Developed Combination System of Desalination plant driven by Renewable Energy

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Abstract: The greatest danger of the world at the present is the scarcity of water, resulting from drought and increased population. To overcome this problem, seawater desalination techniques should be focused on. On the other hand, it is important to provide a source of energy to extract fresh water from desalination plants. Since conventional energy is exhausted, expensive and polluted to the environment, it is necessary to turn to renewable energy as an alternative energy source in remote areas. The appropriate matching between renewable energy and seawater desalination systems is designed in this study according to special and relative considerations factors. The scope of the present work is to design Reverse Osmosis (RO) desalination plant driven by photovoltaic (PV) solar arrays. The design is constructed where developing and examining different parameters affecting the performance of the present combination system. The salt concentration and theflowrate of the supply water was found to have important effect on the permeate flux, permeate concentration, salt rejection percent, recovery percent and specific power consumption. A comparison was made between the present experimental results and a corresponding results of previous work under nearly operating condition. The agreement comparison is fairly good. In the present modification, the cooling medium suppling the photovoltaic plates is the brine water out from the desalination RO plant without the need for additional power for pumping cooling water. The cooling PV panels make an increase in the following: output generated volt, output current, output power, permeate flow rate, efficiency percentage, recovery percent and power ratio. The results is represented for two values of the brine water pressure namely 3.9 and 2.9 bar. The increase of the output power has a mean value of 4.5 % when applying the two values of present brine pressure. It can be noticed that the mean value of the gain in solar efficiency is about 22 % for brine pressure of 2.9 bar while the corresponding gain in solar efficiency is 16.8 % for brine pressure of 3.9 bar. According to decreasing of brine water pressure from 3.9 bar to 2.9 bar, this causes an increase in the permeate flow rate with amean value of 33.5 %.

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Key words: Desalination Technique, Reverse Osmosis (RO**),** Renewable Energy (RE), Photovoltaic Cells (PV), cooling Photovoltaic panels, Energy management. Cooling Technique, Electrical Efficiency.

1. Introduction and literature review

As of today, nearly 25 % of mankind is suffering from insufficient fresh water supply. According to the expected increase in the rapid growth of population in the world, especially the countries, which is suffering economically and is known as developing countries. It worth to mention that, water shortage problems affects more than 80 countries worldwide. The water situation has become difficult and alarming especially in North Africa countries. Based upon the presented studies by the World Health Organization (WHO), it is well known that the water availability per capita is 1000 m^3 in the year, which represents the border line below which it will not be possible to guarantee an acceptable living standard as well as economic development of a country. The international picture will become more darkness if the forecasts made by international Organization called (FAO) on the overall increase in world population are taken into consideration [1].

According to Nile water agreement at 1959 which allocates 55.5 billion m^3 of fresh Nile water per year. Egypt population has been increased to reach more than 90 million. This means that the annual share reduced to 400 m^3 per person by the year 2025 while the moderate standard is about 1600 m^3 per capita, [2]. Now, River Nile is not able to supply water as before, due to the mess use of fresh water in agriculture and domestic use…etc. In view of these findings, water desalination should be ranked among the most prior solutions for water scarcity problem in Egypt. Desalination, in general, consumes energy which is important factor. According to the expected increase in population and the low production of fossil fuels (as it is depleted) over time, and pollution of the environment resulting from its operation, therefore, the renewable energy is considered an alternative solution to overcome this problem.

