by the IAEA, The DEEP-5.1 version program allows designers and decision makers to compare performance and cost estimates of various desalination and power configurations. Desalination options modeled include MSF, MED, VC,RO and hybrid systems. This paper presents the results of the operational performance of RO units in experimental scale. The rate of decline of productivity for a period 38 Days is examined and described by simple power law function. The evaluation of the solvent and salt permeability coefficients with the time of operation is quantified. The results show the recovery, pressure and conductivity across the membrane for 38 days test run. Also, the results show the effect of chemical additives and operational parameters on the performance of the membrane during the cleaning. Based on such individual RO module data (one year) the product flow rate and Total Dissolved Solids (TDS) performance is calculated and RO module replacement ratio can be estimated. These developments can be utilized to improve the quality of surface seawater feed to the level comparable to, or better than the water quality from the well water sources. These new developments enable a more advanced RO system design which should result in increased reliability and lower water cost. And compare the result of reverse osmosis desalination conventional system with a mathematical model is built and solved with ROSA computer programs to get results for the design calculations of the reverse osmosis mode used to remove salt from the feed water. The principles of the reverse osmosis mode, the conditions and factors affecting their operation, are discussed. The number of stages with their arrangements in the reverse osmosis mode is calculated using the ROSA Program. A mathematical model and computer programs including all the mentioned cases are built and applied on the reverse osmosis mode of water stations. The results of these calculations are compared with the practical results and showed a fair good agreement.

## 1. Introduction

Desalination systems that most commonly used in practice are described. These systems are the multiple effect (ME), Multi-stage flash (MSF), vapour compression (VC), reverse osmosis (RO) and the electro dialysis (ED) desalination systems. The most important features for each system is explained. Solar energy powered desalination systems are also reviewed. Finally, a simple practical and economical comparison between some of these systems is recorded. Advancements in membrane materials and other aspects of this technology have lowered overall operating costs, which will ultimately reduce the cost of implementing public water quality improvement programs. Spiral wound elements are normally used in high flow applications.

Gamal Khedr M.1998 the fouling film detected on the surface of RO membranes, which is responsible about the decline of RO performance [1]. Wilf and Schierach 2001 found that the operating parameters of seawater RO system are mainly function of feed water salinity and temperature [2]. El-Saie et al 2002 studied the effect of operating conditions such as feed water temperature, feed water pressure and recovery ratio on the permeate quality, production and system economy[3]. Villafafila and Mujtabab

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2003 found that the higher pressure will lead to higher recovery ratio when they studied the effect of feed flow rate and feed pressure on the recovery ratio for reverse osmosis system [4]. Zhang et al. and Zhou and Tol (2004) described the technical and economic characteristics of different desalination processes and their implementation in China [5]. Abbas 2004 found that increasing the input pressure will increase the recovery ratio when he studied the effect of the operating conditions on reverse osmosis desalination system [6]. S. Nisan and L. Volpi (2004) the economic calculations presented at this occasion were based on the utilisation of the DEEP2 software, initially developed by the IAEA [7]. M. Methnani (2005) IAEA has since then issued the new, DEEP3 version of the software with a number of improvements in both MED and RO models [8]. Helmy 2006 found that the higher recovery ratio can be attained at higher operating pressure and higher feed temperature, while the increase in feed water pH and feed water salinity will lead to opposite effect [9].

RO membrane is tested in a quality control test loop before it is shaped under specific conditions [10]. There are computer models that can simulate the performance of membranes based on feed water characteristics of treatment system. In some tests of membrane an experimental error may be increase due to additional handling and also variations of swatch bench testing may be significant [11]. The fouling film detected on the surface of RO membranes, which is responsible about the decline of RO performance [12]. Membranes generally operate based on three principles and they include (a) Filtration, (b) Diffusion, and (c) Adsorption. Each membrane process utilizes varying degrees of principle to properly function [13].

# 2. EXPERIMENTAL SET-UP

## 2.1 Deep 5.1 Diselination Evaluation Economic Program

Starting with DEEP and navigating through the program

To perform a simple water cost analysis of any dual or single purpose plant, perform the following steps:

Select the New Case button.


