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A Comparison of Solar Energy Gaining between Using Dead Sea Water and Normal Water in Evacuated Tube Collector

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Abstract – *The objective of this study is to investigate experimentally, the feasibility of utilizing the dead sea water, as the working fluid, in evacuated tube solar collector, and thermal storage tank. Two identical systems were designed and built, with indirect thermal storage tank. Eight thermocouples (k-type) were installed, to measure the instantaneous salt water and normal water temperatures, at the inlet and the outlets of the collectors, and the normal water load for the two systems, at inlet and outlet. A pyrometer was used, to measure the instantaneous solar intensity on both systems. The experiments were performed at various mass flow rates, of salt water and normal water. The duration of each experiment is about eight hours. The results show a very good repeatability, of the measured data under identical conditions. In addition, the results reveal that, the difference percentage between collector's load water gain (DIFF) was about 15 %, that the dead sea water collector, is greater than the normal water collector. In addition, the average overall efficiency of the Dead Sea water collector, is greater than the normal water by 10%.*

Key Words: Evacuated Tube Solar Collector, Solar Energy, Thermal System, Dead sea, Storage System.

Nomenclature

A Surface area of each solar collector, (2.652 m^2).

$C_{p,n}$ Specific heat of normal water, (4.181 KJ/kg k).

$C_{p,s}$ Specific heat of salted water, (2.795 KJ/kg k).

DIF Difference percentage between collector's load water gain %.

I Intensity of irradiation (W/m^2).

Q Volumetric flow rate (m^3/s).

$q_{c,n}$ Heat gained by normal water (J).

$q_{c,s}$ Heat gained by salt water (J).

Ts surrounding temperature.

NW normal water.

SW salted water.

LW load water.

T_s Surrounding temperature (°C).

T_1 LW outlet temperature for NW collector (°C).

T_2 NW collector inlet temperature (°C).

T_3 NW collector outlet temperature (°C).

T_4 LW outlet temperature for SW collector. (°C).

T_5 SW collector inlet temperature (°C).

T_6 SW collector outlet temperature (°C).

1. INTRODUCTION

Solar thermal energy is potentially promising energy source, as geothermal and wind energies, capable to meet the world electricity and heating demand. Most of the solar energy applications are, concerned with trapping sunlight as photovoltaic (PV) heat. Because of the low energy density of sunlight, the higher the temperature needed the more complicated, and expensive the system will be. Due to the high reliable solar irradiation in Jordan (5.5 KW h/m^2. D), a domestic usage for solar energy in Jordan has high potential, for about 300 sunny days per year, using solar collector [1].
The importance of this research comes from, the large demand of energy in Jordan, to cover the need of heat energy, for our daily life especially domestic purposes, and building heating systems. Fossil fuels are limited and expensive, but renewable energy, is cheaper and available, in the most days of the year, with yearly global radiation of 2080 kWh/m^2 (Berlin and Paris are about 1000 kWh/m^2, Dubai and Cairo are about 2000 kWh/m^2) [2].

The objective of this research is, to investigate the feasibility of utilizing the Dead Sea (DS) water, as the heat transfer fluid (HTF) and for thermal storage tank, in evacuated tube solar field, to improve solar water heating system performance. In order to achieve large amount of energy, not only for domestic purposes, but also for warming houses.

2. LITERATURE SURVEY

In a study, it was found that the working temperature range, for organics and thermal oils are (12-393) and (20– 400) °C, respectively. Molten salts have been the most widely studied HTF, due to their high working temperature and heat capacity, low vapor pressure and corrosive property, and good thermal and physical properties at elevated temperatures. Molten salts are used in almost all the thermal storage systems. Not only these molten salts can withstand high temperatures, and are suitable for thermal energy storage, and they are relatively cheaper compared to other types of HTFs, such as organics or thermal oils. Molten salts are the most promising HTF candidates at high temperature up to 800 °C [3].