M.Mohsen & J. Jaber. [2001] discussed and proposedthe potential of the development of water desalination using a photovoltaic-powered system in Jordan. A simulation model for the prediction of the PV specific power delivered for a given value of the global isolation was adopted, [3]. While, ***G. Ahmad and J. Schmid. [2002]*** introduced a feasibility study of water desalination in remote areas of Egypt using photovoltaic PV energy 1100 W as the primary source of energy. They investigated the availability of water resources and solar energy in these areas. They also have studied and economically estimated design of a PV powered small scale reverse osmosis water desalination system for brackish water 2000 ppm concentration. They concluded that the cost of producing 1 m^3 of fresh water using the small PV powered reverse-osmosis RO water desalination systems was 3.73 $. This cost was based on using a small system that was operating during the daylight only. If the system size and the daily period of operation were increased, the price of producing fresh water would be decreased in these regions, [4]. In addition to, ***Y.Kim et al. [2009]*** investigated system models of pretreatment and RO networks, systems optimization to minimize the total cost of Sea Water Reverse Osmosis (SWRO) plant design, and the future direction of SWRO technology. They discussed after investigating all the processes, including site-specific features, seawater intakes, pretreatment systems, RO networks, energy recovery systems, post-treatment systems, brine disposal, and the environmental impact of SWRO desalination, system models for predicting the performance of each system. They discussed the optimized results required for a full-scale SWRO plant, [5]. While, ***H.Qiblawey et al. [2011]*** presented reverse osmosis (RO) and electricity generation using photovoltaic technology (PV) with additional battery storage for water desalination. The system was composed of PV panels (433 Wp), softener and compact RO unit with typical daily water production of 500 L and produced clean drinking water from a salty water feed with salt content up to 1700 (mg/L). They presented the technical details of the RO plant, the energy supply and the operation strategies of the system and studied the effect of meteorological data like solar insulation, ambient temperature, and daily sunshine hours on the performance of the RO-PV system. Furthermore, they discussed the effect of operating pressure and temperature on recovery percentage, salt rejection and specific energy consumption in addition to details about the PV current and voltage. They estimated that the PV modules efficiency was about 12%. As the scaling phenomenon was encountered due to nature of water coming from springs, a softener unit was utilized to overcome this problem, [6]. Moreover, ***N. Fraidenraich, et al. [2012]*** described a theoretical study of the specific energy consumption (SEC) of a reverse osmosis RO equipment. It was briefly analyzed the SEC for ideal systems. Then, they obtained analytic expressions for real systems, operating under variable conditions. They analyzed a limiting case, when the applied pressure was equal to the transmembrane pressure at the output of the equipment. They described an experimental study of PV-RO equipment conducted on a commercial multistage desalination unit over a broad range of operating conditions, [7]. ***A.El-Ghonemy [2012]*** discussed and tested the performance of small RO system with a capacity of 50 (m^3/day) used to desalinate brackish water with maximum 2000 (ppm) total dissolved solids which can be used in remote areas. Two similar small scale RO unit have been tested (each unit has production capacity of 50 (m^3 /day)), to investigate the performance and cost analysis. In addition the water resources availability and quality in northern Saudi Arabia is included, [8]. While, **S. Shaaban and H. Yahya [2017]** investigated the performance of reverse osmosis plants in hot climate conditions. A typical Reverse osmosis system was designed and constructed. They used ROSA software for the analysis of seven different membrane elements. The experimental data were utilized in order to validate the simulation results of the ROSA software. They also performed variance-based sensitivity in order to define the most effective design and operating parameters, [9]. Moreover, ***A.Darwish* [2011]** Showed that an immersion cooling technique for the cells, where by a coolant is circulated over the front surface of the cell in addition to its other surfaces. An analysis is given where the cells were placed in a cylindrical glass tube, where a liquid was circulated. He made a comparison to limited experimental data. He showed that Immersion cooling technique is capable of attaining low, uniform temperatures along a PV array surface. Lower temperatures can be achieved using the immersion technique than the back-of-the-cell cooling technique. He concluded that water is the most efficient coolant considered here, but it requires additional sophistication in terms of deionization processing, [10]. while, ***H. Bahaidarah et al. [2013]*** developed a numerical model (electrical and thermal) is using EES (Engineering Equation Solver) softwarein order to study the performance of a hybrid PV water cooled system. The model predicts various electrical and thermal parameters affecting its performance. They also investigated experimentally the effect of cooling across the module by incorporating a heat exchanger (cooling panel) at its rear surface. They found that good agreement with the experimental measurements performed for the climate of Dhahran, Saudi Arabia, [11]. In addition to, ***M. Sardarabadi et al. [2014]*** studied the effects of using nanofluid as a coolant on the thermal and electrical efficiencies of a PV/T (photovoltaic thermal unit). Coolant fluids in the experiments are pure water and silica (SiO2)/water nanofluid 1% and 3% by weight (wt%). By converting the output electrical energy of the PV/T system into an equivalent thermal energy, it was found that the overall energy efficiency for the case with a silica/water nanofluid of 1 wt% is increased by 3.6% compared to the case with pure water. They compared the total energy of the PV/T system, with and without nanofluids with that of the PV system with no collector. It is observed that by adding a thermal collector to a PV system, the total energy for the three cases with pure water, 1 wt% silica/water nanofluid, and 3 wt% silica/water nanofluids was increased by 19.36%, 22.61% and 24.31%, respectively, [12]. Moreover, ***M. Ebrahimi et al. [2015]*** investigated a new way for cooling PV cell using natural vapor as coolant. The performance of solar cell was examined on simulated sunlight. The natural vapor encountered backside of PV cell vertically in various distribution and different mass flow rates. Also, the effect of natural vapor temperature in cooling performance was analyzed. They indicated that the temperature of PV cell drops significantly with increasing natural vapor mass flow rate. They also showed that the best performance of PV cell could be achieved at high natural vapor flow rate, low natural vapor temperature and the obtained optimum distribution condition, [13]. While, ***F. Čabo et al. [2016]*** analyzed, compared and discussed more than 10 research dealt with cooling techniques and temperature control of photovoltaic (PV) panels in general. They compared and examined different cooling techniques and the comparison performed according to type of cooling technique which divided as water forced cooling technique, air forced cooling technique, heat-pipe to air technique, evaporation cooling technique, water passive cooling technique and phase change material (PCM) cooling technique, [14].

2. Experimental test rig

The present test rig described as developed combination system of desalination plant using Reverse Osmosis (RO) technique driven by photovoltaic solar plates as renewable energy application. The test rig schematic diagram is shown in fig. (1). The typical reverse osmosis desalination plant powered with the applied application of the renewable energy is shown in fig. (2).

The aim of the present research is to design a combination system of reverse osmosis for salty water that powered by monocrystalline photovoltaic solar cells. The design is constructedfor developing and examining different parameters affecting the performance of Reverse Osmosis (RO) technique. It illustrates a reverse osmosis desalination plant driven by modified solar energy system. The test rig is divided into two main systems; the first one, includes the parts supplied for the desalination process, while the second system represents the power supply system outfitted by cooled photovoltaic solar cells.

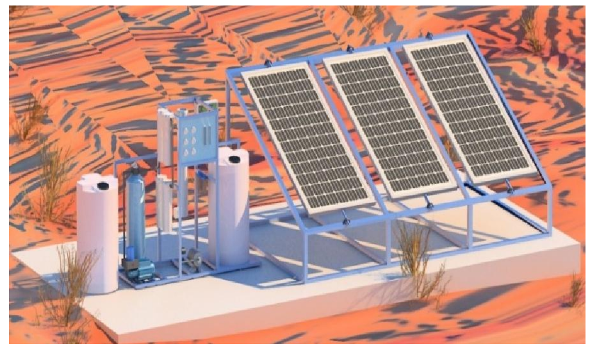


Fig. (1): Schematic diagram of desalination unit with solar system.

