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Treatment of Desalination Brine Using an Experimental Solar Pond

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Abstract— Brine from seawater desalination plants is deposed to the sea causing a negative impact on the marine life. Solar evaporation ponds are especially suitable to dispose of reject brine from inland desalination plants in arid and semi-arid areas due to the abundance of solar energy. Nearly all forms of salt production require evaporation of water to concentrate brine and ultimately produce salt crystals. In this article research, an experimental shallow solar pond (SSP) having a surface area of 1*1 m2 and depth of 20 cm was built. Solar pond using two reflector mirrors extending for five days from 12 to 16 July 2015 was tested. Mirrors, which are movable for five different angles that makes with horizontal, were used as reflectors in order to increase the thermal energy for the surface of the solar pond during the day. The main factors affecting the evaporation rate which are relative humidity, wind speed, ambient air temperature and solar radiation were studied. The results showed that the little of decreasing evaporation rate was observed by increasing relative humidity and maximum evaporation rate was observed at relative humidity of 67.6%, while slight increasing of evaporation rate was observed by increasing ambient air temperature, evaporation rate appears to decrease slightly as wind speed increases and gradual increasing of evaporation rate with increasing solar radiation. Comparisons between experimental and theoretical results have been performed which good agreement has been achieved. Results showed that evaporation rate increases with decreasing the mirror's angle that makes with horizontal β. It was concluded that using two mirrors are very effective more than using one mirror when they are used as reflectors and that the best performance of the evaporation can be achieved when the mirrors are employed as reflectors. In conclusion, this system proved to be promising using two mirrors which reduced the solar pond area and hence reduced area needed for brine evaporation in Gaza strip desalination plants. The research can be further developed to achieve better results using large scale solar pond.

Key words: Brine, solar system, Shallow solar ponds.

I INTRODUCTION

The desalination of seawater is a common method for providing fresh drinking water in The Gaza Strip as a solution to increase water resources . However, the disposal of the brines generated by the desalination process poses significant environmental issues and negative impact, due to the high concentrations of salts and increases in the concentration of transition and heavy metals. This brine is usually discharged to inland water bodies or to the sea and constitutes a threat to ecosystems and species. In the last decade, new demonstration projects have been addressed to achieve an effluent volume reduction by either solar evaporation ponds or thermal evaporation. Brine volume reduction by evaporation techniques results in a solid product that can more easily be disposed of comparing to the original concentrate, whereas the low salinity effluent can be reused to increase the water production ratio or it can be directly discharged into surface or ground water bodies [1].

Due to the environmental concerns that brine disposal can cause, in addition to the high disposal cost, many technologies have been developed for recovery to avoid the disposal into the sea. Examples are renewable energy generation and use in evaporation ponds to produce salt or chemicals for industry. Nevertheless, more investigation is needed to reduce brine quantity and to allow recovery and reuse of brine. Because of the declining economic situation, the Gaza Strip is suffering from energy crisis. On the other hand, solar energy is a renewable resource; it is abundant, inexhaustible and free [2].

Solar evaporation consists of leaving brine in shallow evaporation ponds, where water evaporates naturally thanks to the sun's energy. Salt is left in the evaporation ponds or is taken out for disposal. Evaporation ponds are relatively easy to construct, while requiring low maintenance and little operator attention compared to mechanical systems. In addition, no mechanical equipment is required, except for the pump that conveys the brine to the pond, which keeps low operating costs. Nevertheless, evaporation ponds for disposal of concentrate from desalination plants need to be constructed as per the design and maintained and operated properly so as not to create any environmental problem, especially with regard to groundwater pollution [3]

Solar evaporation is a suitable technology to be used in arid regions where land is available. However, due to the quantity of terrain needed to treat large volumes of brine water , evaporation ponds may have limited use in the Gaza Strip where land is not available. By increasing the evaporation rate, the pond land may reduce. Therefore, the use of available solar energy in Gaza could be appropriate option to increase the evaporation rate. Therefore, the main goal this article is to utilize solar energy for brine water evaporation using shallow solar pond (SSP) and optimize a model suitable for the Gaza Strip.

JUSTIFICATION OF THE STUDY

The Gaza Strip is semi-arid as well coastal region. Fig. 1 shows the annual monthly average variation in solar radiation in the three Climate zones of the Palestinian Territories[4]. Solar insulation has an annual average of 5.4 kWh/m2.day, which fluctuates significantly during the day and all over the year, and approximately 2860 mean-hour sunshine throughout the year. The measured values in the different areas show that the annual average insulation values are about 5.24 kWh/m2.day, 5.63 kWh/m2.day, 5.38 kWh/m2.day in the coastal area, hilly area and Jordan valley respectively. The average annual global horizontal radiation for all stations is 2017 kWh m-2 year-1[4].

