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A Comparison between Different Types of Solar Desalination by Concentrated Mirrors

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Abstract**—** *The objective of this study is to evaluate the several pilot models for the solar desalination with concentrated mirrors through a technical and financial comparison to choose the suitable model for commercial application for such system.*
The study concluded the following results,

- *For technical comparison, the pilot no, 4 was ranked the first and followed by pilots no. 2, 1 and finally no.3.*
- *And for financial comparison, the pilot no.3 ranked the first while pilot no, 4 ranked the second followed by 2 & 1as the last. It is worth noting that the finically difference between all plants is very small about 2% difference.*
- *The total comparison that takes the technical evaluation effect on the financial evaluation the pilot No. 4 achieved the lowest cost followed by pilot No.2 then pilot No.1 and pilot No. 3 came at the end*
- *The results illustrated the suitability of pilot No.4 after all the modifications to be the first commercial plant from such desalination method.*

Keywords**—** *Solar Desalination, technical comparison, environmental comparison, financial comparison*.

I. INTRODUCTION

Due to the shortage of fresh water quantities with the population growth and the water needs raise due to civilization demands that means the insufficient of fresh water for existing and future human usage, the world directed to desalinating of saline water for its huge availability on the earth.

Since 1940 the desalination development started concentrating on several thermal methods starting from normal distillation that developed to multistage flash (MSF), Multi evaporation desalination (MED) And Vapor Compression Desalination (VCD), also freezing in icy zones and solar desalination in sunny zones were applied. The applications of membranes methods started in 1970.

Nowadays desalination market providing over 24 million m3/d. Last 37 years prove that: desalination is the most important method for solving water shortage problem [1]. Due to the high cost of construction and operation & maintenance of all applied desalination technologies with the shortage in its recovery ratios and big harm in its environmental impacts, the researchers worked hard to overcome these weak points that prevent the enlargement of this industry to achieve the human life progress rate. Both Solar desalination and bio desalination were the most promising methods for such targets.

Solar desalination still represents a natural hydrologic cycle on a small scale. Solar energy is used to convert water characteristics from saline water to fresh water with (simple process, low cost and low environmental impact, it is used for small communities, rural areas and isolated areas) [2]. Solar energy enters through a sloping transparent glass and heats a basin of salt water as shown in figure 1. The heated water evaporates and then condenses on the cooler glass. The condensed droplets run down the panels and are collected to be use as fresh water.

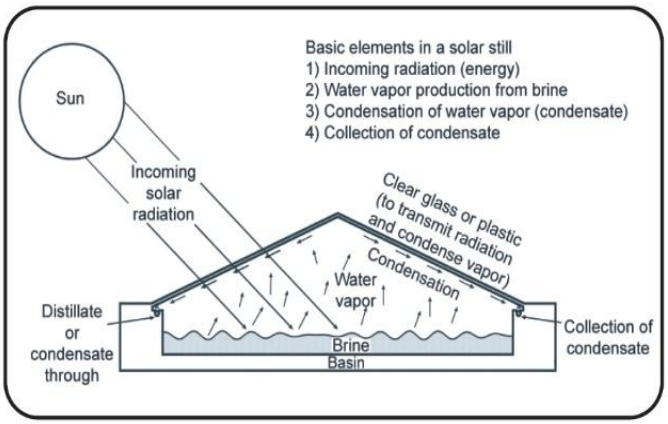

Fig. 1. Conventional Solar Desalination

The conventional solar desalination is the most suitable system for Arab countries and Middle East for its sunny weather and the huge desert coastal areas. The ease of the system and its low O&M needs make it promising for being the optimum solution for this zone. The conventional solar desalination has small productivity and low recovery ratio compared with other existing technologies that difficult the depending on it standing alone specially it depend on the sunshine period that affects its productivity in winter period where sunshine period is minimum [3].

The researchers worked hard to develop the solar desalination system in the recent years. Several efforts and trials had been done to increase the productivity by recycling of saline water and use better glass porosity with change the fresh water collecting procedure but all these trials achieved only 20-45 % improve in the productivity which still very low [4].

Some other procedures were made as using assisting energy as electricity or oil fuel underneath the water path to raise the water temperature quickly but this increase both construction and running costs [4].