RO desalination plant

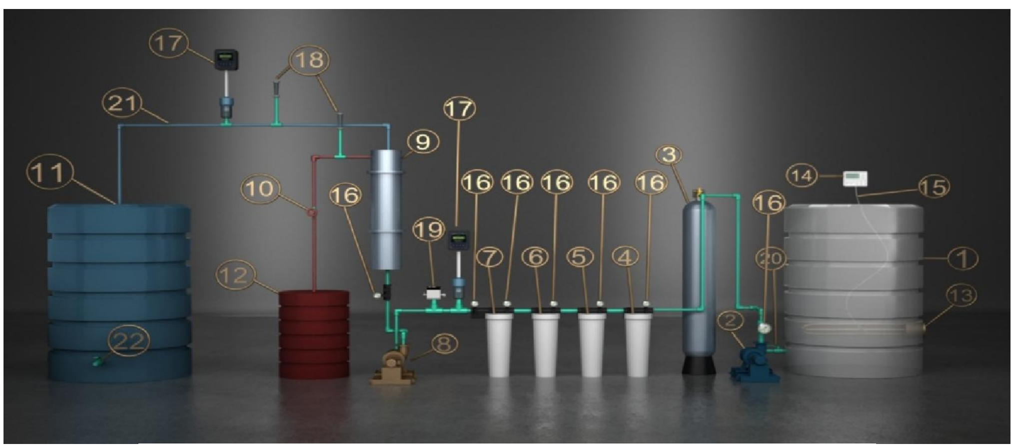
Figure (3) shows the schematic diagram of RO desalination plant. The present reverse osmosis (RO) water desalination plant consists of: the pretreatment part which includes, the feed pump that delivers the salty water to the multimedia filter which removes hanging and colloidal particles greater than 20 micron from the salty water. The salty water is pass over cartridge filters stages to prevent scaling and fouling. It removes the suspended particles greater than 5 micron. Dissolved organic is filtered by the second cartridge filter, which verified as the activated carbon cartridge filter while the precipitation and scaling is prevented through softener resign cartridge.

The last one as the first one but the porosity size is one micron. After that, the salty water is passed to the unit of salt separation. Salt separation section consists of the high-pressure pump that pumps the salty water with high pressure across the membrane, which housed in a pressure vessel. The output pure water, permeate, is stored in the fresh water tank while the pressurized concentrated water (brine) is rejected to the drain.

It worth to mention that flow regulating valve control the percentage of feed water that is going to the concentrated stream. The system also includes control valves, (feed/product) tanks, measuring instruments, auxiliary components and supply pipes.

A FILMTECTW30-4040 RO membrane has 7.25 m^2 active area, with rated pressure up to 8 bar, the permeate flow rate is about 9 m^3/day and the salt rejection is 99.5 %. The operation conditions of the presented polyamide thin film composite membrane are: Stand temperature up to 45 °C, pressure up to 41 bar, the maximum pressure drop is 0.9 bar, the pH range for continuous operation is between 2:11 and the maximum feed silt density index is about 5. A pressure vessel for an element with 101.6 mm (4 inch) diameter and 1000 mm length was selected for the present system. The selected pressure vessel was chosen with a high pressure rating enough to compensate the irreversible fouling caused by saline water. The most efficient reverse osmosis systems utilize high pressure to purify large volumes of water and it is ideally suited to deliver smooth, high pressure salty water to the separation membranes of the reverse osmosis unit. A high-pressure centrifugal pump is used to maintain the designed feed flow rate (0.2-0.5 m^3/h) and the designed high pressure (2-11) bar and the rated ampere of the high pressure pump is 1.5 A. A fixed speed motor is used to operate this centrifugal pump. The max pressure for the present low pressure feed pump is 3.5 bar while the max flow rate is 2 m^3/h and the rated ampere for the low pressure pump is 2.5

Figure (2): Typical Reverse Osmosis (RO) desalination plant and Photovoltaic (PV) panel system.



1. Salty water tank.
2. Low pressure pump.
3. Multimedia filter.
4. 5-Micron cartridge filter.
5. Carbon cartridge filter.
6. Resign cartridge filter.
7. 1-Micron cartridge filter.
8. High pressure pump.
9. Pressure vessel/RO membrane.
10. Concentrate valve.
11. Fresh water tank.
12. Brine tank.
13. Electric heater.
14. Temperature controller.
15. Temperature thermocouple.
16. Pressure gauge.
17. TDS meter.
18. Flow meter.
19. Low pressure switch.
20. Intake valve.
21. pipe line.
22. Output valve.

Figure (3): Schematic diagram of the applied RO desalination unit.

Generated power system

The used photovoltaic system includes PV arrays, DC/AC (direct current / alternative current power inverter), battery bank and charge controller as shown in fig. (4). The presented photovoltaic modules are composed of 72 high efficiency mono-crystalline solar cells which has overall dimensions of 156x156 mm coated by anti-reflecting coating. These modules can produce power range from 290 to 308 WP (peak watt) with an approximate efficiency of 15.95%" and a nominal voltage of 24V. These modules are in fact made of solar cells encapsulated between sheets of ethylene vinyle acetate (EVA), highly transparent, anti-shock, 4mm tempered glass which protects the module against climatic effects. A302-1K0-F3inverteris used to convert the DC current power from the solar cells to AC current power for the required application. Charge controller is also used to prevent battery overcharging and prolongs the battery life of the PV system.

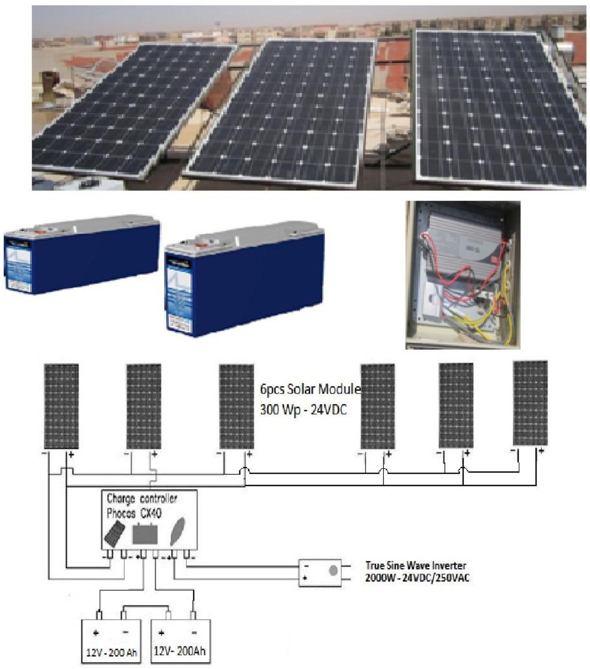


Figure (4): photovoltaic (PV) solar system.