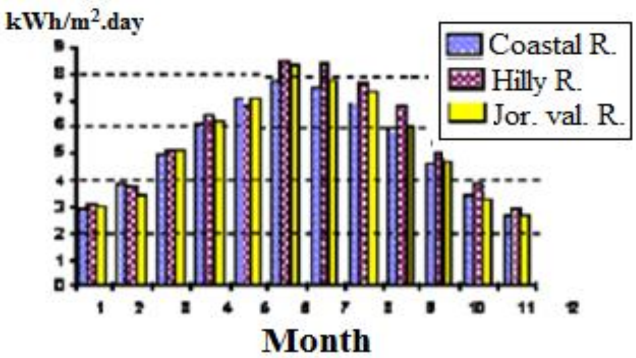

Figure 1Annual monthly average variations in solar radiation in the three climate zones of the Palestinian Territories [4]

I. SHALLOW SOLAR POND (SSP)

The shallow solar pond is a large solar energy collector that consists of a plastic envelope containing water [6]. As the name of convective shallow pond suggests, the depth of water is relatively small ,usually between 4 and 15cm [7], and the layer is homogeneous.

The concept underpinning the SSP has been known since the beginning of the twentieth century, when Willsie and Boyle used the idea to produce shaft power. They tried various designs of solar pond and one of these was composed of a wooden tank lined with tar paper and covered with a double glass window, while each side and bottom were insulated with hay. The water level in the tank was 7.5cm. Other designs included asphalt and sand for insulation, however, the latter could not be kept dry, so the heat loss from the base was high. In 1906 and 1908, Willsie and Boyle succeeded in raising the temperature from 38 to 80℃ by using dual stages, and single and double glass covers (of 110m^2); 11kW of peak power was obtained. Also in the beginning of the twentieth century, Shuman] ran a steam engine on the same system used by Willsie and Boyle. Furthermore, shallow ponds were used in Japan for domestic purposes in the 1930s. After about half a century, the shallow pond technique was suggested to produce power by D'Amelio [8], and research to develop SSPs was adopted by The Office of Saline Water, US Department of Interior [9].

More recently, a research team at the University of Arizona developed an SSP to be combined with a multiple-effect solar still for the purpose of desalination. This system produced 19m^3/day of distilled water using 5 ponds (each about 90m x 2m) [10].

Around 1975, the Lawrence Livermore Laboratory in California, USA [11] and the Solar Energy Laboratory at the Institute for Desert Research in Israel [12] were established and teams were formed for solar energy research. The former research center constructed several large-scale SSP projects in different designs [13] and soon after, many significant results were obtained and published by W. Dickinson and other researchers [11]. In the latter center, the SSP was involved in a large-scale project of solar energy and good experiment results were delivered. After that, Kudish and Wolf [14] designed a portable shallow pond for camping and military use. During the past 30 years, SSPs have been used in many countries, such as Iran [14] and Egypt [15].

A typical SSP consists of a low-depth volume of water enclosed in 60 m x 3.5m (approximately) plastic bag, with a blackened bottom and colorless top film. This bag is insulated below with foam insulation and on the top with single or double glazed panel, as shown in Fig. 2 [13]. The shallow solar pond can be operated in batch or continuous modes. In batch operation, the water is insulated during daytime. Before nightfall, it is pumped into a large insulated tank for night storage and then pumped back into the bag after sunrise every day. If the water flows continuously through the water bag, this operational method is then called the flow-through mode, which is also named by some researchers [13] as deep salt less solar pond [16].

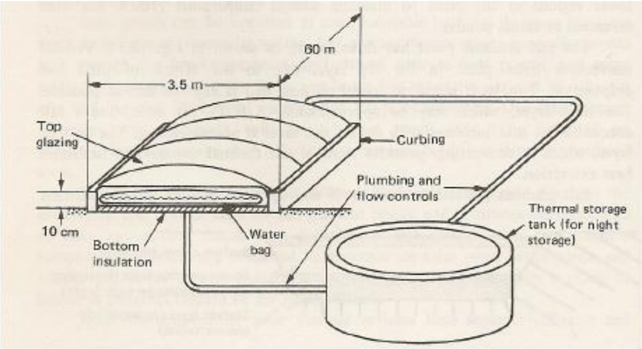

Figure 2A typical shallow solar pond [17].

II. FORMULATION OF MIRROR SYSTEM USED AS A REFLECTOR

For overcoming heat loss due to heat transfer from the surface of the solar pond to the atmosphere during nights and also for increasing the solar energy harnessing area during days, a reflection mirror system as shown in Fig. 3 was designed and used. In this section, a mathematical formulation of this system will be given. For calculating the amount of the sun light energy which is reflected by the reflectors, a mathematical formulation was carried out. In the derivation of the equations, the model seen in Figure 3 was used.