*Fig 1: Screen of the newest feature of DEEP 5*

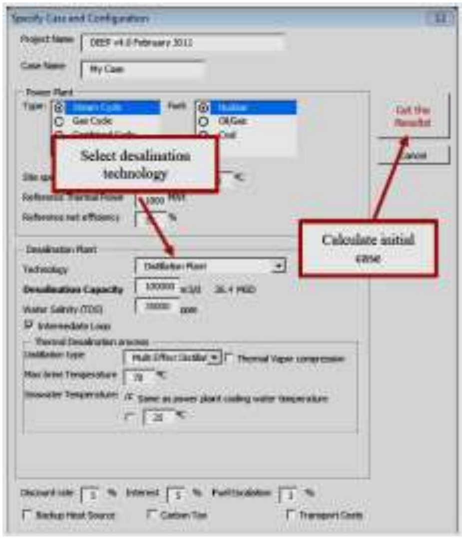



*Fig 2: s Screen of the specify case and configuration of DEEP 5*

## 2.2 Reverse Osmosis System Set Up

Having determined that Reverse Osmosis (RO) system would be the most energy and space efficient for purification and desalination system next is to build and test such a system. Aiming for a small-scale system, a 55.0 lit. per hour system is sufficient. For the reverse osmosis part of the system, the main components are the pump, filters, and the membrane. The pump needs to supply the required high pressure to drive the water across the membrane and. Also, a typical reverse osmosis system has (5) stages. The first stage consists of a sediment filter. These filters are made from thermally bonded fibers of polypropylene and are used to trap sediment. Second and third stage filters are filter Active carbon granules filter, and the third filter is carbon hardwood .

The filter is manufactured from high purity acid-washed activated carbon, finished with an outer polypropylene spun bonded pre filtration medium, and has a protective polypropylene netting as well as end caps with compression gaskets.

The water exist 3ed filter divided to two tubes each tube contact with high pressure pumps (E-CHEN)(E-203-300A) . this pump designed for residential reverse osmosis system the technical specification of this pump:

- Model E-203-300A
- Voltage 24V DC
- Rated current 2.8 A
- Flow at 70 psi 2 lit/min
- Ports 3/8" FPT (inlet/outlet)

Each pump supplying the fourth stage reverse osmosis membrane filter. As mentioned earlier, the spiral wound membrane is most common. (3012 RO membrane) provides advanced and reliable reverse osmosis membranes for commercial RO water system. Polyamide thin-film composite is the membrane type. The membrane has a maximum operating temperature of 45°C, maximum operating pressure of 300 psi, and works with a pH range of 2-11. The membrane has excellent salt and organic rejection, microbiological resistance, and usually lasts 3-5 years. Membranes also require housing, or membrane pressure vessels.

These vessels need to be sealed and able to withstand high pressures. The inlet allows water to pass through the membrane and the outlet has an opening for the permeate, the fresh water, and an opening for the concentrate.

The fifth stage is post carbon filter it is designed to improves testes and it is removing any residual impurities and provides a finer conditioning of pure water. Before the tube of water enters the post, carbon filter divided in two tubes one enter the post carbon filter and another enter the storage tank.

We have in this system two gage of pressure.

1- Raw water pressure.
   Raw water pressure gage it is before the two pumps to masseur the feed water pressure.
2- Drain water pressure.
   Pressure gage after RO filter this gage placed when the water out from membrane to masseur waste water pressure.

Al so we have in this system intelligent control, visualized working status through LCD screen.

1- Automatic washing function, this business can be realized before starting the water machine and washed once every 20 seconds of water, effectively extending the use of film Life.
2- Water protection, if there is no running water or water pressure is very low, it can automatically shut down.
3- Full water stop function, when pure water bucket is full, reaches the preset pressure, automatically shut down.

Figure 2.1 shows a simple schematic of a reverse osmosis system using the line layout. The arrows show the flow of water and the location of the inlet and outlet at each stage. Figure 2.2 is a photo of the reverse osmosis system assembled.

Brief water chart

1 : LP switch 2 : 10” PP filter (5μm)

3 : 10” active carbon filter

4 : filter carbon hardwood.