Two batteriesare considered as the heart of all standalone photovoltaic (PV) electrical systems. Their function is to balance the outgoing electrical requirements with the incoming power supply. They offer a reliable source of electricity thatcan be used when solar energy is not available. The present system has four connected batteries each of 12 V and 200 ampere-hour (AH).

The present system development.

The present system described as reverse osmosis (RO) desalination plant powered with photovoltaic panel (PV) system. It worth to mention that as the photovoltaic panel temperature increases the output power from panel decreases. Hence, the pressurized brine (concentration stream) output from reverse osmosis (RO) desalination plant is used as cooling fluid at the back surface of the photovoltaic through attached cooling tank before entering the brine tank (direct cooling contact). Stainless steel water cooling tank is attached to the rear surface back of the photovoltaic panel to absorb the heat from the module. The cooling tank included three valves. The first one for the pressurized brine entry and the second one for the rejected water (hot) after cooling process while the third valve for the air release from the tank during cooling process. Figure (5) shows the installation process of cooling tank under the photovoltaic panel. Finally, the hot rejected water after passes through the cooling tank is stored in brine tank.

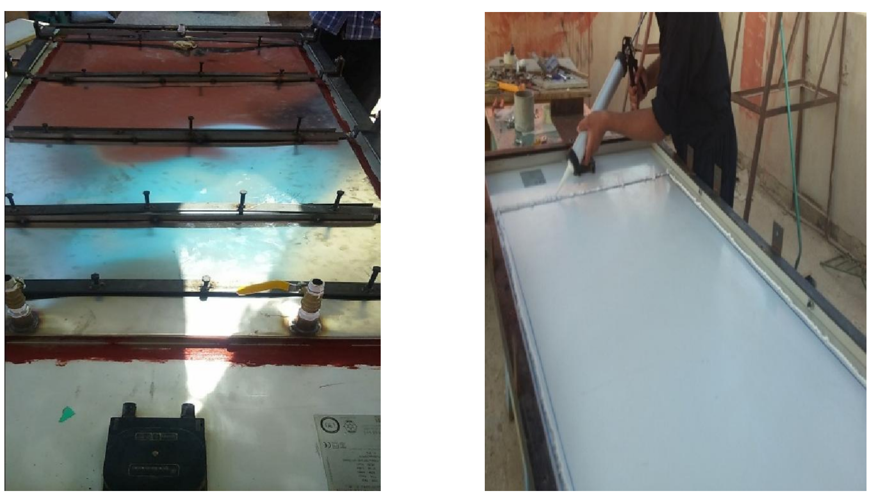


Figure (5): Cooling tank on the back of solar plate

3 Experimental procedures

The first stage is operatinglow pressure pump that gives 2 bar head and delivers the supply water from feed tank to the pretreatment stages. The pretreatment stages is used to obtain water free of impurities and to prevent fouling and scaling as pre-steps before salt separation process through RO membrane. Then the high pressure pump of 3 to 7 bar rated head and 0.154 to 0.460 (m^3/hr) flow rate rises the water's dynamic pressure to overcome the osmotic effect of the salt solution through the membrane, causing water permeation from the saline side of the membrane to the freshwater which directed towards the product tank. Salts are rejectedfrom the membrane as concentrated water with high pressure through the side outlet of the pressure vessel to attached cooling tank after that the concentrated water stored in the brine tank.

The salty water (pressurized concentrated brine) is used to cooling photovoltaic through attached cooling tank in the back of the photovoltaic. The reverse osmosis (RO) desalination plant powered with photovoltaic (PV) array system. Power system composed of six solar panels, each of 300 W, connected in parallel. Two batteries connected in series, each of 12 V, are used to store energy produced by PV arrays for later consumption. A system charge controller is used to protect batteries from over-charge, over-discharge and sometimes provide load control functions.

4 Experimental measurements

In the present work the more interesting parameters is studied, such as supply water flow rate, its temperature, its pressure (feed pressure) and its concentration. These parameters effects on the permeate flux, permeate concentration, salt rejection percentage, recovery percent and specific power consumption. The solar irradiance from the sun and cooling of photovoltaic effects on the output current of PV panel, output voltage of PV panel, output power of PV panel, increasing in permeate flow rate and increasing in efficiency of PV panel.

Pressure gauge, thermocouples, flowmeters, conductivity meter, Vantage Pro2 weather station and UT203clampmeter have been calibrated first, then it connected to the system in order to study the effect of these parameters.

Pressure gauges are used to measure the pressure drop across the four stages of the cartridge filter, sand filter, feed pump discharge line and the discharge of high pressure pump. The scale of feed pump discharge gauge is ranged from 0 to 3.5 bar. While the other gauges ranged between 0 to 10 bar with an accuracy of (± 0.1 bar). Two identical flowmeters are used to measure permeate water flow rate and concentrate water flow rate. Rotameters used are ranged from 2 to 18 liter /min, with a minimum reading of (0.5 liter /min) and an accuracy of ± 4 %.

Conductivity meters that depends on the TDS (Total Dissolved Solids) to determine the feed water and permeate water salinity in ppm. Thermocouple used in the feed line to determine the feed water temperature which effects on system performance. The temperatures were measured by using (K-type) thermocouples (with an accuracy of ± 0.2 °C). Vantage Pro2 weather stationis a device used for measuring solar irradiance. Digital clamp meter model UT203is used to measure the output DC current and DC voltage from the solar cells.