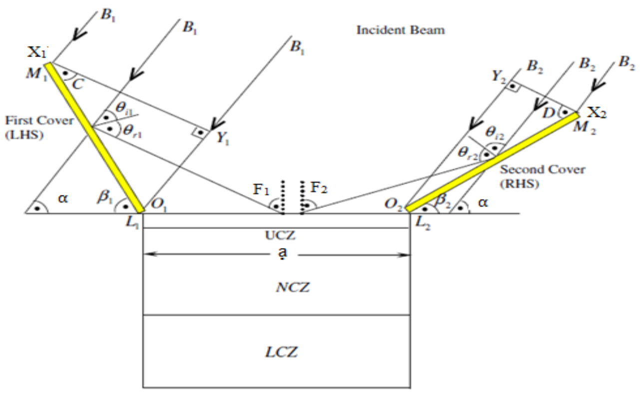

Figure 3. Schematic diagram of the reflectors (adapted from [18]).

$X_1Y_1 = M_1L_1 \times \cos C$ (1)

Note: for calculation results see appendix E.

where:

C = the angle between X_1Y_1 and the reflector and it is a function of time.

M_1L_1 = the side length of the reflector. C is given by

$C = 90 - [180 - \alpha - \beta_1] = 90 - 180 + \alpha + \beta_1 = -90 + \alpha + \beta_1$ (2)

Note: for calculation results see appendix E.

Substituting C in Eq. (3.47), the length of X_1Y_1 in the triangle, $X_1Y_1O_1$, is

$X_1Y_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1)$

The projection area of the reflector normal to the incident light, SM_1, is

$SM_1 = X_1Y_1 \times ḁ$ (4)

where ḁ is the length of one side of the pond or the length of the reflector.

Substituting the value of X_1Y_1 given

$SM_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1) \times ḁ$

Note: for calculation results see appendix E.

The amount of the solar energy which will be reflected by the first reflector into the solar pond is

$G_1 = SM_1 \times B_1$ (6)

Note: for calculation results see appendix E.

where B_1 is amount of the solar energy falling on one-meter square area perpendicular to the incident light per unit time and it is equal to B_2. The amount of the solar energy which will fall on one-meter square area of the solar pond in per unit time, U_1, is obtained using G_1

$U_1 = G_1 / ḁ^2$ (7)

Or

$U_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1) \times B_1 / ḁ$ (8)

Note: for calculation results see appendix E.

A. *Solar energy reflected by the second mirror*

Following the similar way an expression which will give the amount of the energy to be reflected from the other reflector, U_2, is

$U_2 = M_1L_1 \times \cos(90 + \alpha + \beta_2) \times B_1 / ḁ$ (9)

Note: for calculation results see appendix F.

where M_1L_1 is equal to M_2L_2.

In the computational modeling, it is necessary to know the angles between the light beams coming from reflectors and the normal of the surface of the solar pond. These angles were denoted by F_1 and F_2, respectively, and their expressions have been obtained using the geometry of the system shown in Figure 3 in terms of $\mathcal{E}$, β_1 and β_2

$$F_1 = 90 + \alpha - 2\beta_1 \qquad (10)$$

Note: for calculation results see appendix E.

and

$$F_2 = 270 - 2\beta_2 - \alpha \qquad (11)$$

Note: for calculation results see appendix F.

These equations have been used in the theoretical model calculations. In order to model the solar pond with mirrors, numerical solution of the equations, defining how much energy is incoming from reflectors to the pond surface, is implemented to our existing code [19,20].

III.EXPERIMENT DESCRIPTION

A. *Detailed description of the construction of SSP*

A schematic diagram of the constructed small scale SSP is shown in Figure 4 and as a photo in Fig. 5.

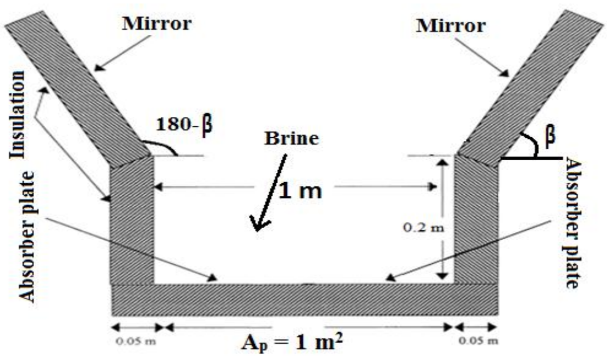

Figure 4. SSP schematic diagram

Figure 5. Photographic of Locally Fabricated SSP

The locally made shallow solar pond is shown in Fig. 5 consists wooden box (Carpentry Timbre) with a depth of 0.2 m and a bottom surface area of 1.0 m^2. A galvanized-iron sheet (0.001m thick) was used for fabricating the pond with a depth of 0.2 m and a bottom surface area A_p of 1 m^2, which acts as the absorbing surface for the incident solar radiation of the pond. The surface of the absorber plate exposed to the sun was painted by black paint to maximize the amount of the absorbed solar radiation. In order to minimize the heat losses from the sides and back of the SSP, a 0.05 m thick layer of sawdust was used as an insulating material.