5 : Feed water pressure meter

6 : Feed water solenoid valve
7 : Pump 8 : 3012 RO membrane
9 : HP switch 10 : Tank
11 : Post active carbon 12 : faucet
13 : wastewater pressure meter
14 : combined valve

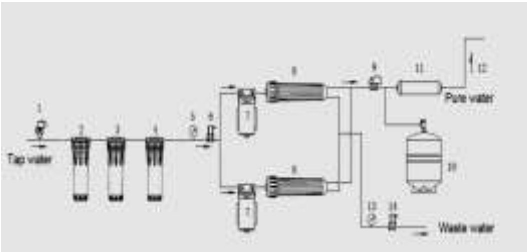



*Fig 3: RO system line layout*

*Fig 4: Photo of RO system*

- ***AD11 & AD12 Waterproof pH Testers***

AD11 and AD12 are waterproof pH and temperature testers. The housing has been completely sealed against humidity. All pH readings are automatically temperature compensated (ATC), and temperature values can be displayed in °C or °F units. The meter can be calibrated at one or two points for pH with auto-buffer recognition and against five memorized buffer values. Measurements are highly accurate with a unique stability indicator right on the LCD. The models are also provided with a low battery symbol which warns the user when the batteries need to be replaced. The AD11P pH electrode, supplied with the meter, is interchangeable and can be easily replaced by the user. The encapsulated temperature sensor allows fast and accurate temperature measurement and compensation.

- ***AD31 & AD32 Waterproof EC/TDS Testers***

AD31 and AD32 are waterproof EC, TDS and temperature testers. The housing has been completely sealed against humidity. All EC and TDS readings are automatically temperature compensated (ATC), and temperature values can be displayed in °C or °F units. The EC/TDS conversion factor (CONV) can be selected by the user, as well as the coefficient β (BETA) for temperature compensation. The instruments can be calibrated at one point. Measurements are highly accurate with a unique stability indicator right on the LCD. The models are also provided with a low battery symbol which warns the user when the batteries need to be replaced. The AD32P probe supplied with the meters is interchangeable and can be easily replaced by the user.

The encapsulated temperature sensor allows fast and accurate temperature measurement and compensation.

***Operating of Reverse Osmosis System***

Confirm the correct connection of the water circuit and there are sufficient water supplies and/or electricity. Then testing the machine as follows:

1. Open the water inlet valve, ball valve and turn on power when the filter is full of water, pure water can flow into the tank.
2. When the water flow fluently and the purifier perform well : about 5 to 10 minutes : , check if every connection joint are well and if there are any leakage at the interface of membrane housing or filter.
3. Close the faucet and water storage tank valve, wait for about 30s, check that whether the waste water has stopped, and booster pump stops running.
4. Open the faucet and check if pure water can outflow, when no pure water outflow, check if the water pressure is too low or high pressure switch can not be reset.

5. While in working conditions, close the feed water ball valve, and then check whether the water purifier is stop working, otherwise, checks the low-pressure switch.
6. Confirm all are correct; we can use the machine safely.

***Water Quality Testing***

To test for water quality, PH, TDS, Temp. The results of the test determine if the water is safe to drink or not. The pH test measures the acidic or basic character of water and values in the range 6.5-8.5 is generally accepted as safe. Total alkalinity is the ability of water to resist changes in PH. We begin to take samples of the output from a sample of pure water and a sample of the waste water as flaw:

- ***pH measurement***

Taking all measurement, use the submerge the electrode in the sample to be tested while stirring it gently. Measurements should be taken when the stability indicator (hourglass) disappears. The pH value automatically compensated for temperature is shown on the primary LCD level while the secondary one shows the sample temperature. the measurements are taken in different samples successively, rinse the probe thoroughly to eliminate cross-contamination. After cleaning, rinse the probe with some of the sample to be measured the time between reading 10 min.

- ***TDS Measurement***

Taking all measurement for the desired EC or TDS mode by pressing the SET/HOLD button is applied. Submerge the probe in the solution to be tested while stirring it gently. Measurements should be taken when the stability indicator (hourglass) disappears. The EC or TDS value automatically compensated for temperature is shown on the primary LCD level while the secondary one shows the sample temperature. Before taking any measurement, make sure the meter has been calibrated (Cartage is displayed). And the measurements are taken in different samples successively; rinse the probe thoroughly to eliminate cross-contamination. After cleaning, rinse the probe with some of the sample to be measured, the time between reading 10 min.

- ***Pressure Measurement***

Taking pressure readings each of the tap water and waste water the time between reading 10 min**.**

## 2.3 Reverse Osmosis System Analysis (ROSA)

ROSA—the industry-leading RO system design tool for decades—makes it easy for user to design a reverse osmosis plant to meet user required water treatment specifications. it works by enter the concentration of ions in the feed water, select the type of FILMTEC™ element, and try different vessel configurations. ROSA does all the complex math for user and produces a complete, but simple-to-understand, report predicting the water quality and flow rate.