5. Discussion of the results

Introduction

This research presents the experimental results which include the main effective parameters that affect the performance of the RO desalination plant. The desalination plant was designed to operate by solar energy using mono-crystalline solar cells. The main effective parameters that affect the performance of the desalination plant are: the salt concentration of the feed water, the feed Pressure of the salty water, the feed water temperature and the supply flow rate (and/or) feed water pressure. The results include the following objects that affected by that parameters: the Permeate flux, the permeate concentration, the salt rejection percent, the recovery percent and the specific power consumption.

Effect of flow rate of the supply water and its concentration on the present parameters.

In the present work the experimental results deduced within the range of the feed flow rate 0.12 to 0.31 (m^3/hr) and the temperature of the supply water is remain unvaried T=25 ^{0}c. While the variation of the salt concentration in the feed water is from 1000 ppm to 2000 ppm.

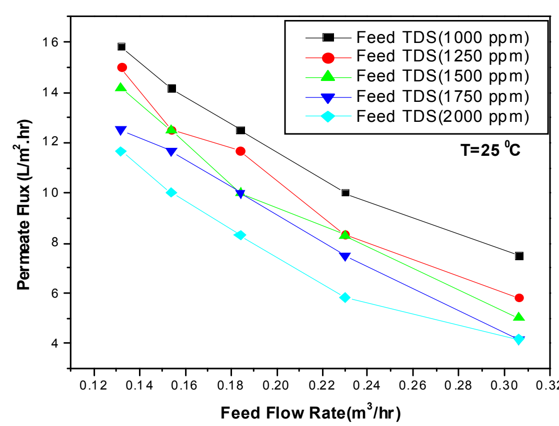


Figure (6): Permeate flux variation with feed flow rate and its concentration.

Figure (6) presents the variation of permeate flux. The permeate flux is defined as:

$$\boldsymbol{PermeateFlux}\ (\boldsymbol{L/hr.m^2}) = \frac{\boldsymbol{permeateflowrate}(\boldsymbol{L/hr})}{\boldsymbol{Activeareaofmembrane}(\boldsymbol{m^2})}$$

Inspection of the figure under consideration it can be noticed the following: The permeate flow rate decreases continusly with the increase of feed flow rate since the capacity of the desalination system unvaried. Increasing the salt concentration of the supply water the rate of permeate water is decreased. Since the pump power has constant value that proportional directly with feed flow rate and feed pressure. Then as the flow rate increases the pressure of the supply water decreases and consequently the net driving pressure and the permeate flow rate decreases.

Figure (7) presents the effect of the following parameters: feed flow rate that universally proportional to the feed flow pressure and feed salt concentration. It can notced that the output permeate concentration TDS reaches from 20 to 115 ppm.

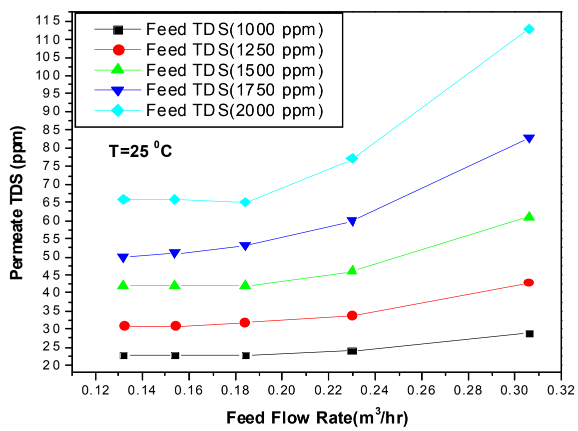


Figure (7): Effect of supply water flow rate and its concentration on the permeate concentration (ppm).

As shown from the figure, the development of permeate TDS (ppm) with the feed flow rate (m^3/hr) has two ranges. The first range is the value of permeate salt concentration (ppm) remain unvaried with the increase of flow rate of feed water up to Q = 0.2 (m^3/hr). Beyond this range a continues increase of permeate salt concentration (ppm) with the increase of feed flow rate. This is due to the capacity of the membrane of the desalination plant. A second reason is referred to the decrease of feed flow pressure. The permeate concentration (ppm) is directly proportional to feed water salt concentration (ppm) and supply flow rate.

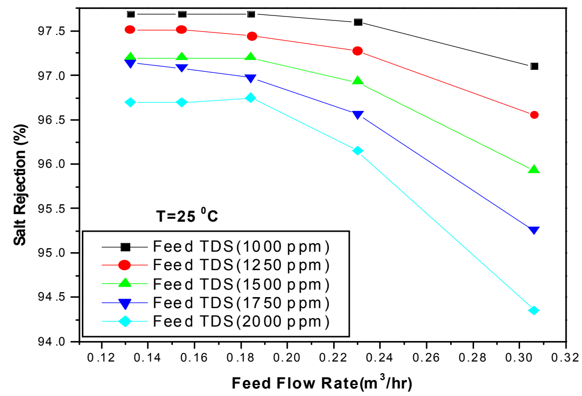


Figure (8): Variation of salt rejection percent with feed flow rate and its concentration.

Salt Rejection Percent is defined as:

$$\frac{Feedwaterconcentration(ppm) - Permeateconcentration(ppm)}{Feedwaterconcentration(ppm)} X\ 100$$

Figure (8) shows the development of the salt rejection percent with the feed flow rate and its concentration. The salt rejection percent ranges from 94 % to 98 %. Also shown from the figure a decrease of salt rejection as the feed water salt concentration (ppm) increase. This decrease has a higher rate at feed water concentration TDS = 2000 ppm, while the decrease of salt rejection rate has lower value with feed water TDS = 1000 ppm.

Figure (9) shows the recovery percent variation with feed flow rate and feed concentration. The recovery percent is defined as

$$\frac{Permeateflowrate\ (m^3/hr)}{Feedflowrate\ (m^3/hr)} X\ 100.$$

As shown from the figure, the recovery is universly proportional to the increase of feed flow rate and directily proportional to the feed water concentration.