A movable plane mirror with an area equal to that of the pond surface (1 m^2) is hinged at the top of the pond to increase the intensity of solar radiation incident on the pond cover and to improve the thermal performance of the pond. The mirror was also used as an insulation cover for the pond during the night by using 0.05m thick layer of sawdust lying between the back surface of the mirror and a wooden sheet. The angle β between the mirror and the horizontal is usually adjusted to increase the amount of solar radiation reflected to the pond (Fig. 5).

B. *Experimental procedure*

The experiment was carried out using the following steps: the experiments were carried out outdoors from 12 AM to 12 PM for 11 successive days (12–22 July) of the summer season of the year 2015. To follow-up the brine evolution, brine sample from the seawater desalination plant located in Deir Al-Balah (Gaza Strip, Palestine) was collected to determine its chemical constituents. The climate at the site was always wet and hot with no rain fall during the studied period.

The brine sample was collected in clean bottles without any air bubbles. The bottles were tightly sealed and labeled outside in the field and constantly weighed. The pond is filled with natural brine at 12 AM by continuous addition of brine until the pond becomes completely filled with brine to an initially depth of 0.075 m inside the SSP. The level of water in the pond was fixed at 12 cm by using an overflow system consisting of PVC pipe with 2 inches diameter.

The system was oriented to face south to maximize the solar radiation received by the pond. The ambient air temperature and Relative humidity conditions, wind speed and solar radiation at which the experimental work were done, recorded every 1 hour during the day at the field work by means of an computerized automatic weather data (http://www.accuweather.com).

Brine is heated by solar radiation and thus it gets evaporated, the levels of water in the studied solar pond were measured in situ every 24 hours (1 day) using ruler, then Evaporation rates determined by the difference between initial and final readings. During evaporation process, brine samples were taken in sequence at different densities for chemical analysis. All brine samples were analyzed for major ions (Na^+, and Cl^-) by titration, pH and total dissolved solids TDS were determined by pH and TDS meters respectively.

To evaluate theoretically and experimentally the performance of the solar pond, the design of the evaporation pond was accomplished using three distinct scenarios: 1)The first scenario was used two reflecting mirrors with five different angles (β) for both mirrors, this scenario extending for five days from 12 to 16 July 2015. The angles were 125°, 130 °, 135 °, 142 ° and 145 °., 2)The second scenario was without using any mirrors at 17 July 2015 and 3) The third scenario was by using one reflecting mirror with five different angles extending for five days from 18 to 22 July 2015.

The daily rate of evaporation of the solar pond for each scenario is then calculated with the aid of Eq. (1). The theoretically and experimentally results then compared with each other. A computer program was prepared for the solution of the evaporation rate equations for the solar pond. The input parameters to the computer program include climatic, and design parameters. Another computer exercise has been performed for calculating the total solar-radiation incident on the mirror and that reflected to the pond. The same procedure is repeated with new values of different climatic conditions for every day through the experiments and so on.

IV.RESULTS AND DISCUSSION

A. *Effect of brine salinity on salt (NaCl) output:*

To illustrate the utility of predicting salt-making process, brine sample was collected from the desalination plant. Sample No.1 have NaCl concentration differ than that of sample No. 2 as shown in Table 1. Note that sample No. 2 collected and analyzed after 10 days during the experiment of brine evaporation.

TABLE 1. BRINE CHEMICAL ANALYSIS

No.	Test	Unit	Sample No. 1	Sample No. 2
1	pH	-	7.78	8.03
2	TDS	Mg/L	63360	-
3	EC	Ms	99000	>199000
4	Cl^{-1}	Mg/L	35600	100000
5	Na^{+1}	Mg/L	37622	60774

The first sample takes 10 days of evaporation to concentrate the brine sufficiently to begin collecting salt, about 8.03 kg are then collected at the end of the period. The second sample produced about 6.77 kg of salt and took about 8 days. The total amount of 14.8 kg of salt was produced from salt-making process during the experiment period. There is an increased amount of salt about 15.7% when salinity increased from 73222 mg/l to 160774 mg/l.

The experiments are continued every day until the level of water decreasing and becomes equal to zero and the layers of salt begin to appear as shown in Fig. 6.

Figure 6. Growth rate of salt

The salt (solid) samples were collected in small polyethylene plastic bags and tightly sealed and labeled in the field to be weighed using an electronic balance and for examination techniques (Fig. 7). The salt samples were carefully kept away from any atmospheric conditions until examinations.

Figure 7. Output salt samples

B. *Solar evaporation rates process*

In this section, the results obtained from the model and experiment were discussed and compared with each other, and then the effects of the various parameters were examined.