ROSA Introduction to RO Plant Design, Project Information, Feed water Data ,Scaling Information, System Configuration, Report.

***Fig 5 : Project Description***

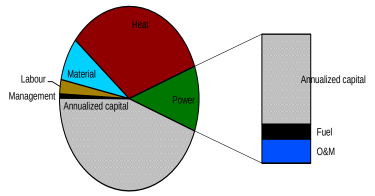
*Fig 6:Feed water Data*

*Fig 7: Scaling Information*

*Fig8: System Configuration*

Desalination plant

| | | | |
|---|---|---|---|
| **Type** | **MED** | | |
| **Total Capacity** | **1000** | **$m^3/d$** | |
| **Feed Salinity** | **35000** | **ppm** | |
| Combined Availability | 77% | | |
| Water Production | 0.28 | M $m^3/yr$ | |
| Power Lost | 0.0 | MW(e) | *Extraction of 2 MW at 75°C (Power lost ratio=0%)* |
| Power Used for desalination | 0 | MW(e) | |




| **Capital Costs of Desalination Plant** | *MED* | | *Total (M$)* | *Specific ($/m3 d)* | *Share* |
|---|---|---|---|---|---|
| Construction Cost | 1 | - | 1 | 1,177 | 74% |
| Intermediate loop cost | - | - | - | - | 0% |
| Backup Heat Source | - | - | - | - | 0% |
| Infall/Outfall costs | - | - | 0 | 77 | 5% |
| Water plant owners cost | 0 | - | 0 | 59 | 4% |
| Water plant contingency cost | 0 | - | 0 | 124 | 8% |
| Interest during Construction | 0 | - | 0 | 145 | 9% |
| **Total Capital Costs** | 2 | - | 2 | 1582 | |
| **Annualized Capital Costs** | | | 0 | | |
| Sp. Annualized Cap Costs | | | | **0.43** | $/m3 |

| **Operating Costs of Desalination Plant** | MED | | Total (M$) | | Specific ($/m3) | Share |
|---|---|---|---|---|---|---|
| ***Energy Costs*** | | | | | | |
| Heat cost | 1 | | 1 | | 4.97 | 83% |
| Backup heat cost | - | | - | | - | 0% |
| Electricity cost | - | - | - | | - | 0% |
| Purchased electricity cost | 0.0 | - | 0.0 | | 0.15 | 2% |
| **Total Energy Costs** | 1 | - | 1 | | 5.11 | 85% |
| ***Operation and Maintenance Costs*** | | | | | - | 0% |
| Management cost | - | - | 0.13 | | 0.47 | 8% |
| Labour cost | - | - | 0.09 | | 0.32 | 5% |
| Material cost | 0.0 | - | 0.0 | | 0.07 | 1% |
| Insurance cost | 0.0 | - | 0.0 | | 0.02 | 0% |
| **Total O&M cost** | 0 | - | 0 | | 0.89 | 15% |
| **Total Operating Costs** | 1 | - | 2 | | **6.00** | |

| | | |
|---|---|---|
| **Total annual cost** | **1.80** | **M$** |
| Water production cost | 6.431 | $\$/m^3$ |
| Water Transport costs | - | $\$/m^3$ |
| **Total water cost** | **6.431** | **$\$/m^3$** |

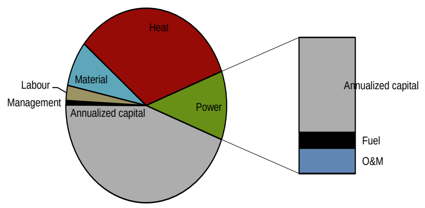
*Fig9: screen a report is generated showing the main results for the defined case(MED)*

# 3. Results and discussion

## 3.1 Results and schematic diagram of DEEP

## Desalination plant

| | | | |
|---|---|---|---|
| **Type** | **MSF** | | |
| **Total Capacity** | **1000** | **$m^3/d$** | |
| **Feed Salinity** | **35000** | **ppm** | |
| Combined Availability | 81% | | |
| Water Production | 0.30 | M $m^3/yr$ | |
| Power Lost | 0.0 | MW(e) | *Extraction of 3 MW at 117.5°C (Power lost ratio=0%)* |
| Power Used for desalination | 0 | MW(e) | |