In another study, it was found that, salt hydrates are attractive for heat storage purposes, in dwellings because they have a high volumetric storage density (350 MJ/m^3), and a relatively high thermal conductivity (0.5 W/m K), compared to organic PCMs. Also, salt hydrates are cheaper. Among the pairs of materials that have been listed, silica gel/water, magnesium sulfate/water, lithium bromide/water, lithium chloride/water, appear to be at the most advanced stage of research [4].

Various experiments were conducted in order to characterize the overall performance, of evacuated tube solar collectors, as used in the local Lebanese market. The results are in good agreement with similar results, published by manufacturers and independent testing authorities. The main conclusion, is that the heat-pipe collectors have a much better efficiency, than the water-in-glass collectors. Those later are however, more widely used locally owing, to their lowest initial cost and, their relatively short payback periods [5].

In an experimental study, it was found that, the temperature rise in the nano fluid is 19.0% higher than water at the exit of the collector. The maximum efficiency, of the system using 0.3% TiO_2 nano fluid is 0.73, and for distilled water it is 0.53. The efficiency of the system has increased by 16.67% compared to its base liquid. The greater the solar insolation, the higher the temperature difference achieved for the TiO_2 nano fluid. The ETSC system using a water based Al_2O_3 nano fluid is predicted to have an 8% higher efficiency, compared to the water based TiO_2 nano fluid [6].

The abundance of solar energy in Jordan, is evident from the annual daily average of global solar irradiance was explained, which ranges between 5 and 7 kWh/m^2 day on horizontal surfaces. This corresponds to a total annual value of 1600–2300 kWh/m^2 year. It was determined that the mean value of solar energy, in Amman city equals 5324 kW. h/m^2 day. As expected, Amman receives the most solar energy in June (mean value = 7995 kW. h/m^2), and July (mean value = 7875 kW. h/m^2), and the least in December (mean value = 2676 kW. h/m^2[7].

The use of solar thermal collector, as an input energy for cooling system was discussed. The experimental investigation was performed to characterize solar collectors, that have been integrated with an absorption chiller. The results showed that, in the maximum solar radiation, the outlet temperature that can be reached is about 78 °C, the utilized energy is about 70 KW and the solar collector has an efficiency of 64% [8].

In an experimental study, carried out for a comparison of the energy performance of flat plate collectors (FPCs) and evacuated tube collectors (ETCs), in domestic solar water heating systems located in different climate areas, in order to ascertain solar energy utilization. They concluded that, the maximum outlet temperature of the FPC, is higher than the ETC, most of the times. The evacuated tube collector performs better only in cold climate areas [8].

In a review study, a details investigation of evacuated tube solar collectors, having heat pipe and direct flow were carried out. All the design parameters which influence the collector performance, are investigated and discussed. More specifically, the tracking system, the collector design, the mass flow rate, the optical design, and the kind of working fluid, the main studied parameters. This work presents the future ideas that can be carried out, to improve the performance of evacuated tube solar collectors [9].

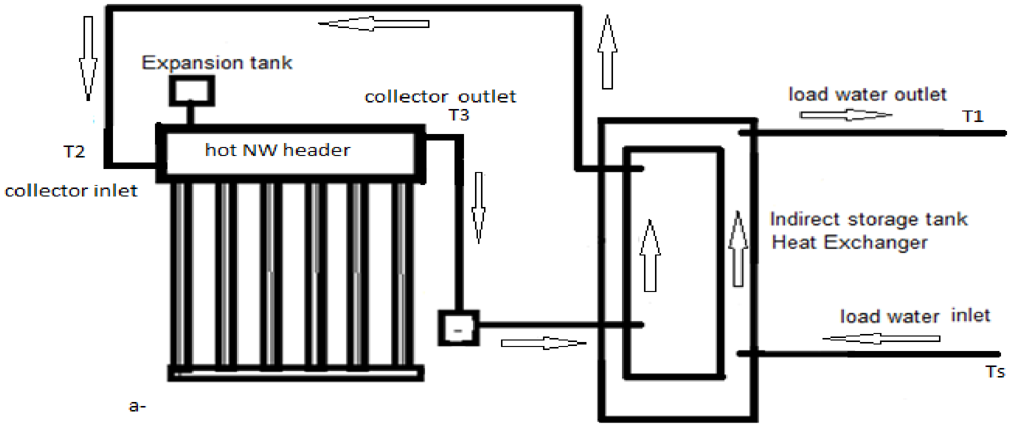
New molten salts, proposed to reduce the storage costs in CSP plants, highlighting the result obtained in the molten salt composed by 48% Ca $(NO_3)_2$, 7% $NaNO_3$, 45% KNO_3. Their use as storage material, has been evaluated in the projected Levelized **Cost** of Energy (LCOE), reducing considerably the storage cost and contributing to a promising future, for the development of solar technology [10].