In year 2002, El Nadi in his report about desalination methods proposed the idea of using the concentrated sun rays concaved mirrors to increase the square meter productivity in solar desalination system [4].

A serial of studies built on such idea was started producing several models for the solar desalination by concentrated

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mirrors trying every time to overcome the faced problems and increase the recovery ratio with the increase of square meter productivity.

First pilot illustrated in figure 2 built by Meshaly, O. et al., [5] and operated for 1 year on Suez Canal. It proved that the idea is very acceptable for producing fresh water with a reasonable amount and high quality. The study 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 total cost is minimized compared to other desalination systems. The system saves about 70% of the required area, 75 % of the initial costs and 40 % of the running costs when compared with old conventional solar desalination system.

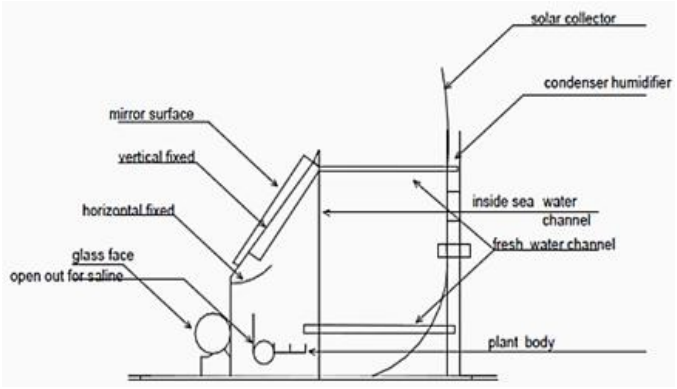

Fig. 2. pilot plant model 1

El Hosseiny, O.M. et al. [6] continued the experiment on the pervious pilot plant to be model 2 after adding the recycling pump for effluent brine to be added to new water to increase its temperature. The study work was divided into 2 phases. The first phase: operate the pilot under different climate conditions and the second phase: define the design criteria for the pilot plant. The modification increased by 2-3 times the productivity and solve some operation problems.

Fig. 3. Photo of the model 2 pilot with recycling pump

El Sergany, F. A. GH. [7] had continued the study on the same pilot plant. The study covered the main factors affected the unit operation and obtains its best values for the system success. It concluded that the climate conditions of air temperature and sun shine rate are the parameters affecting the system efficiency by huge effect that the summer production is more than 180% of winter production. The mirror 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 [8] suggested applying the pilot plant all over coastal places in Egypt and other hot countries. He had modified the plant to be applied as using multiple longer mirrors, and increasing the length and the number of channels, also improve the condensation heating system before entering the pilot and studying the K factor in different locations, to reach to maximum efficiency.

Naguib, A.H. et al. [9] made the pilot model 3 from acrylic consisted of a sloped back box with 3 serial seawater channels divided into two series V-shaped channels, 2 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 with flow rate (52-54 l/h),TDS 19500 ppm gave low fresh water rate (0.67-1.08 l/h) and TDS (20-40 ppm. Hydraulic load has been reduced to 636 1000 lit/m2/day. The study done in winter from September to December and reached to only 2-8 % recovery ratio. Figure 4 illustrates the diagram of the pilot and figure 5 shows its photo.

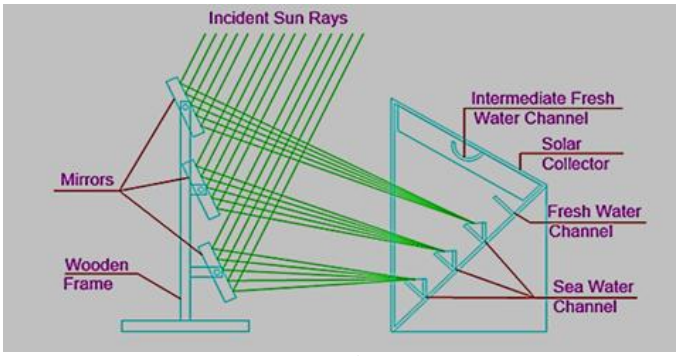

Fig. 4. Diagram of pilot model 3

Fig. 5. Photo of pilot model 3

In year 2018, a modifications made by Rania Adel, et al. [10] in pilot no.3 producing pilot no.4 by change the face with