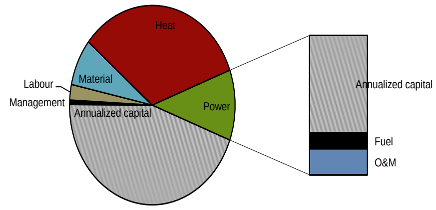

| **Capital Costs of Desalination Plant** | *MSF* | | *Total (M$)* | *Specific ($/m3 d)* | *Share* |
|---|---|---|---|---|---|
| Construction Cost | 1 | - | 1 | 1,177 | 66% |
| Intermediate loop cost | 0 | - | 0 | 159 | 9% |
| Backup Heat Source | - | - | - | - | 0% |
| Infall/Outfall costs | - | - | 0 | 77 | 4% |
| Water plant owners cost | 0 | - | 0 | 67 | 4% |
| Water plant contingency cost | 0 | - | 0 | 140 | 8% |
| Interest during Construction | 0 | - | 0 | 165 | 9% |
| **Total Capital Costs** | 2 | - | 2 | 1785 | |
| **Annualized Capital Costs** | | | 0 | | |
| Sp. Annualized Cap Costs | | | | **0.46** | $/m3 |

| **Operating Costs of Desalination Plant** | MSF | | Total (M$) | Specific ($/m3) | Share |
|---|---|---|---|---|---|
| ***Energy Costs*** | | | | | |
| Heat cost | 0 | | 0 | 1.29 | 53% |
| Backup heat cost | - | | - | - | 0% |
| Electricity cost | - | - | - | - | 0% |
| Purchased electricity cost | 0.1 | - | 0.1 | 0.28 | 12% |
| **Total Energy Costs** | 0 | - | 0 | 1.57 | 65% |
| ***Operation and Maintenance Costs*** | | | | - | 0% |
| Management cost | - | - | 0.13 | 0.45 | 18% |
| Labour cost | - | - | 0.09 | 0.30 | 12% |
| Material cost | 0.0 | - | 0.0 | 0.07 | 3% |
| Insurance cost | 0.0 | - | 0.0 | 0.03 | 1% |
| **Total O&M cost** | 0 | - | 0 | 0.84 | 35% |
| **Total Operating Costs** | 0 | - | 1 | **2.42** | |
| **Total annual cost** | | | | **0.85** | **M$** |
| Water production cost | | | | 2.879 | $\$/m^3$ |
| Water Transport costs | | | | - | $\$/m^3$ |
| **Total water cost** | | | | **2.879** | **$\$/m^3$** |

***Fig10: screen a report is generated showing the main results for the defined case(MSF)***

## Desalination plant

| | | | |
|---|---|---|---|
| **Type** | **VC** | | |
| **Total Capacity** | **1000** | **$m^3/d$** | |
| **Feed Salinity** | **35000** | **ppm** | |
| Combined Availability | 81% | | |
| Water Production | 0.30 | M $m^3/yr$ | |
| Power Lost | 0.0 | MW(e) | *Extraction of 1 MW at 141°C (Power lost ratio=0%)* |
| Power Used for desalination | 0 | MW(e) | |



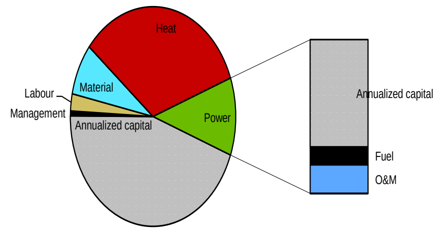

| **Capital Costs of Desalination Plant** | *MED* | | *Total (M$)* | *Specific ($/m3 d)* | *Share* |
|---|---|---|---|---|---|
| Construction Cost | 1 | - | 1 | 1,177 | 66% |
| Intermediate loop cost | 0 | - | 0 | 159 | 9% |
| Backup Heat Source | - | - | - | - | 0% |
| Infall/Outfall costs | - | - | 0 | 77 | 4% |
| Water plant owners cost | 0 | - | 0 | 67 | 4% |
| Water plant contingency cost | 0 | - | 0 | 140 | 8% |
| Interest during Construction | 0 | - | 0 | 165 | 9% |
| **Total Capital Costs** | 2 | - | 2 | 1785 | |
| **Annualized Capital Costs** | | | **0** | | |
| **Sp. Annualized Cap Costs** | | | | **0.46** | **$/m3** |

