International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Modifying the Acrylic Plant to Improve the Desalination by Solar Mirrors

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Abstract**—** *The objective of this study is to improve the recovery ratio and the efficiency of the Acrylic direct Solar desalination system plant using concentrated mirrors with minimum cost. The study was applied on a pilot plant that was erected in the experimental laboratory site area of faculty of engineering, Ain Shams University, Cairo, Egypt. This study was made in four months covered spring and summer seasons which simulated the best climatic period to help in obtaining the best performance of the pilot plant.*

The pilot modifications were made a glass face to increase the Sun rays passing through it and heat the raw water without any losing in energy. The raw water heated by additional solar collector made from a red copper in wooden box lined with a glassy wool and covered with galvanized steel sheet painted with a black and covered with a glass. The system used three mirrors of galvanic steel to concentrate sun rays on seawater channels and directed for the all Sunshine period. The system used a very small pump with flow rate 36 l/h to give a chance to raw water to take the suitable retention time in the pilot to heat.

The measurements for temperature, TDS, PH, and the flow rate of inlet and outlet waters were made. And recorded the air temperature, humidity ratio and the sunshine period had been taken.

The results of fresh water were varied from 3.2 l/h to 18.2 l/h which were good in quality and quantity of produced fresh water with minimum cost. The study showed that the recovery ratio was (8%-45%) which is a good ratio for all solar desalination plants and TDS was in the range of WHO recommendations even though the degree of salinity of inlet seawater that told us the high efficiency of the pilot plant in salts removal. The modifications success in raising the acrylic plant recovery ratio from (1- 4%) to (8- 45%) i.e. about from 8 to 10 times.

Keywords**—** *Water Treatment, Seawater Desalination, Solar Desalination, Renewable Energy Concentrating Solar Rays by Mirrors.*

I. Introduction

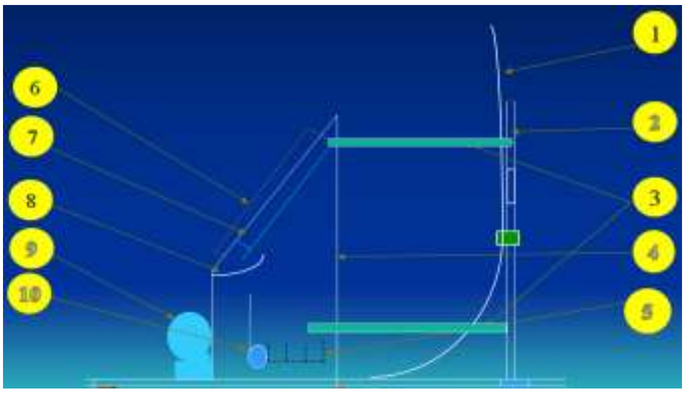
Water resources in Egypt are limited to the Nile River, rainfall and flash floods, deep groundwater in the deserts and Sinai, and potential desalination of sea and brackish water. Each resource has its usage limitation, whether these limitations are related to quantity, quality, space, time, or exploitation cost [1].

With the construction of Ethiopian Renaissance Dam the Egypt water share in River Nile will decrease. Also the population growth increases with the increase in water needs for industrial and agricultural needs. So, in the near future Egypt will suffer from water shortage. For the shortage of water resources in Egypt and Arab countries, A need to develop low cost technology to deal with seawater as water resource are increased. From last studies, it was proved that the desalination system made of acrylic had low productivity in comparison of steel plants. The objective of this work is to improve the acrylic plant using solar mirrors of producing potable water from seawater with minimum cost depends on concentrated solar rays under the best climatic conditions for such system in spring and summer in Egypt.

Solar-powered desalination processes are generally divided into two categories, direct and indirect systems [3]. The direct systems are those where the heat gaining and desalination processes take place naturally in the same device. The basin solar still represents its simplest application, the still working as a trap for solar radiation that passes through a transparent cover.

In indirect solar system, the plant is separated into two subsystems, a solar collector and a desalination unit. The solar collector can be a flat plate, evacuated tube or solar concentrator and it can be coupled with any of the distillation unit types described previously which use the evaporation and condensation principle, such as MSF, VOC, MED and MD for possible combinations of thermal desalination with solar energy. Systems that use PV devices tend to generate electricity to operate RO and ED desalination processes [2].

In 2002 Dr. El Nadi proposed an idea of a low cost desalination unit that depends on solar rays concentrations by concave mirrors [4].



1. Solar collector.	6. Mirror surface.
2. Condenser humidifier.	7. Vertical fixed.
3. Fresh water channel.	8. Horizontal fixed (arms).
4. Inside Sea water channel.	9. Glass face.
5. Plant body	10. Open out for saline.