To illustrate the utility of predicting solar evaporation rates, using the steps outlined above and numerically analysis the evaporation process using three distinct scenarios, The first scenario was used two reflecting mirrors with five different angles for both mirrors, this scenario extending for five days from 12 to 16 July 2015, the second scenario was not used any mirrors (without mirror) in 17 July 2015, and the third scenario was used one reflecting mirror with five different angles extending for five days from 18 to 22 July 2015 (Table 2).

Each scenario requires a weather data and site specific information file that were created using the measured data covering the period from 12 to 22 July 2015 at which the experimental work was done derived. The online databases were recorded every 1 hour during the day at the field work by means of an automatic weather data (http://www.accuweather.com), and used as an input to the computer excel model. Solar radiation, ambient air temperatures, relative humidity RH and wind speed were recorded every one hour. Evaporation were observed in situ daily using a scale ruler. Hourly evaporation was approximated by using penman equation explained above for each hour and proportioning the distribution of the daily total evaporation to the 24 h period.

TABLE 2: AVERAGE HOURLY AMBIENT AIR TEMPERATURE, MAXIMUM AMBIENT AIR TEMPERATURE AND MINIMUM AMBIENT AIR TEMPERATURE FOR THE THREE SCENARIOS.

Scenario	Date	Average ambient air temperature, °C	Maximum ambient air temperature, °C	Minimum ambient air temperature, °C
Two mirrors	12/7/2015	26.71	32	22
	13/7/2015	27.04	33	22
	14/7/2015	27.75	34	23
	15/7/2015	26.54	30	24
	16/7/2015	27.625	34	21
Without mirror	17/7/2015	27.54	34	22
One mirror	18/7/2015	27.623	32	24
	19/7/2015	27.875	33	23
	20/7/2015	27.54	33	23
	21/7/2015	27.875	33	22
	22/7/2015	28.21	35	23

C. Effect of the reflector mirrors on evaporation rate

To see the effect of the reflectors depending on their positions, simulations have been carried out in five different angles β. The angle between the horizontal axes and RHS reflector β_2 was kept at 35°, 38°,45°,50° and 55° using one reflector mirror.

When using two reflector mirrors, mirror 1 (LHS reflector) and mirror 2 (RHS reflector) make β1 and β2 angles with horizontal, respectively ,the angle between the horizontal axes and LHS reflector was kept at 35°, 38°, 45°, 50° and 55° and the same angles for RHS reflector.

To see the effect of the reflectors depending on their dimensions, the lengths of the reflector mirror we changed for different values and substituted in equations 5 and 6. The data in Table 3 and 4 indicated that evaporation rate did not change when dimensions of the reflector mirrors have changed.

TABLE 3: EFFECT OF REFLECTOR MIRROR DIMENSIONS ON EVAPORATION RATE USING ONE MIRROR

One mirror (RHS)									
Angle of mirror, β	Rs, MJ /m²/d	%RH	T, °C	U, Km/hr	Date	Evaporation rate (mm/d)			
						ḁ =1m	ḁ =2m	ḁ =4m	ḁ =6m
β2 =35°	10.47	68.83	28	10.17	18/07/15	3.34	3.34	3.34	3.34
	10.45	67.42	28	9.88	19/07/15	3.74	3.74	3.74	3.74
	10.44	68.38	28	9.46	20/07/15	3.69	3.69	3.69	3.69
	10.42	66.63	27.5	9.21	21/07/15	3.65	3.65	3.65	3.65
	10.40	67.46	29	9.13	22/07/15	4.59	4.59	4.59	4.59
β2 =38°	10.47	68.83	28	10.17	18/07/15	3.18	3.18	3.18	3.18
	10.45	67.42	28	9.88	19/07/15	3.55	3.55	3.55	3.55
	10.44	68.38	28	9.46	20/07/15	3.5	3.5	3.5	3.5
	10.42	66.63	27.5	9.21	21/07/15	3.46	3.46	3.46	3.46

	10.40	67.46	29	9.13	22/07/15	4.4	4.4	4.4	4.4
β2=45°	10.47	68.83	28	10.17	18/07/15	2.84	2.84	2.84	2.84
	10.45	67.42	28	9.88	19/07/15	3.15	3.15	3.15	3.15
	10.44	68.38	28	9.46	20/07/15	3.09	3.09	3.09	3.09
	10.42	66.63	27.5	9.21	21/07/15	3.05	3.05	3.05	3.05
	10.40	67.46	29	9.13	22/07/15	3.98	3.98	3.98	3.98
β2 =50°	10.47	68.83	28	10.17	18/07/15	2.63	2.63	2.63	2.63
	10.45	67.42	28	9.88	19/07/15	2.9	2.9	2.9	2.9
	10.44	68.38	28	9.46	20/07/15	2.84	2.84	2.84	2.84
	10.42	66.63	27.5	9.21	21/07/15	2.79	2.79	2.79	2.79
	10.40	67.46	29	9.13	22/07/15	3.73	3.73	3.73	3.73
β2 =55°	10.47	68.83	28	10.17	18/07/15	2.44	2.44	2.44	2.44
	10.45	67.42	28	9.88	19/07/15	2.68	2.68	2.68	2.68
	10.44	68.38	28	9.46	20/07/15	2.62	2.62	2.62	2.62
	10.42	66.63	27.5	9.21	21/07/15	2.56	2.56	2.56	2.56
	10.40	67.46	29	9.13	22/07/15	3.49	3.49	3.49	3.49