| **Operating Costs of Desalination Plant** | VC | | Total (M$) | Specific ($/m3) | Share |
|---|---|---|---|---|---|
| ***Energy Costs*** | | | | | |
| Heat cost | 0 | | 0 | 0.51 | 31% |
| Backup heat cost | - | | - | - | 0% |
| Electricity cost | - | - | - | - | 0% |
| Purchased electricity cost | 0.1 | - | 0.1 | 0.30 | 18% |
| **Total Energy Costs** | 0 | - | 0 | 0.81 | 49% |
| ***Operation and Maintenance Costs*** | | | | - | 0% |
| Management cost | - | - | 0.13 | 0.45 | 27% |
| Labour cost | - | - | 0.09 | 0.30 | 18% |
| Material cost | 0.0 | - | 0.0 | 0.07 | 4% |
| Insurance cost | 0.0 | - | 0.0 | 0.03 | 2% |
| **Total O&M cost** | 0 | - | 0 | 0.84 | 51% |
| **Total Operating Costs** | 0 | - | 0 | **1.66** | |
| **Total annual cost** | | | | **0.63** | **M$** |
| Water production cost | | | | 2.119 | $\$/m^3$ |
| Water Transport costs | | | | - | $\$/m^3$ |
| **Total water cost** | | | | **2.119** | **$\$/m^3$** |

***Fig11: screen a report is generated showing the main results for the defined case(VC)***

Desalination plant

| | | |
|---|---|---|
| **Type** | **RO** | |
| **Total Capacity** | **1000** | **$m^3$/d** |
| **Feed Salinity** | **35000** | **ppm** |
| Combined Availability | 81% | |
| Water Production | 0.33 | M $m^3$/yr |
| Power Lost | 0.0 | MW(e) |
| Power Used for desalination | 0 | MW(e) |




**Capital Costs of Desalination Plant**

| | MSF | RO | Total (M$) | Specific ($/m3 d) | Share |
|---|---|---|---|---|---|
| Construction Cost | - | 1 | 1 | 1,177 | 80% |
| Intermediate loop cost | - | - | - | - | 0% |
| Backup Heat Source | - | - | - | - | 0% |
| Infall/Outfall costs | - | - | 0 | 77 | 5% |
| Water plant owners cost | - | 0 | 0 | 59 | 4% |
| Water plant contingency cost | - | 0 | 0 | 124 | 8% |
| Interest during Construction | - | 0 | 0 | 34 | 2% |
| **Total Capital Costs** | - | 1 | 1 | 1470 | |
| **Annualized Capital Costs** | | | **0** | | |
| **Sp. Annualized Cap Costs** | | | | **0.34** | **$/m3** |

**Operating Costs of Desalination Plant**

| | MSF | RO | Total (M$) | Specific ($/m3) | Share |
|---|---|---|---|---|---|
| *Energy Costs* | | | | | |
| Heat cost | - | | - | - | 0% |
| Backup heat cost | - | | - | - | 0% |
| Electricity cost | - | - | - | - | 0% |
| Purchased electricity cost | - | 0.1 | 0.1 | 0.30 | 26% |
| Total Energy Costs | - | 0 | 0 | 0.30 | 26% |
| *Operation and Maintenance Costs* | | | | - | 0% |
| Management cost | - | - | 0.13 | 0.40 | 35% |
| Labour cost | - | - | 0.09 | 0.27 | 23% |
| Material cost | - | 0.05 | 0.1 | 0.17 | 14% |
| Insurance cost | - | 0.01 | 0.0 | 0.02 | 2% |
| Total O&M cost | - | 0 | 0 | 0.86 | 74% |
| Total Operating Costs | - | 0 | 0 | 1.16 | |
| Total annual cost | | | | 0.49 | M$ |
| Water production cost | | | | 1.502 | $/$m^3$ |
| Water Transport costs | | | | - | $/$m^3$ |
| **Total water cost** | | | | **1.502** | **$/$m^3$** |

***Fig12: screen a report is generated showing the main results for the defined case (RO)***

## 3.2 Results of RO system experimental model

In this section 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. In the study, the temperature is constant. The feed water is changed in ninth values on salinity, PH and conductivity. These cases are measured and record at every ten minutes to see the different in the salinity, conductivity and PH values. The Brackish water used from the Laboratory water source and then changed in the salinity of it. At the operation pressure equal (10 bar) and the constant temperature 25.4°C with various feed water PH valves, found increasing in the PH valves of the permeate water and brine water. Figures (5) show the relation between conductivity of the water used through the experimental work. In general, the conductivity of the feed water takes the maximum value and then decreases when the water passes the RO membrane. After the ten minutes of the operation time the conductivity of the permeate water with increases from (0.04 µs to 7.32 µs) and the conductivity of the brine water increases from (2.76 µs to 20 µs) as the conductivity of the feed water increases from (0.52 µs to 20 µs) with increases the operating time.