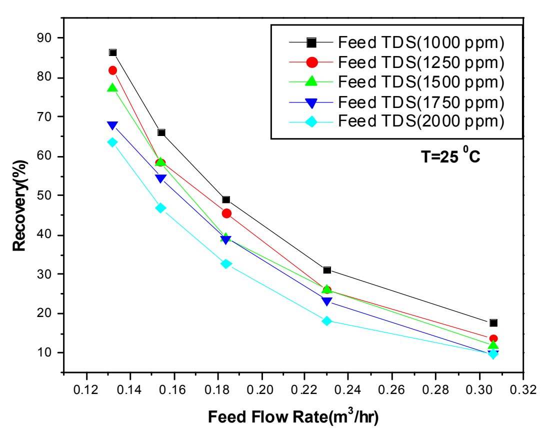


Figure (9): Recovery percent development with feed flow rate and its concentration.

The case of feed water concentration TDS or ppm is 1000 there is a higer recovery, while the case of feed water concentration TDS or ppm is 2000 has lower recovery and needs more energy to compansate the increase of feed water ppm to reach a reasnable recovery percent, see fig. (10).

Figure (10) presents the variation of specific energy consumption (kw/(m^3/hr)) which defined as

$$specificpowerconsumption(KW.hr/m^3) = \frac{powerconsumption(KW)}{Permeateflowrate(m^3/hr)}$$

The demand of energy has lower values througth a lower range of feed flow rate and lower concentration of the supply water while ahigher energy is needed with higher values of feed flow rate and higher values of salt concentration in the feed water. The increase of specific energy consumption is more pronounced througth higher values of feed flow rate.

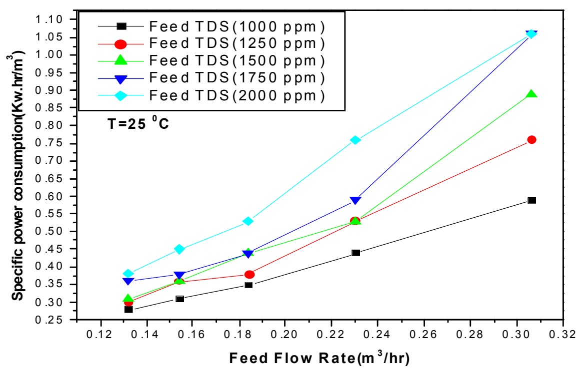


Figure (10): Specific energy consumption development with supply water flow rate and its concentration.

Comparison between the present results and the previous work

A compression was made between the present experimental results and the pervious of the corresponding work of S.Shabaan et al, [9], and H.Qiblawey et al, [6], for a nearly the same working conditions. Figure (11) presents the permeate flux variation under different values of the feed pressure while fig. (12) shows the recovery percent development with the increasing of the feed water pressure. The agreement of the present results with that of Ref. [9] and [6], arefairly good.

Cooling effect of the photovoltaic solar plates

It worth to mention that, the salty water (pressurized concentrated brine from RO plant) is used to cooling photovoltaic through attached cooling tank on the rear side of the photovoltaic panel. The sesults is presented for two values of the brine water pressure 3.9 and 2.9 bar The results are conducted to study the enhancement of solar gain that include: the solar irradiance, the output current, the output voltage and the output power. The cooling PV panels make an increase in the following: Increasing in permeate flow rate, efficiency gain percentage, increasing in recovery percent and power ratio percent.

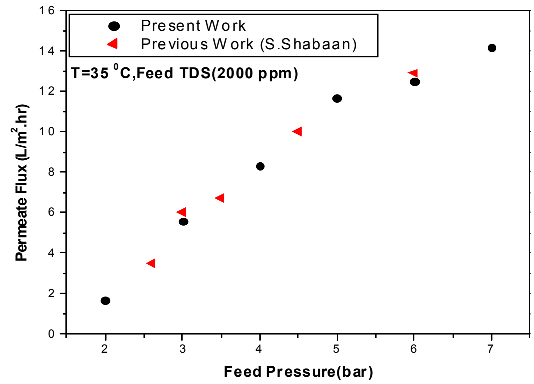


Figure (11): permeate flux variation with the feed pressure.

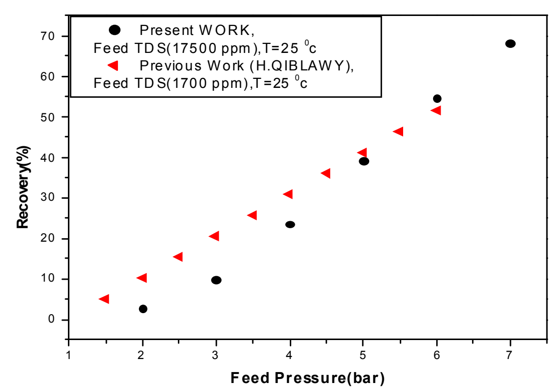


Figure (12): Recovery percent variation with the feed pressure.

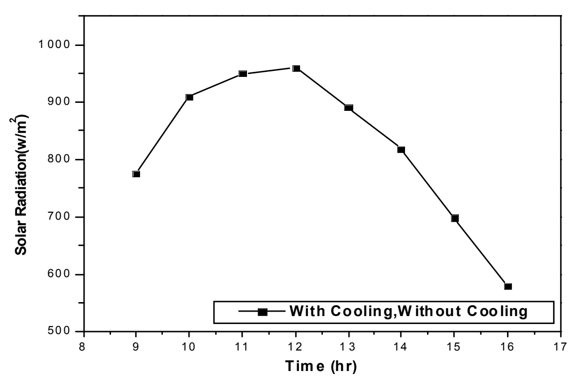


Figure (13): Irradiance variation with time.

Figure (13) shows the variation of the incident solar radiation on the PV arrays (w/m^2) with time. The result shows that the maximum value of the incident radiation reaches about 1000 (w/m^2) at the location of 10th of Ramadan city-Egypt, which has an angle of latitude of 30^o.