All the previous research, dealt with the use of several fluids such as molten salts, sodium liquid, nano fluids and others to collect the largest amount of thermal energy resulting from the solar energy falling on the solar collectors to raise the efficiency of these collectors. This research address for the first time, the use of salty Dead Sea Water, and its impact on the efficiency of the evacuated solar collector.

The objectives of this paper are to raise the heat gain by the working fluid, by using Dead Sea mineral water (brine), which has a larger specific heat capacity, than normal water. In addition to raise thermal storage mass, for indirect storage tank, for house heating system. This paper address for the first time, the use of salty Dead Sea water and its impact, on the efficiency of the evacuated solar collector.

3. EXPERIMENTAL APPARATUS

Two identical systems were designed and built, with the same instrumentations, and indirect thermal storage system, are shown in fig. 3.1, and fig. 3.2. One using Dead Sea Water, while the other using normal water. Eight thermocouples were installed, to measure the instantaneous salt water, normal water temperatures at the inlet, and outlet of the collector, and the normal water load, for the two systems, at the inlet and at the outlet with two identical heat exchangers and two identical (five liters) expansion tanks. Electrical multimeter. Four identical flow meters. Six pin recorder, and a Pyrometer was used to measure the instantaneous solar intensity, incident on both systems.



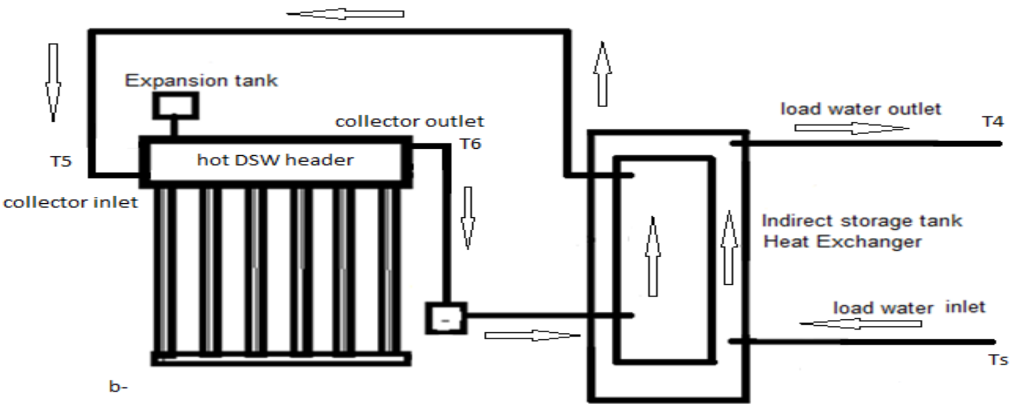


Fig. 3.1 Sketch of the (a) Normal Water and (b) Dead Sea Water collector, systems, respectively.

Fig. 3.2 Two identical evacuated tube solar water systems with indirect storage tank.

4. METHODOLGY

The two systems with the same instrumentations, operate at identical conditions, orientated 25 ° SE, collectors' slope of 37 °. The first set of experiment was repeated 5 times, to show the repeatability of the data collected in the experiments. The second set experiments are for checking the effect of varying the flow rates of the heat exchangers load water, on the heat gain of the collectors. The third experiments are for checking, the effect of changing the collectors flow rates, on the performance of the systems at constant load also on the heat gain.