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glass instead of acrylic, increase the condenser length and return of hot brine water. So, the sea water moves into a solar collector for increasing water temperature. The heated sea water moves through a series channels exposed to concentrated sun rays by mirrors. When the sea water boils vapor to connect to the cold layer to condense fresh water droplets and then they are collected in fresh water channels directly to fresh water tank. The residual heated water moves to sea water tank in a closed loop. Hydraulic load has been reduced to 296 lit/m2/day. The study was done from May to July period and reached to 24.8-44.9% of recovery ratio

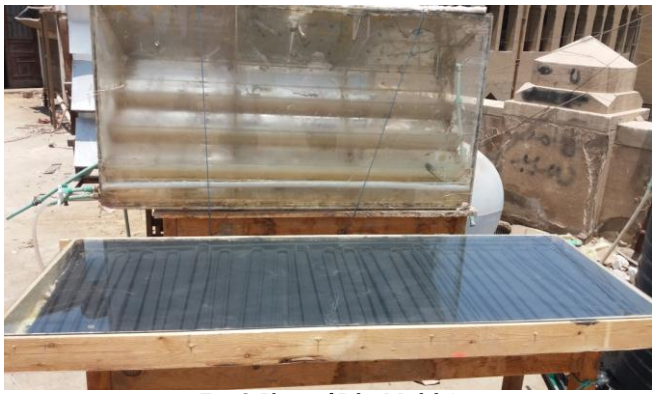

Fig. 6. Photo of Pilot Model 4

II. Materials & Methods

This study was made to determine the suitable model for the technique of solar desalination by concentrated sun rays mirrors. The study made technical and financial comparison between the four pilot models according to weighting system covering several comparison faces.

The technical comparison was made with several factors that had been chosen to cover all the technical aspects could affect the system success. And after reviewing the practical results of each pilot model the chosen factors covered the following comparison points

1- Body material.
2- Face material.
3- Number of raw water channels.
4- Using heat condenser.
5- Return of raw water.
6- Rate of desalination process.
7- Hydraulic load.
8- Percentage of recovery ratio.
9- Average temperature inside the pilot.
10- Average air temperature.
11- Sunshine period time.

The weight of each factor depends on the extent impact on the pilot's efficiency due to practical application review. To compare technically between the four different pilots, several factors had been chosen to cover all the technical aspects could affect the system success. During the practical application the effect of some factors on the evaluation of the system was higher than the other factors. Therefore, the factors with the greatest effect such as (body material, face material, raw water channel, Rate of desalination process, hydraulic, % R.R, T inflow and Average air) took weight value 10. Factors with the small effect such as (return raw water, heat condenser and sunshine period time) took weight value 5. The technical factors evaluation and weighting were made due to a several discussions with experts in the field of desalination as consultants, plant owners, and operators of plants, maintenance companies and production companies.

The comparison takes into consideration the following points

- Pilot no. (3) Results were produced in the winter season in which the solar mirrors effect will decrease due to climatic condition. So, to compare it with the other pilots its results are multiplied by a value determined from pilot no. (4) Summer results taking into consideration the effect of the modifications made on pilot no. (4) That increase its productivity. The resulted value was ratio is 5.3 but it took only 4 to take the modification effects.
- Pilots no. (3) & (4) used acrylic to observe the water path in the system. However, the acrylic material was not the suitable choice to be used because it absorbed a large part of the sun that decrease the temperature in the pilot and affected on the evaporation process in it.
- The use of the glass yielded good results but it makes the system breakable so we only have to have glass for the face side of the pilot.
- All these plants have the same operation and maintenance with some difference due to the construction material type and needs.
- All studied pilots have the same environmental impacts that minimizes its effect on environment.

The financial comparison after reviewing the practical costs of each pilot model made according to the prices of January 2017 not the prices of each model when it was erected for making the comparison real.

III. Results & Discussions

Table (1) shows the technical comparison between the four models made for such the system of solar desalination with concentrated sunrays mirrors depending on the practical applications of them and the authors experiences.

For the compared four pilots are followed the same system, there was not any changes in the impact on the environment.