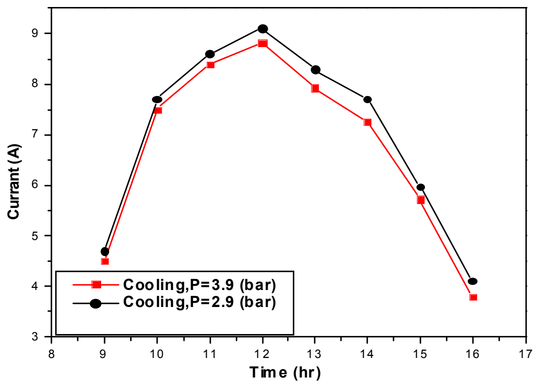


Figure (14): Cooling pressure effect on the generated current.

Figure (14) presents the measured value of the current out from the photovoltaic plates in the case of cooling. The figure is drawn for two values of the brine water pressure namely 3.9 and 2.9 bar. The effect of increasing pressure of the brine water, decreases the optained current by about 4.3 %. This is due to the decrease of brine flow rate accompaning the increase of the brine water pressure.

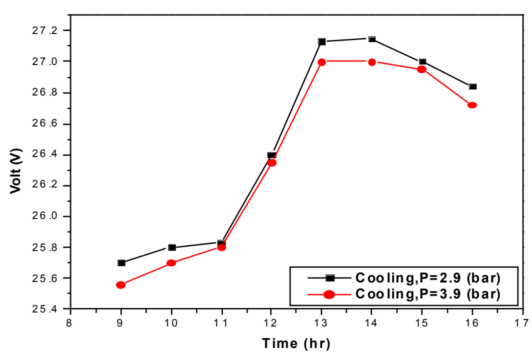


Figure (15): Cooling pressure effect on the generated volt.

Figure (15) shows also the measured value of output volt under the condition of: cooling the photovoltaic plates, the brine water pressure is 3.9 and 2.9 bar and temperature of brine water is 25 $^{\circ}$c. As shown from the figure there is an increase in the volt affecting by the decrease in pressure of the brine stream. This increase is pronounced at the mid day.

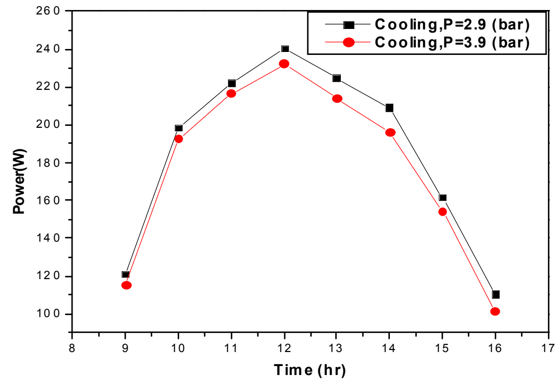


Figure (16): Cooling water pressure effect on the output power of 2 m^2 PV solar plate

The increase of the values of the current and volt reflects an increase in the gained solar power (W) for photovoltaic solar plate of 2 m^2. The increase of the output power has a mean value of 4.5 % when applying the two values of present brine pressure with cooling which is due to variation in brine flow rate. Since the arrays include 6 plates of 2 m^2 each, then the total increase in power due to pressure decrease from 3.9 bar to 2.9 bar is 50 Wasa mean value through the daylight. Figure (16) shows also the outpu power under the different brine pressure.

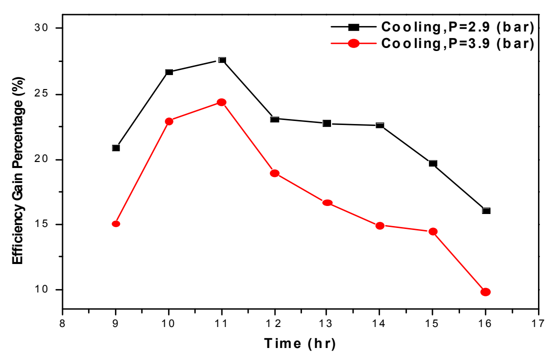


Figure (17): Solar photovoltaic plates efficiency with applying two values of cooling water pressure.

The efficiency gain percentage is defined as:

$Efficiencygainpercentage$ (%)= [$(efficiencyofPVplatwithcooling - efficiencyofPVplatwithoutcooling)$]/[$(efficiencyofPVplatwithoutcooling)$]

Figure (17) presents the percentage increase in solar efficiency due to the decrease of supply pressure. The maximum value of the increase in the efficiency is nearly at the mid-day light. It can be noticed that the mean value of the gain in solar efficiency is about 22 % for brine pressure of 2.9 bar while the corresponding gain in solar efficiency is 16.8 % for brine pressure of 3.9 bar.

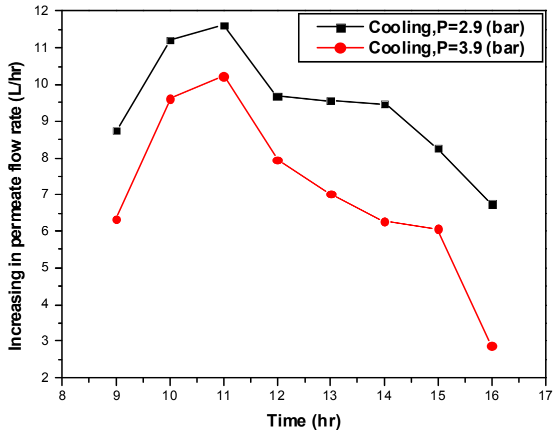


Figure (18): Effect of cooling water pressure on the permeate flow rate.

$$[\text{Increase in permeate flowrate (L/hr)}] = \frac{[\text{power increase (W)}]}{[\text{specific power consumption (W.hr/L)}]}$$

The effect of supply pressure on the increase of permeate flow rated with applying cooling the arrays is shown in fig. (18). Inspection of the figure under consideration. It can conclude that the pressure is universly proportional to the increase in permeate flow rate which is due to the decrease in supply (brine) flow rate (as affected by the increase in pressure) where supply pressure is universely proptional to the brine flow rate. The mean value of the increase in permeate flow rate is about 9.4 L/hr for a brine water pressure of 2.9 bar. According to decreasing of brine water pressure from 3.9 bar to 2.9 bar, this causes an increase in the permeate flow rate with amean value of 33.5 %

Figure (19) shows the recovry percentage, which defined as $\frac{Permeate flowrate\ (m^3/hr)}{Feed flowrate\ (m^3/hr)} X\ 100$. for the two values of pressure (with applying cooling for the two cases). From the figure it can noticed that, a slight increase of pressure on the recovery values due to pressure decreases.