5. Collectors Theory and Calculations

To study which of the two working fluids, is more efficient in transferring energy from the two identical solar water heaters, we need to study the outlet power absorbed, from the load water for each system, and compare these values between each other and relatively with the solar input power.

5.1 Overall solar radiation gain H (J) for test time interval is:

$H = \mathbf{G_{DSCC}} \times A \times$ (time interval).

5.2 Overall DSW collector load water (LW) heat gain (J) for test intervals is Q_{DSW}:

$Q_{DSW} = \dot{m}\, C_p \times (((T_{4b} + T_{4a})/2) - T_s)$ x (time interval)

Where Q_{DSW} is DSW heat gain for one-time interval

$QNW = (\Sigma\, \dot{m} \times cp \times (((T1b + T1a)/2) - Ts))$ x (time interval)

Where $\dot{m}$ = LW flow rate **kg**/s, C_p = specific heat of collector load water (4.181) kJ/kg. K. In addition, T_{4b}, T_{4a} are the final and initial temperatures respectively of the 20-minute interval of the heat exchanger LW outlet flow. T_s is the LW inlet temperature entering the heat exchanger.

5.3 Overall NW collector LW heat gain (J) for all test intervals is QNW:

$Q_{nw} = \dot{m} \times C_p \times (((T_{1b} + T_{1a})/2) - T_s)$ X (time interval)
where Q_{nw} is the NW heat gain for one-time interval

Where $\dot{m}$ = LW flow rate **kg**/s, C_p = specific heat of load water (4.182) kJ/kg. K, $(T_{1b} + T_{1a})/2$ = average temperature between two successive load water outlet temperatures of the heat exchanger.

System Efficiency:
$\boldsymbol{\eta} = \frac{Q}{H}$ collector efficiency

5.4 Difference percentage between collector's load water gain QDSW & QNW is DIFF:

$DIFF = ((Q_{DSW} - Q_{NW}) / Q_{NW})$ x 100%

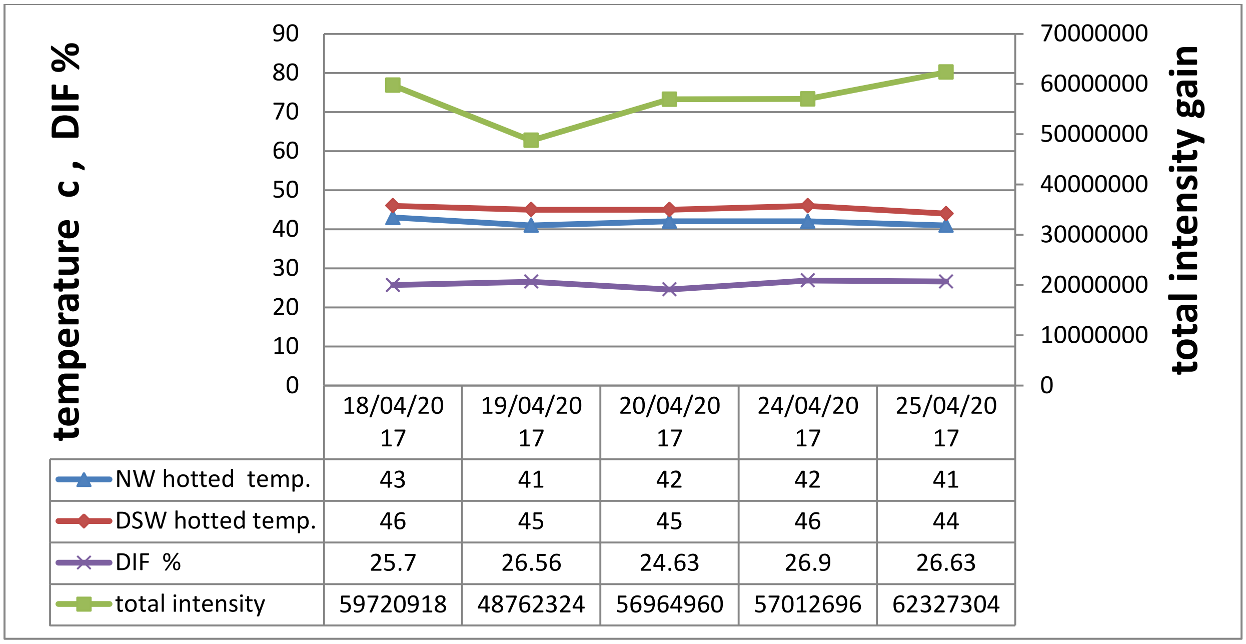
in another words:

$DIFF\% = (\eta_{DSW} - \eta_{NW}) / \eta_{NW}$

For checking the accuracy of the results, the same above equations can be used for calculating the heat rejected from the collectors, just in DSW system, replace C_p (4.181) kJ/kg. K for normal water by C_p (2.795) kJ/kg. k for DSW.

6. RESULTS AND DISSCUSSIONS

The first set of experiments was performed, in order to check the repeatability of the data collected, for the two systems, for several days, at the same operating conditions of flow rates of NW, SW collectors. The two flow meters are identical, and calibrated with normal water with a density of 1000 kg/m^3, 25 ^{0}C. The mass flow rate of DSW must be multiplied by the density ratio of DSW to NW (1.29:1). The results are shown in Fig. 6.1. The figure show that the variation of the NW temperature is about ± 4%. The variation of DSW is about ± 2%. The variation DIFF% is about ± 4%. This shows a very good repeatability of the collected data.



	18/04/2017	19/04/2017	20/04/2017	24/04/2017	25/04/2017
NW hotted temp.	43	41	42	42	41
DSW hotted temp.	46	45	45	46	44
DIF %	25.7	26.56	24.63	26.9	26.63
total intensity	59720918	48762324	56964960	57012696	62327304

Fig. 6.1 Repeatability tests for constant LW, NW and SW, at a flow rate of 3 L/min.

The second test, was performed to show load water temperatures and solar irradiance, as a fuction of day time. The results are shown in fig. 6.2. The figure shows, the variation the irradiance of solar energy on both systems. As expected, the irradiance increases as the time of the day passed, reaching maximum at 1:00 PM, then decreases with the lowest value at 4:40 PM. The temperatures; T_1, the load outlet temperatures for normal water collector, and T_4, the load water outlet temperature for Dead sea water, increase until meximum at 3:00 PM. Where T_3, the normal water outlet temperature, and T_6, the sea water outlet, increase with time, reaching maximum at 4:20 PM.