TABLE 4. EFFECT OF REFLECTOR MIRRORS DIMENSIONS ON EVAPORATION RATE USING TWO MIRRORS

Two mirrors (RHS and LHS)									
Angle of mirror, β	Rs, MJ /m²/d	%RH	T, °C	U, Km/hr	Date	Evaporation rate (mm/d)			
						ḁ =1m	ḁ =2m	ḁ =4m	ḁ =6m
β1=β2 =35°	10.57	61.42	27.00	9.63	12/07/15	4.59	4.59	4.59	4.59
	10.56	60.79	27.50	10.29	13/07/15	4.16	4.16	4.16	4.16
	10.54	65.04	28.50	10.08	14/07/15	3.95	3.95	3.95	3.95
	10.52	70.21	27.00	10.13	15/07/15	3.38	3.38	3.38	3.38
	10.51	65.92	27.50	9.38	16/07/15	3.83	3.82	3.82	3.82
β1=β2 =38°	10.57	61.42	27.00	9.63	12/07/15	4.65	4.65	4.65	4.65
	10.56	60.79	27.50	10.29	13/07/15	4.14	4.14	4.14	4.14
	10.54	65.04	28.50	10.08	14/07/15	3.93	3.93	3.93	3.93
	10.52	70.21	27.00	10.13	15/07/15	3.47	3.47	3.47	3.47
	10.51	65.92	27.50	9.38	16/07/15	3.77	3.77	3.77	3.77
β1=β2 =45°	10.57	61.42	27.00	9.63	12/07/15	4.6	4.6	4.6	4.6
	10.56	60.79	27.50	10.29	13/07/15	4.13	4.13	4.13	4.13
	10.54	65.04	28.50	10.08	14/07/15	3.88	3.88	3.88	3.88
	10.52	70.21	27.00	10.13	15/07/15	3.53	3.53	3.53	3.53
	10.51	65.92	27.50	9.38	16/07/15	3.49	3.49	3.49	3.49
β1=β2 =50°	10.57	61.42	27.00	9.63	12/07/15	4.63	4.63	4.63	4.63
	10.56	60.79	27.50	10.29	13/07/15	4.18	4.18	4.18	4.18
	10.54	65.04	28.50	10.08	14/07/15	3.76	3.76	3.76	3.76
	10.52	70.21	27.00	10.13	15/07/15	3.41	3.41	3.41	3.41
	10.51	65.92	27.50	9.38	16/07/15	3.15	3.15	3.15	3.15
β1=β2=55°	10.57	61.42	27.00	9.63	12/07/15	4.68	4.68	4.68	4.68

	10.56	60.79	27.50	10.29	13/07/15	4.26	4.26	4.26	4.26
	10.54	65.04	28.50	10.08	14/07/15	3.72	3.72	3.72	3.72
	10.52	70.21	27.00	10.13	15/07/15	3.19	3.19	3.19	3.19
	10.51	65.92	27.50	9.38	16/07/15	2.85	2.85	2.85	2.85

The concluded regression model equations of brine evaporation are shown as follows in Table 5 and 6:

TABLE 5. THE CONCLUDED REGRESSION EQUATIONS FOR BRINE EVAPORATION USING ONE MIRROR

One mirror						
Angle β	Parameters	Estimate	Standard error	R^2	Residuals	Intercept
β2 =35°	U	-1.13846	0	1	0	-179.607
	T	0.908896				
	%RH	-0.24522				
	Rs	17.76127				
	E(mm/d) = 17.76Rs-0.245(%RH)+0.91T-1.14U-179.607					
β2 =38°	U	-0.928	0	1	0	-139.775
	T	0.860304				
	%RH	-0.22247				
	Rs	13.71736				
	E(mm/d) = 13.72Rs-0.222(%RH)+0.86T-0.928U-139.775					
β2 =45°	U	-0.5127	0	1	0	-65.0362
	T	0.764461				
	%RH	-0.18134				
	Rs	6.128827				
	E(mm/d) = 6.13Rs-0.181(%RH)+0.764T-0.513U-65.0362					
β2 =50°	U	-0.27107	0	1	0	-21.1513
	T	0.715664				
	%RH	-0.15283				
	Rs	1.625545				
	E(mm/d) = 1.626Rs-0.153(%RH)+0.716T-0.27U-21.1513					
β2 =55°	U	-0.13858	0	1	0	0.755127
	T	0.679059				
	%RH	-0.13376				
	Rs	-0.64117				
	E(mm/d) = -0.641Rs-0.134(%RH)+0.679T-0.138U+0.75513					