Fig. 1. Pilot Plant Model [4]

Meshaly, O. et al., [4] made a model for that unit figure (1) and proved that this idea is applicable to produce fixed quantity and good quality for produced desalinated water. His study covered the main elements affected the unit operation and obtains its best values for the system success. Also it

Amin, R.A.S.; Ibrahim, M.S.A.; Mostafa, A.Z.M.; and Hussien, H.M., “Modifying the acrylic plant to improve the desalination by solar mirrors,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 227-231, 2019.

deduced the optimum area for the used mirror and the best methodology for humidifier condenser & the saline water internal channel path length. The system achieved low power consumption compared to other desalination systems per m3 production. The initial cost, operation cost are minimized compared to other systems. The system saves about 70% of the needed area, 75 % of the initial costs and 40 % of the running costs when compared with old solar desalination system.

El Hosseiny, O.M. et al. [5] continued the experimental work on the previous solarplant model. His study was divided into two phases first experimental work byoperating the plant in the site under several climatic conditions and the second was identifying design criteria for the plant. The study deduced the design equations and reached a fresh water flow of 25 l/d/m2 as minimum in March and increased to 180 l/d/m2 as maximum in July.

El Sergany, F. A. GH. [6] had continued her study on the same pilot plant. The study concluded that the climate conditions: air temperature and sun shine rate are affecting the system efficiency by big effect that the summer production is more than 180% of winter production and about 100% more than the average production. The mirror surface area is proportional gradually with the production rate. Also the shape of this mirror and the convection angle affects the fresh water production. The optimal convection angle was 15° and the area should not less than the plant open side area to get the maximum production value at summer period.

El Nadi et al. [7] suggested applying this plant all over coastal places in Egyptand other hot countries and some modification on the plant to be applied such as using multiple longer mirrors, increasing the length and the number of channels and studying the K factor in different locations, thus to increase the plant's efficiency.

Alaa Hisham et al. [8] made a pilot from acrylicsheets consisted of a sloped back box, three serial seawater channels divided into two series V-shaped channels, two fresh water channels, a solar collector of red copper pipes to reduce the temperature of the sloped back, mirrors of chrome sheets , and dosing pump to feed the pilot with raw seawater flow rate of seawater (52-54 l/h),TDS 19500 ppm gave low fresh water rate (0.67-1.08 l/h) because of acrylic material, and TDS (20-40 ppm). Figure (2) shows the acrylic pilot plant.

Fig. 2. The acrylic pilot plant [8]

II. Materials & Methods

Upgrading the seawater desalination system using solar rays concentrating mirrors by some modifications on the pilot built by Alaa Hisham, [8] study in 2015, to increase desalinated water production rate with minimum cost as possible.

Several modifications had been made in the study pilot to determine the study target from such system as follows:

1. A sloped back box made from transparent acrylic sheets with a glass face with dimensions (200 cm length * 70 cm width *100 cm height) to allow to sunrays passing through the pilot without any losing.
2. Three serial seawater channels inside the box, the seawater channels are divided into two series V- Shaped channels with dimensions (200 cm length * 9 cm width of upper surface *9 cm length) to increase the surface area exposed to sun rays.
3. Two fresh water channels, the first was on the top of pilot study and the second was at the bottom of glass face to collect the fresh water droplets without any losing.
4. The seawater channels were exposed to indirect Sun rays using concentrating mirrors made from galvanic steel sheet with total surface area 2 m^2 divided to 3 mirrors with dimensions (200 cm length * 33 cm width) to concentrate sunrays to the pilot to heat the raw water.
5. The mirrors are fixed by wooden frame to can be adjusted according to Sun ray's direction; each mirror is directed to a certain channel in the pilot to concentrate Sun rays on it indirectly.
6. The vertical face of the pilot is made from glass and exposed to the direct Sun to allow Sun rays to pass through the pilot and did not absorb it.
7. The sloped back is used to condensate the evaporated water on it forming fresh water, then it is collected into fresh water channel.
8. On the upper side of the sloped back there was a layer of red copper inlet pipes lying under the isolation foam sheet trying to reduce temperature of condensation face.