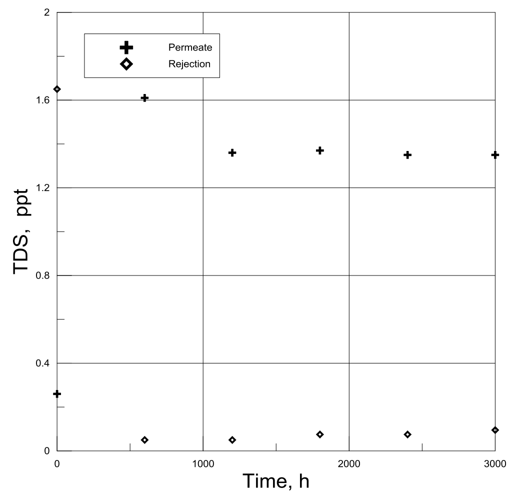



***Figure 13: Permeate and system rejection vs. operation time during experiment***

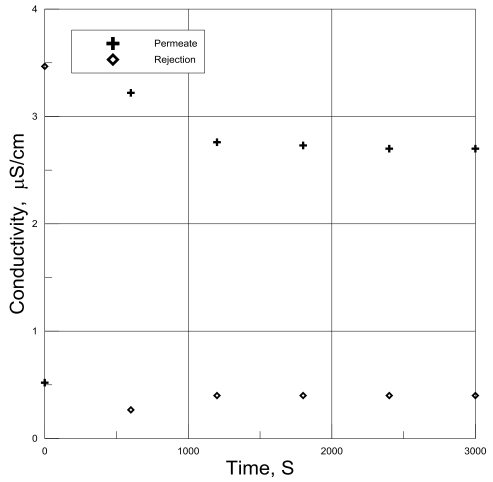



*Figure 14: Permeate and system rejection vs. operation time during experiment*

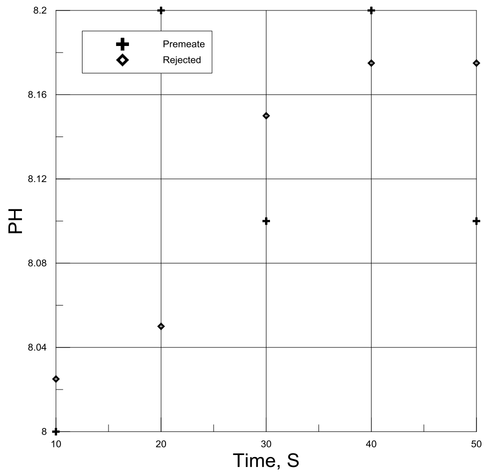



*Figure 15: Permeate and system rejection vs. operation time during experiment*

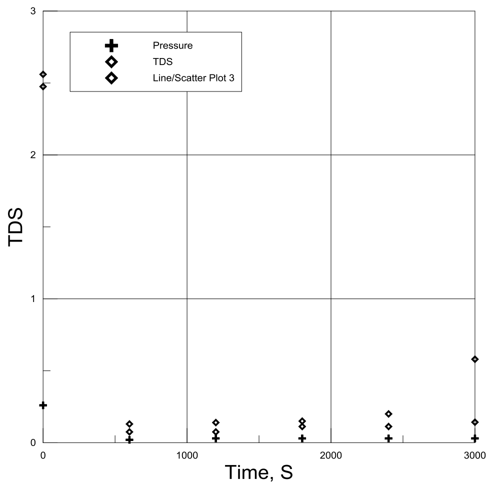



*Figure 16: Permeate and operation time during the experiment*

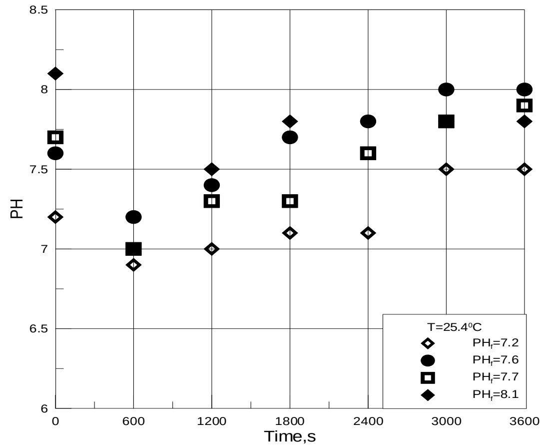



*Figure 17: Permeate and operation time during the experiment*

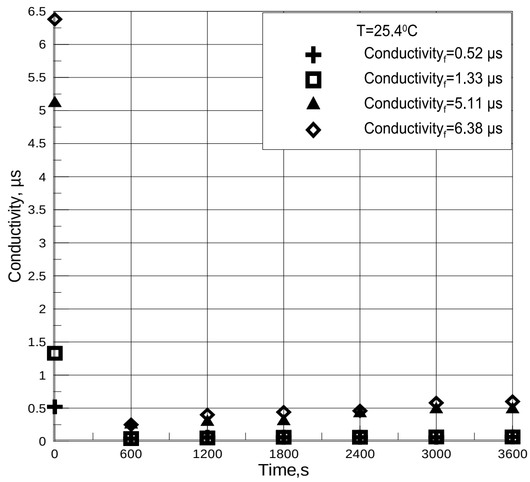



*Figure 18: Permeate and operation time during the experiment*

*Table (1) Membrane Operating data*

| Operating time, h | Permeate flow rate, lit/h | Temperature º C | Conductivity µS/cm | Ph of Permeate |
|---|---|---|---|---|
| 1 | 400 | 35.1 | 17.52 | 8.1 |
| 2 | 395 | 35.2 | 2.93 | 7 |
| 3 | 390 | 35.2 | 2.95 | 7.2 |
| 4 | 380 | 35.2 | 3.05 | 7.3 |
| 5 | 350 | 35.4 | 3.18 | 7.4 |
| 6 | 345 | 35.5 | 3.21 | 7.5 |
| 7 | 330 | 35.6 | 3.25 | 7.55 |
| 8 | 320 | 35.6 | 3.32 | 7.65 |
| 9 | 310 | 35.7 | 3.35 | 7.7 |
| 10 | 305 | 35.8 | 3.38 | 7.8 |
| 11 | 300 | 35.9 | 3.42 | 7.8 |
| 12 | 290 | 35.9 | 3.45 | 7.8 |

*Table (2) Average Water Quality Results During Experiment*

| Analyze | Raw Water | Reverse Osmosis Membrane |
|---|---|---|
| Turbidity | 2.11 | 0.14 |
| TDS | 8.1 | 1.47 |
| Conductivity µS/cm | 17.52 | 3.2 |
| Ph of Permeate | 8.1 | 7.5 |

*Table (3) Average Water Quality Results (ROSA)program*

| Pass Streams (mg/l as Ion) | | | | | |
|---|---|---|---|---|---|
| Name | Feed | Adjusted Feed | Concentrate | Permeate | |
| | | | Stage 1 | Stage 1 | Total |
| NH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| K | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Na | 786.75 | 786.75 | 921.89 | 20.95 | 20.95 |