TABLE 6. THE CONCLUDED REGRESSION EQUATIONS FOR BRINE EVAPORATION USING TWO MIRRORS

Two mirrors						
Angle β	Parameters	Estimate	Standard error	R^2	Residuals	Intercept
β1=β2 =35°	U	-0.51559	0	1	0	-115.236
	T	0.060771				
	%RH	-0.04607				
	Rs	11.91926				
	E(mm/d) = 11.92Rs-0.046(%RH)+0.061T-0.516U-115.236					
β1=β2 =38°	U	-0.5246	0	1	0	-150.069
	T	0.01953				
	%RH	-0.02496				
	Rs	15.21147				
	E(mm/d) = 15.21Rs-0.025(%RH)+0.019T-0.525U-150.069					
β1=β2 =45°	U	-0.32797	0	1	0	-201.731
	T	-0.01718				
	%RH	0.000645				
	Rs	19.8606				
	E(mm/d) = 19.86Rs+0.00064(%RH)-0.017T-0.328U-201.731					
β1=β2 =50°	U	-0.16342	0	1	0	-254.51
	T	-0.07504				
	%RH	0.000313				
	Rs	24.85698				
	E(mm/d) = 24.857Rs+0.00031(%RH)-0.075T-0.163U-254.51					
β1=β2 =55°	U	-0.06071	0	1	0	-305.506
	T	-0.05097				
	%RH	-0.01147				
	Rs	29.60008				
	E(mm/d) = 29.6Rs-0.01147(%RH)-0.051T-0.061U-305.506					

Where:
E = the evaporation rate expressed as mm/day,
R_s= the solar radiation (MJ $m^{-2}day^{-1}$),
RH = the relative humidity (%),
T = the ambient air temperature, °C,
U = Wind speed, Km/hr.

The previous models have shown the importance of the variables as the global solar radiation, relative humidity, ambient air temperature and wind speed. It assumed that secondary variables had been neglected, the coefficient of determination R^2 for the final models was 100% .

Tables 5 and 6 show that when solar radiation was 10.99 MJ/m^2/d, daily average humidity was 66% , average ambient air temperature was 28℃ and daily average wind speed was 9.5km/hr, the mirror's angle makes with horizontal was 55°, 50°,45°,38° and 35°, the evaporation rate resulted was 2.56mm, 4.1mm ,6.9mm, 11.62mm and 14.06mm respectively when using one mirror and 17.03 mm, 15mm, 12.98mm, 10.98mm and 9.5mm respectively when using two reflector mirrors. This is about 84.93%,72.72% ,46.81% and 30.7% improvement in the efficiency of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror when β was 55°,50° and 45° respectively. There is performance deficiency about 5.47% and 32.16% of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror when β was 38°,50° and 35° respectively (Tables 7 and 8). This means that reflectors play a vital role on the performance of solar ponds contributing to harvesting much more solar energy and increasing the energy harvesting area.

TABLE 7. THE INCREASED EFFICIENCY IN EVAPORATION RATE USING ONE MIRROR AND TWO MIRRORS AND COMPARING IT IN CASE OF WITHOUT USING ANY MIRROR

Evaporation rate (mm/day)			
Mirror Angle	One mirror	Two mirrors	The increased efficiency %
β = 35°	4	4.5	11.11
β = 38°	3	5	40
β = 45°	2.7	4	32.5
β = 50°	2.5	3.6	30.6
β = 55°	2.2	3	26.7
Evaporation rate (mm/day)			
Without mirror	One mirror		The increased efficiency %
2.5	4		37.5
	3		14.3
	2.7		7.4
Evaporation rate (mm/day)			
Without mirror	Two mirrors		The increased efficiency %
2.5	4.5		44.44
	5		50
	4		37.5
	3.6		30.6
	3		16.7

TABLE 8. REDUCTION PERCENTAGE IN SOLAR POND AREA USING ONE MIRROR AND TWO MIRRORS:

Evaporation rate (mm/day)			
Mirror Angle	One mirror	Two mirrors	Percent reduce in solar pond area %
β = 35°	4	4.5	88.89
β = 38°	3	5	60
β = 45°	2.7	4	67.5
β = 50°	2.5	3.6	69.4
β = 55°	2.2	3	73.3
Evaporation rate (mm/day)			
Without mirror	One mirror		Percent reduce in solar pond area %
2.5	4		62.5
	3		83.33
	2.7		92.6
Evaporation rate (mm/day)			
Without mirror	Two mirrors		Percent reduce in solar pond area %
2.5	4.5		55.6
	5		50
	4		62.5
	3.6		69.44
	3		83.33