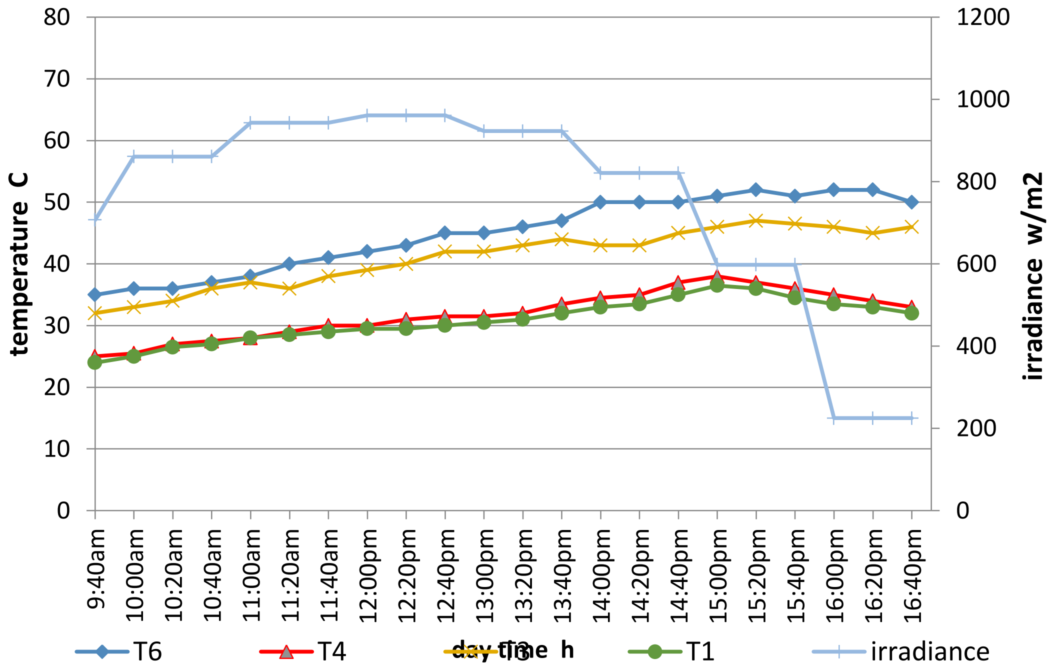
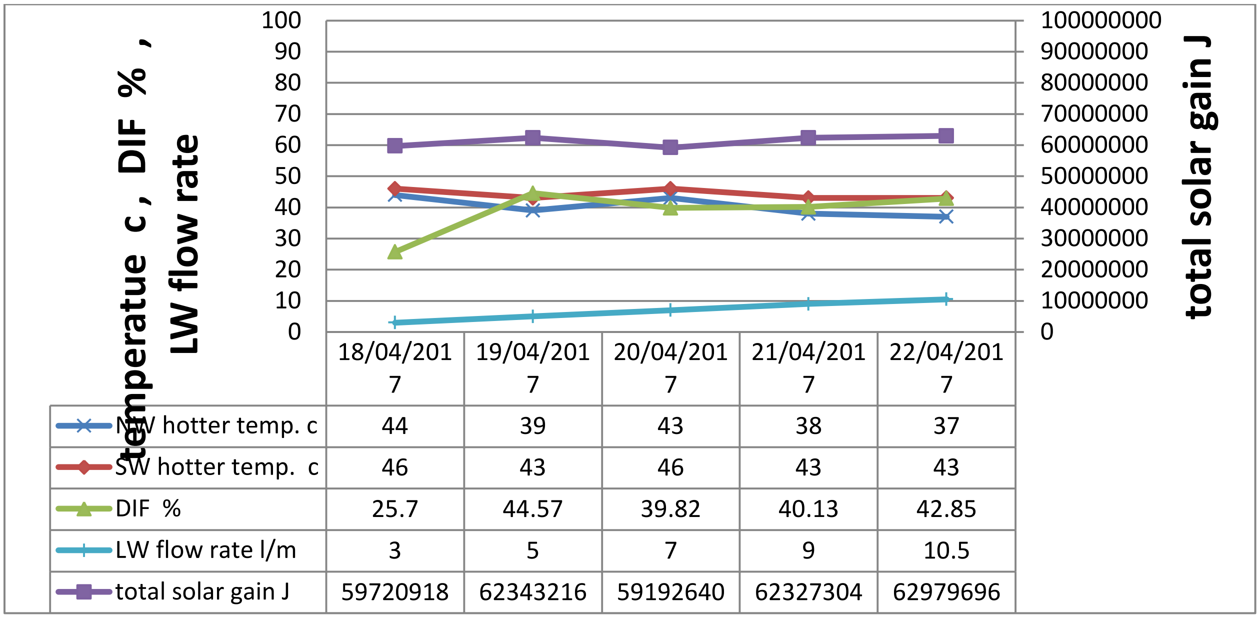


Fig. 6.2 Load water temperatures and solar irradiance versus day time for the two systems.