The weight of each factor depends on the extent impact on the pilot's efficiency. From the technical comparison table (1) the weight effects determined in each item as followed:

- Coated black steel is a very good material due to heat retaining inside the pilot and make the pilots body break less, so it was evaluated by weight (10) while, acrylic advantages' was seeing the follow-up water however, it lost a large amount of sun rays absorption and has little ability to retain heat inside the pilot, so it was evaluated by weight (4).
- Glass face material of the pilot efficiency is good because it reflects the sun rays inside the pilot and enables us to follow water paths, so it was evaluated by weight (8) and acrylic absorbs sun rays so it was evaluated by weight (4).

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TABLE 1. Technical Comparison between Different Solar Desalination by Concentrated Mirrors Models

		Plant No. 1		Plant No. 2		Plant No. 3		Plant No. 4	
Construction Date		2007		2010		2015		2018	
Comparison Face	Wt	Item	Wt	Item	Wt	Item	Wt	Item	Wt
Body Material without Face	10	Coated Black Steel	10	Coated Black Steel	10	Acrylic	4	Acrylic	4
Face Material	10	Glass	8	Glass	8	Acrylic	4	Glass	8
Raw Water Channel	10	One	5	One	5	Three	10	Three	10
Heat Condenser	5	Non	0	One	3	One	3	Double	5
Return of Raw Water	5	No	0	Yes	5	No	0	Yes	5
Discharge of Fresh Water (liter/day)	10	42.37	4	142.5	7	34.4	3	176.4	8
Hydraulic Load liter/m^2/day	10	1000	4	1000	4	636	8	296	9
Recovery Ratio R.R %	10	3.5-6	4	7-9.3	5	2-8	4	24.8-44.9	9
Average Inflow T°c	10	41.5	6	50.8	7	26	4	55	8
Average Air T°c	10	33	7	37.3	9	24	5	34.64	8
Sunshine Time hr/day	5	12.10	3	12.10	3	11.10	2	13:35	5
Total Tech. Evaluation	95	----	51	----	61	----	47	----	79
% Total Evaluation		53.68%		64.21%		49.47%		83.15%	

- Increasing the number of raw water channel increases the exposed area to evaporation which increases the amount of fresh water produced and thus increases the efficiency of the plant so it was evaluated by weight (5) where is only one raw water channel and also was evaluated by weight (10) where there are three raw water channels.
- Heat condenser increases the heat inside the pilot plant which increases the efficiency of the plant so where it wasn't found, it was evaluated by weight (0), but when it was only one, it was evaluated by weight (3) and when it existed by double, it was evaluated by weight (5).
- Return of raw water increases the chance of producing the amount of fresh water produced which raises the efficiency of the pilot, so it was evaluated by weight (5), when we aren't using this method, it was evaluated by weight (0).
- Increasing the discharge of raw water decreases the retention time inside the pilot subsequently decreased of the amount of produced fresh water and decreased the efficiency of the plant. So, it was evaluated by weight (4) when rate of fresh water was 42.37 l/day, it was evaluated by weight (7) when rate of fresh water was 142.5 l/day. It was evaluated by weight (3) when
- rate of fresh water was 34.4 l/day, it was evaluated by weight (8) when rate of fresh water was 176.4 l/day.
- whenever it is small it increases the evaporation rates thus increasing the efficiency of the plant so, it was evaluated by weight (4) ,when it was 1000 l/m2/d ,it was evaluated by weight (8), when it was 636 l/m2/d and it was evaluated by weight (9), when it was 296 l/m2/d.
- Recovery ratio it is a major gateway to the efficiency of the plant so it was evaluated by weight (4), when it was (3.5-6) %. It was evaluated by weight (5), when it was (7-9.3) %. It was evaluated by weight 4 when it was (2-8) % and it was evaluated by weight (9), when it was (24.8-44.9) %.
- Increasing the average temperature inside the pilot subsequently increases the evaporation rates and also increases of the amount of fresh water produced and increases the efficiency of the plant so it was evaluated by weight (6) where it was 41.5 ºC, it was evaluated by weight (7), when it was 50.8 ºC., it was evaluated by weight (4), when it was 26 ºC and it was evaluated by weight (8), when it was 55 ºC.
- The average air temperature represents the average temperature inside the pilot subsequently increases the efficiency of the plant so it was evaluated by weight (7) ,when it was 33 ºC, it was evaluated by weight 9 where it was 37.3 ºC ., it was evaluated by weight (5) ,when it was 24 ºC and it was evaluated by weight (8) ,when it was 34.64 ºC .
- Increasing of sunshine period time increases the chance for absorbing more heat energy and could increase the number of hours of the operation of the plant which increases its efficiency so, it was evaluated by weight (3), when it was 12.10 hours, it was evaluated by weight (2), when it was 11.10 hours and it was evaluated by weight (5), when it was 13.35 hours.