It worth to mention that the feed flow rate for pressure 3.9 bar is about 0.23 (m^3/hr) while the corresponding value for the feed flow rate for pressure 2.9 bar is about 0.306 (m^3/hr). Due to varying the feed flow rate, it can interprete the itersection which apper in the figure under consideration.

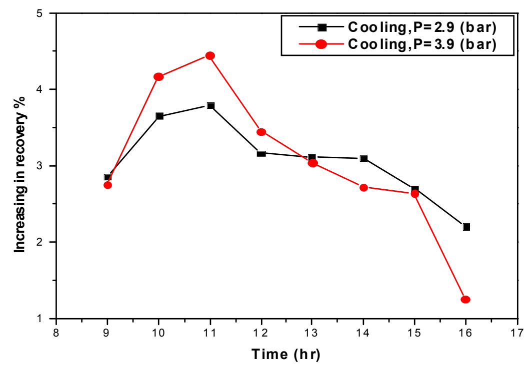


Figure (19): Supply brine water pressure effect on the recovery percentage.

The power ratio is defined as:

$$[Powerratiopercent\ (\%)] = \frac{[actualconsumedpowerofthedesalinationplant\ (W)]}{[generatedsolarpower\ (W)]} x\ 100$$

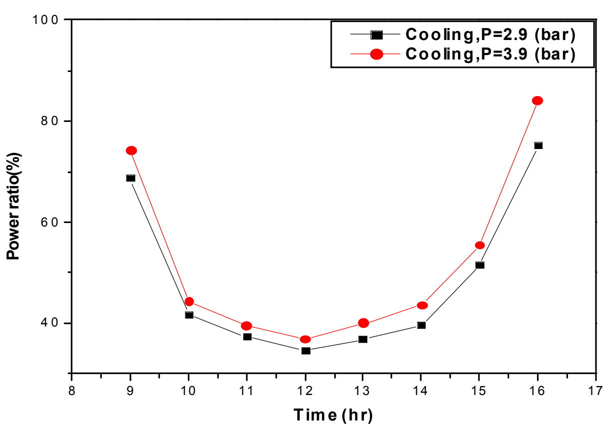


Figure (20): Supply pressure effect on the power ratio.

The pressure effect on the power ratio is shown in fig. (20) with applying cooling for the two cases. Inspection of the figure under consideration it can conclude that, the effect of decreasing the brine water pressure increases the stored energy in the batteries. Since it decrease the value of power ratio.

7. Conclusions

In the present case, the reverse osmosis technique powered by cooled photovoltaic solar cell was constructed and used for desalinating water samples with different salinity ranged between 1000 ppm to 2000 ppm. The feed flowrateis varied from 0.12 to 0.31 (m^3/hr) while the feed water temperature is keeping 25 ˚c.

From the preceding discussion, the following conclusion could be deduced:

1- The increase of the salt concentration was found to decrease permeate flux, recovery percent and salt rejection percent, while it increases the permeate concentration and specific power consumption. The maximum permeate flux was found to be about 16 (L/m^2.hr) at a maximum applied flow rate 0.12 m^3/h, keeping the temperature of the feed water of 25 ° Cand the feed water concentration 1000 ppm.

2- As the feed flow rate of the supply water increases, the permeate flux decreases, the recovery percent and salt rejection percent while, it increases permeate concentration and specific power consumption.

3- By making comparison with the previous work under nearly working condition it can concluded that good agreement between the two results with respect to the permeate flux and recovery percent.

4- By making a cooling of the photovoltaic panel by the output salt water (pressurized brine from RO plant) for two values of the brine water pressure 3.9 and 2.9 bar it can found that:

- The mean value of the gain in solar efficiency is about 22 % for brine pressure of 2.9 bar while the corresponding gain in solar efficiency is 16.8 % for brine pressure of 3.9 bar.

- The mean value of the gain in permeate flow rate is about 9.4 (L/hr) for brine pressure of 2.9 bar while the corresponding gain in permeate flow rate is 6.8 (L/hr) for brine pressure of 3.9 bar.

- it can noticed that, a slight increase of pressure on the recovery values due to pressure decreases.

- The power ratio is decreased by a mean value of 14.1 % for 3.9 barwhilethe corresponding power ratio is 20.7 % for 2.9 bar.

It can conclude that the moderate supply pressure of the supply brine water pressure besides making cooling for photovoltaic plates, this gives a better solar efficiency (and/or) increase of the gained solar power. This increase in power makes an increase of the permeate water flow rate and in the stored power in the solar batteries. The latter increase in the stored power gives an increase for the time of operating the plant especially at night.

Nomenclature

A	Current Ampere (A)
AH	Capacity (AH)
P	Pressure of the Feed Water (bar)
P_{max}	Maximum Power (W_p)
T	Temperature of the Feed Water (°C)
TDS	Total Dissolved Solids (ppm) (mg/L)
V	Voltage (V)
W_p	Peak Power (W_p)

Greeks

µS/cm	Micro Siemens per cm (µS/cm)
$ή_M$	Modules Efficiency (%)

Abbreviations

AC	Alternating Current
AH	Ampere-hour
EVA	Ethlene Vinyle Acetate
PV	Photovoltaic Cells
RES	Renewable Energy Source
RO	Reverse Osmosis
DC	Direct Current

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