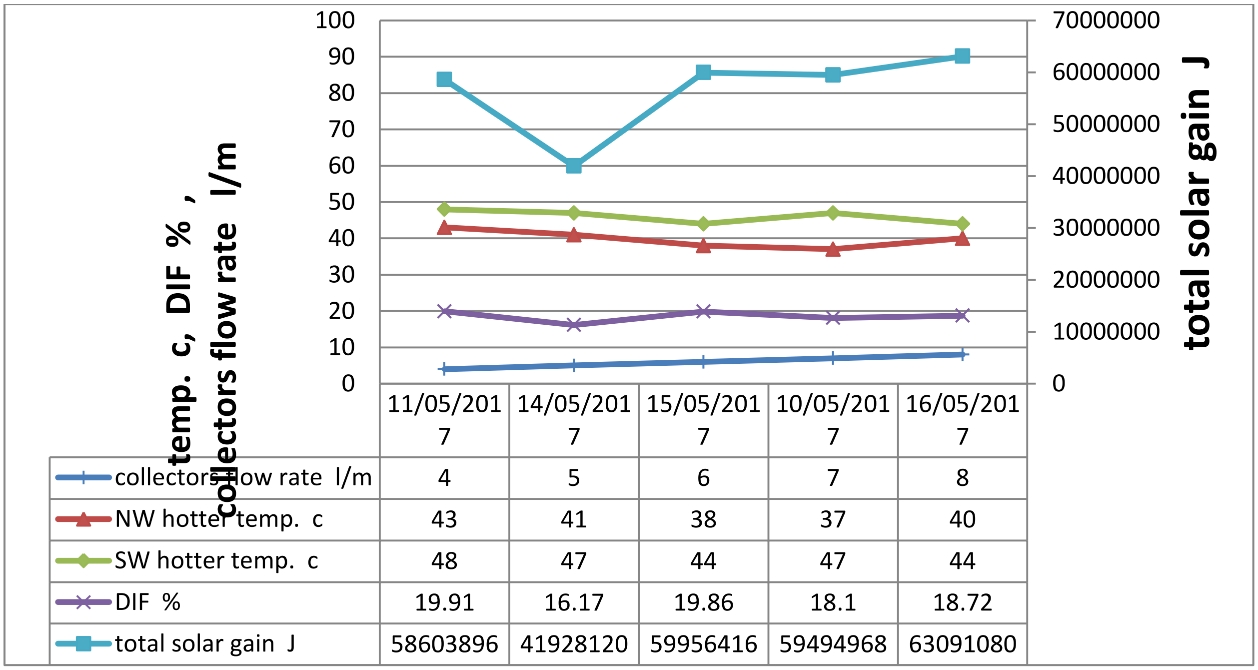
The third test was performed, to find the effect of varying the load water flow rate under a constant collector's flow rate of 9 L/min. on the DIF % and on the hottest collector's temperature as shown in Fig. 6.3. Results shows that the DIF % was about 42±2 %. The DSW gain is greater than the NW one for a LW flow rate equal or greater than 5 L/min. and about 25 % for LW flow rates less than 5 l/m. the DSW hottest collector temperatures are greater than the NW collector, for all the test days.



	18/04/2017	19/04/2017	20/04/2017	21/04/2017	22/04/2017
NW hotter temp. c	44	39	43	38	37
SW hotter temp. c	46	43	46	43	43
DIF %	25.7	44.57	39.82	40.13	42.85
LW flow rate l/m	3	5	7	9	10.5
total solar gain J	59720918	62343216	59192640	62327304	62979696

Fig. 6.3 LW flow rate variation at constant collector's flow rate of 9 L/min.

The fourth test illustrates the effect of varying the collectors flow rate, at constant LW flow rate of 6 L/min. on the collector's heat gain DIF, and on the hottest collectors' temperatures, for all the days of this test. Fig. 6.4 shows that for all collector's flow rates the DIF was about 18 ±2 % that the DSW gain was greater than NW one. DSW collector hot temperature during all test days was greater than the NW one for about 6.0 ±2 °C.