V. Conclusions

In this article the brine characteristics were studied by using shallow solar pond SSP. The main input parameters for three different scenarios (solar pond without mirror, solar pond using one mirror and solar pond using two mirrors) where solar radiation, ambient air temperature, relative humidity and wind speed were used as variables. The method described herein cover one technique for evaporating brine is solar evaporation that does not require fuel but may take days or weeks to accomplish and is limited to geographic areas with high evaporation and little precipitation. At the end of the experiments the following important conclusions were drawn: Evaporation rate increases with decreasing the mirror's angle that makes with horizontal. Gradual increasing of evaporation rate with increasing solar radiation using two reflector mirrors. Reflectors play a vital role on the performance of solar ponds contributing to harvesting much more solar energy and increasing the energy harvesting area. Experimental and theoretical model results, obtained for the solar pond without a mirror, with one reflector mirror and with two reflector mirrors are in a good agreement with each other. Mirrors are very effective when they are used as reflectors and that the best performance of the pond can be achieved when the mirrors are employed as reflectors. Using one mirror and two mirrors reduced the solar pond area and hence reduced area needed for brine evaporation in Gaza strip desalination plants.

VI.References

[1] Mogheir Y. and Al Bohissi N., Optimal Management of Brine from Seawater Desalination Plants in Gaza Strip: Deir AL Balah STLV Plant as Case Study, Journal of Environmental Protection, 6, 2015, pp. 599-608.

[2] Truesdall J., Mickley M. and Hamilton R., Survey of membrane drinking water disposal methods, Desalination, 102, 1995, pp. 93–105.

[3] Koening L., R&D Progress Report No 20, Office of Saline Water, Washington, DC, 1958.

[4] "Palestinian Energy Authority." [Online]. Available: http://pea-pal.tripod.com/. [Accessed: 20-Jun-2013].

[5] Alaydi. D., The Solar Energy Potential of Gaza Strip, Glob. J. Res. …, vol. 11, no.7, 2011.

[6] Duffie, J. A. and Beckman W. A., Solar engineering of thermal processes, 3rd edn. , New Jersey: John Wiley & Sons, 2006.

[7] Garg, H., Advances in solar energy technology: collection and storage systems. V1, Dordrecht: D. Reidel Publishing Company, 1987.

[8] D'Amelio, L., Thermal machines for the conversion of solar energy into mechanical power' UN Conference on New Sources of Energy, Rome, 1961, pp.12.

[9] Brice, D., Saline water conversion' Advances in Chemistry Series, American Chemical Society, 38 , 1963, pp. 190-199 .

[10] Hodges,C. N. Thompson, T. L. Groh, J. E. and Frieling, D. H. 'Solar distillation utilizing multiple-effect humidification' Office of Saline Water Research and Development Progress, 1966. (Report No. 194).

.

[11] Dickinson W. C. and Cheremisin off, P., Solar energy technology handbook. New York: Marcel Dekker,1980, pp. 374.

[12] Solar Energy Laboratory at the Institute for Desert Research in Israel website, Solar Ponds. Available at: http://www2.technion.ac.il/~ises/papers/IsraelSectionISESfinal.pdf (Accessed: Jan. 2011)

[13] Kreider, J. F. and Kreith, F., Solar heating and Cooling Active and Passive Design. 2nd edn. London : Hemisphere,1982, pp. 284

[14] Ali, H., Mathematical modelling of salt gradient solar pond performance, Energy Research, 10(4), 1986, pp. 377-384.

[15] Sebaii, A., Thermal performance of a shallow solar-pond integrated with a baffle plate' Applied Energy, 81(1), 2005, pp. 81-33.

[16]Enersalt website Solar pond. Available at: http://www.enersalt.com.au/Local%20Publish/html/more_info.html (Accessed: Mar. 2011).

[17] Casamajor, A. B. and Parsons, R. E. 'Design Guide for Shallow Solar Ponds' Lawrence Livermore Laboratory, Livermore, California, 1979.(UCRL-52385Rev.1).

[18] Nalan C¸ . Bezir a, Orhan Do¨nmez b, Refik Kayali b,*, Nuri O¨ zek a, "Numerical and experimental analysis of a salt gradient solar pond performance with or without reflective covered surface, 2008".

[19] Kayali R, Bozdemir S, K±ymac K. A rectangular solar pond model incorporating empirical functions for air and soil temperatures. Sol Energy 1998;63: pp: 6–345.

[20] Kayali R. Derivation of analytic functions for air and soil temperatures and usage of these functions in a computer model developed for solar ponds. J Eng Environ Sci., 1993, pp17–65