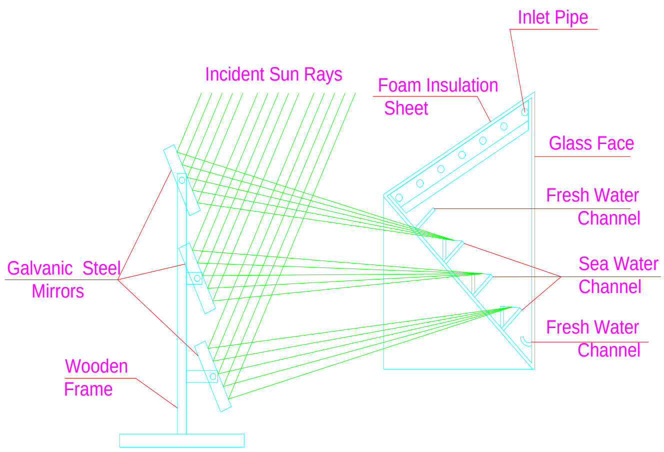


Fig. 3. Sketch for Proposed System

9. A solar collector was a red copper pipes put in a wooden box lined with a layer of glassy wool and a layer of

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

galvanic steel painted with a black polish and covered with a glass sheet to increase the temperature of raw water before entering the pilot.
10. A fresh water tank, seawater tank, and cold-water tank.
11. Very small pump is used to feed the pilot plant with small flow from sea water tank to give a chance to raw water to heat.
12. Connecting pipes between units are made from polypropylene.

Fig. 4. Pilot Plant

Operation Program

The pilot operation program was designed to cover most of climatic conditions in Egypt, so the study period was about four months to cover the best climatic conditions in summer to determine the pilot recovery ratio under the climatic period.

The program of operation was consisted from the following items:

1. Air temperature is measured several times during operation day.
2. The volume of raw seawater is recorded daily before and after operation.
3. The volume of fresh water and brine are recorded after operation.
4. Working hours of operation is recorded to calculate the flow rate of raw seawater, desalinated water, and brine.
5. Three different samples are taken daily from different location to measure parameters and their changes.
6. Every location of samples represents a type of water in the operation:
   - Sample (1): raw seawater
   - Sample (2): desalinated water
   - Sample (3): brine
7. The measured parameters are pH value, water temperature, TDS.

III. RESULTS & DISCUSSIONS

The results of the work done due to the operation of the developed pilot plant during the study period from April 2018 till July 2018 to measure the factors and calculate the recovery ratio and the efficiency.

From the four months results the effects of the studied parameters as temperature, inflow rate, TDS concentration, pH value and air humidity could be illustrated here after.

TABLE 1. Average raw water analysis results

Date	Time of sunshine	TDS	Q	pH	Humidity	T of inflow	T of raw	T of air
	hr	ppm	l/hr		%	ºC	ºC	ºC
April	12:19	25950	360	7.4	52	34	27	29
MAY	12:59	24920	37	7.4	53	42	30	34
JUNE	13:14	28600	37	7.6	48	60	40	36
JULY	13:55	31370	39.7	7.6	55	65	41	37

TABLE 2. The desalinated fresh water analysis results

Date	TDS	pH	Q	Tfresh
	ppm		l/hr	ºC
April	120	7.3	32	33
MAY	120	7.2	10	42
JUNE	120	7.1	12	51
JULY	120	7.2	18.2	54

TABLE 3. Average saline water analysis results

Date	TDS	pH	Q	T of saline
	ppm		l/hr	ºC
April	25950	7.6	328	35
MAY	25130	7.5	27	43
JUNE	28750	7.8	25	54
JULY	31440	7.8	21.5	56

From the four months results, it is observed that the inflow rate affecting the recovery ratio due to the flow velocity inside the unit and the contact time in the unit that made the results changed due to good contact time as shown in Figure 5.

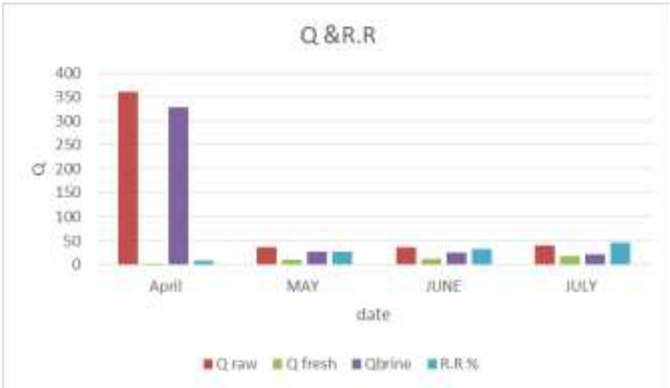


Fig. 5. Different flow rate and recovery ratio

Using the modified solar collector increasing the recovery ratio and the efficency by increasing the temperature of the inflow raw water. As the inflow raw water heated, the rate of evaporation increased then the condensation rate increased as a result the recovery ratio increased.as shown in Figure 6.