	11/05/2017	14/05/2017	15/05/2017	10/05/2017	16/05/2017
collectors flow rate l/m	4	5	6	7	8
NW hotter temp. c	43	41	38	37	40
SW hotter temp. c	48	47	44	47	44
DIF %	19.91	16.17	19.86	18.1	18.72
total solar gain J	58603896	41928120	59956416	59494968	63091080

Fig. 6.4 Collectors flow rate variation at constant LW flow of 6 L/min.

After twenty days of systems operation, with about eight hours a day (about 160 hour), evacuated tube inner surfaces, inside surface of the heat exchangers, and inner surfaces of fittings were checked for fouling precipitation and corrosion. There was no fouling inside the evacuated tubes for normal and Dead Sea water collectors, but for heat exchangers and fittings there were a very thin brittle layer of scale, just in the Dead Sea Water system without any corrosion appearance. In addition, there was no fouling or corrosion existence in heat exchanger surfaces or fittings of normal water system.

7. Uncertainty Analysis

The ΔT of the experiment results from measuring errors of the load water thermal power is calculated by Kline and McClinton method, which based on careful specifications, of the uncertainties in the various primary experimental measurements.

$$\delta E = \left[\sum_{j=1}^{M}\left(\frac{\partial R}{\partial X_j}\,\delta X_j\right)^2\right]^{1/2} \quad 7.1$$

Where j, M, δR and $\delta \boldsymbol{X_j}$ are the specific parameter counter, number of the independent variables M, uncertainties (Error) associated with the dependent E, and independent $\boldsymbol{X_j}$ respectively.
The LW thermal power gain Q for NW collector was calculated as:
$Q = m\,\mathbf{C_p}\,\Delta T$ 7.2
Where m, C_p, ΔT are LW flow rate, specific heat and temperature difference, respectively. The 12:40 pm trial of the first experiment was taken as an example,
$m = 0.05 \pm 6\ \%$kg/s, $C_p = 4.182$ kJ/kg. K and $\Delta T = 27\text{-}20 = 7 \pm 0.4\ \%$ K
The temperature reading recorded after passing through the thermocouple error Et, the recorder error Er and the multimeter error Em, respectively. Therefore, the uncertainty in temperature ET reading will be

ET = Et + Er + Em = 0.004+0.003 + .01 = 1.7 %
So
ΔT = T1 – T in = Tout – Tin

Therefore, error EΔT for ΔT is:

EΔT =ETout + ETin = (1.7 + 1.7) % = 3.4 %

Then the uncertainty δQ for Q can be determined by using equation 7.1

$$\frac{\partial Q}{\partial m} \times EM = C_p \times \Delta T \times EM = 4182 \times 7 \times 0.06 = 1756.4$$

$$\frac{\partial Q}{\partial T} \times ET = m \times C_p \times E\Delta T = 0.05 \times 4182 \times 0.034 = 7.1094$$

$$\delta Q = [(\mathbf{1756.44})^2 + (\mathbf{7.1094})^{\mathbf{2}}]^{\mathbf{1/2}} = 1756.5$$

The error percentage EQ is

$$\delta Q = \frac{1756.5}{1820920} = 9.64\times 10^{-4} = 0.0964\ \% \approx 0.01\ \%$$

The uncertainty value for calculating LW heat gain was found to be, 1756.5 J or 0.01 %. Therefore, research results were very acceptable.

8. RESULTS

The following conclusions can be drawn

1. The results reveal that, the DSW system gained energy of about 15±2 % (SIFF %), more than the NW system, and the DIFF % did not depend on the solar total gain or on the collector's orientation and ranged for all experiments from 13 to 17 % but it trends in general to increase as collectors and LW flow rates increase. In addition, the average hottest

collector's temperature differences were about 5 ±1 °C that the DSW collector was greater than the other one for all experiments.

2. The average hottest collector's temperature differences were about 5 ± ^{0}C, and the DSW collector was greater than the normal water for all the experiments.
3. The efficiency of the collector using salt water, was higher than the efficiency of the collector using normal water of about 10%.
4. There was little fouling layer appeared in the fittings, and the heat exchanger of the Dead Sea Water.

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