According to table (1) it is clear that pilot No. (4) Is the best in technically followed by pilot No. (2), pilot No. (1), No. (3) Are the last.

For Financial comparison, Increasing the successive prices of the same material may make the comparison unfair between different pilot systems because each of them was created at a

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different time, so that the comparison is fair between pilots, we will price all the pilot's units for the same year (2017) and also the study unified the hydraulic loads for all pilots to make the comparison real significance.

Table (2) shows the financial comparison.

TABLE 2. Financial Comparison between Different Solar Desalination by Concentrated Mirrors Models

The Cost of different Elements		Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
Initial Cost (LE)	Tanks	3,500	3,500	3,500	3,500
	Body	4,100	4,100	2,000	1,850
	Mirrors	800	800	300	300
	Piping and Fitting	800	800	800	1000
	Solar Collector	2,000	2,000	2,000	6,150
	Total	10,900	10,900	8,600	12,800
Running Cost (LE/10 years)	Workers' Salaries	720,000	720,000	720,000	720,000
	Electric Consumption	3,600	3,600	3,600	6,000
	Maintenance	24,000	24,000	14,000	14,000
	Rehabilitation	6,500	6,500	5,200	8,000
	Total	754,100	754,100	742,800	748,000
Total Cost (LE) along Life Time (10 Years)		765,000	765,000	751,400	760,800

According to table (2) it is clear that pilot No. (3) Is the minimum in initial cost and running cost, subsequently it is the cheapest pilot, and pilots No. (1, 2) are identical in initial cost and running cost and are the most expensive pilots, pilot No.4 is the most expensive in initial cost but the moderate in running cost , so it ranked 2 of the financial comparison. The difference between the pilots are very small in cost.

IV. Overall Compersion

The overall comparison takes into consideration the technical evaluation effect on the financial values that was made by dividing the financial value of the model by its technical percentage value of it to get the real cost of it including the technical effect into consecration.

Table (3) shows the overall comparison between the four models of the solar desalination with concentrated sunrays mirrors.

According to table (3) it is clear that pilot No. (4) Is the best pilot model for such system followed by pilot No. (2) then pilot No. (1) and finally pilot No. (3).

TABLE 3. Overall Comparison between Different Solar Desalination by Concentrated Mirrors Models

	Plant No. 1	Plant No. 2	Plant No. 3	Plant No. 4
Technically Weight	51/95	61/95	47/95	79/95
% Technically	53.68%	64.21%	49.47%	83.15%
Total Cost (LE) along Life Time (10 Years)	765,000	765,000	751,400	760,800
Comparison Factor	1,425,111	1,191,403	1,518,900	914,972

V. Conclusions

The study made the comparison (technical and financial) between the four applied models for the solar desalination by concentrated mirrors system. The evaluation comparison methods resulted the following:

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- In terms of technical comparison, the pilot no, 4 was ranked the first and followed by pilots no. 2, 1 and finally no.3.
- According to the reality of the plants follow the same system and have the same effect on the environment. So, no environmental comparison.
- With regard to financial comparison, the pilot no.3 ranked the first while pilot no, 4 ranked the second followed by 2 & 1as the last. It is worth noting that the finically difference between all plants is very small about 2% difference.
- From the total comparison that takes the technical evaluation effect on the financial evaluation the pilot No. 4 achieved the lowest cost followed by pilot No.2 then pilot No.1 and pilot No. 3 came at the end
- The results illustrated the suitability of pilot No.4 after all the modifications to be the first commercial plant from such desalination method.

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