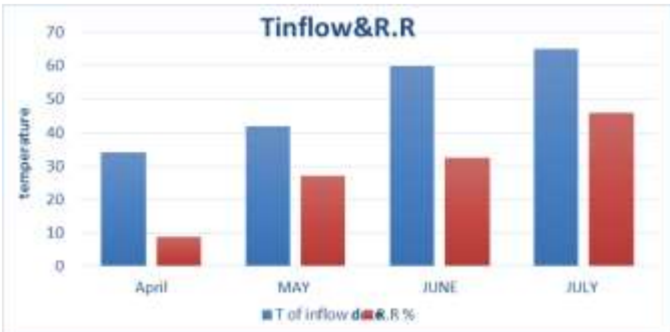


Fig. 6. Temperature of inflow raw water and the recovery ratio

The TDS values of resulted fresh water were 120 ppm regardless the raw water TDS was entering the system plant which is showing the high efficiency of the system in salt removal.

The pH values of the produced fresh water were between 7.1 & 7.3 which are accepted according to Egyptian &WHO specifications for drinking water. Figure 7 shows the different values of pH for the three types of water.

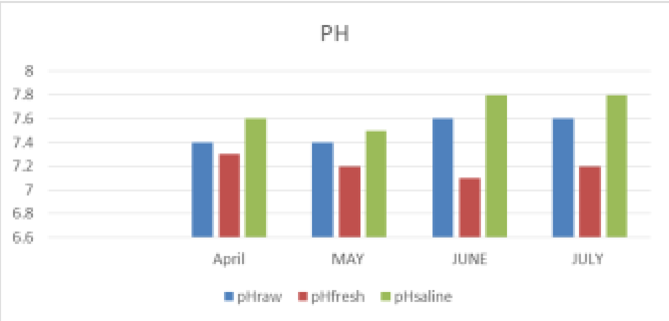


Fig. 7. Different values of pH

The decrease of the pH of fresh water than raw water and saline water because the amount of the dissolved solids in fresh water is lower than the dissolved solids in raw water and saline water.

If the surface area of the reflecting mirrors increased, the produced fresh water increased because the mirrors concentrate the sun rays to the channels of raw water to raise its temperature and heat it, then the rate of evaporation increased then condensed producing fresh water.

If the number of seawater channels increased, the produced fresh water increased because the surface area exposed to sun rays increased which make the seawater to evaporate faster.

Comparison with Previous Work

The comparison is done here with two types of solar desalinated plants previously made the first used acrylic as the construction material is similar to our study. as shown in Figures 8.

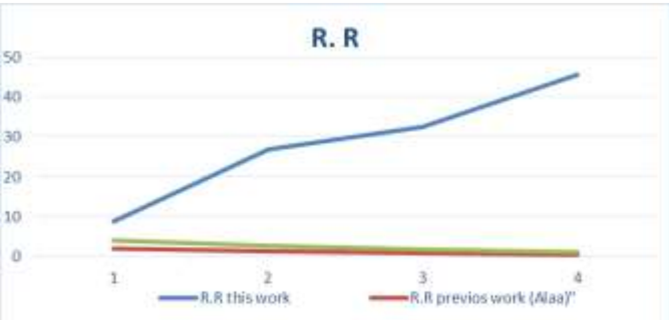


Fig. 8. Recovery Ratios of plant1and plant2.

The previous work (Alaa plant) was made in winter as the worst climate and this work was made in spring and summer as the best climate so the comparison between the two plants was not fair to solve the problem, the results of plant 2 should be multiplied by a factor about 2 to decrease the difference of air temperature between winter and summer and the difference of modifications made on the pilot plant. After modifying plant 2 results, the recovery ratio of plant 2 is still lower than the recovery ratio of plant 1that told us the modifications made on the pilot plant increased the recovery ratio and the efficiency of plant 2 (8% - 45%) and the recovery ratio of plant 1 was(0.5% - 2%) and after the factor was (1% - 4%) .

IV. Conclusions

Due to the discussion of the study results and from the conducted data we could conclude the following:

1. The temperature of air is the most critical factor in the operation process. As it increases the plant recovery ratio increases.
2. The sunshine time is not a main parameter as air temperature, even the plant efficiency is increased with the sunshine period increase.
3. The plant can be used in larger scale production with minimum cost because it will depend on the solar rays alone.
4. Raw water TDS has very low effects on the fresh water production.
5. The modifications improved the productivity of the Acrylic plant from 8 -10 times compared with old one from totally acrylic.
6. Modifying the acrylic material with a glass face increasing the efficiency from 8-10 times, the change of the whole body from acrylic to glass may increase the unit productivity.
7. The unit efficiency could be increase more if the acrylic material replaced with a black steel except the face from glass.
8. The efficiency increased if the number of channels increased due to the increase of contact time inside the unit.
9. The plant uses small area of land compared to its production compared with other solar energy desalination plants, that is suitable for small communities.
10. The plant maintenance is easy, and the components can be brought without trouble also minimum maintenance needs are required.
11. The capital cost is the cheapest in all systems available for desalination. Mainly because depending on solar rays, minimum units were used, and minimum material.

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