| Mg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ca | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sr | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ba | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HCO3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NO3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cl | 1213.25 | 1213.25 | 1421.65 | 32.31 | 32.31 |
| F | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SO4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SiO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Boron | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TDS | 2000.01 | 2000.01 | 2343.55 | 53.27 | 53.27 |
| pH | N/A | N/A | N/A | N/A | N/A |

# 4 CONCLUSION

- Increasing plant capacity drastically decreases overall unit product cost, despite an overall increase in the capital cost (i.e., economy of scale).
- The unit product cost for the RO process consists of approximately desalination of higher-salinity feed water depends on the required capacity.

- The MSF process would be the technology of choice for capacities above 25,000 $m^3$/d, while the MEE process should be chosen for capacities on the order of 10,000 m3/d, and the VC for capacities on the order of 3,000 m3/d.
- The separation of salt and permeate flux were mainly dependent on the concentration of the feed solution.
- The permeate flux increased with increasing flow rate; for high feed flow rates it seemed to reach its maximum values asymptotically.
- The initial concentration and initial volume of the solution played an important role in determining the flux and the concentration in the permeate.
- The number of stages with their arrangements in the reverse osmosis mode are calculated using the ROSA Program. A mathematical model and computer programs including all the mentioned cases are built and applied on the reverse osmosis mode of water stations. The results of these calculations are compared with the practical results and showed a fair good agreement.

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