ENHANCING THE PERFORMANCE OF SOLAR STILL USING A SOLAR DISH CONCENTRATOR UNDER EGYPTION CONDITIONS

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ABSTRACT

The aims of the present experimental work is to improve the performance of solar still through increasing the freshwater productivity. In order to improve the freshwater productivity of solar still, a solar dish concentratorwas addedto increase the amount of solar radiation absorped by the absorber plate. Two solar stills were designed, constructed and tested in the present experimental study to compare the productivity of the solar desalination system. One of them is a solar still coupled with a solar dish concentratorand the other is the conventional solar still. The experimental results showed that the daily freshwater productivity for solar still coupled with a solar dish concentrator is higher than that of conventional solar still. The freshwater productivity reached approximately 4.25 L/m^2 day for the solar still coupled with a solar dish concentrator while its value was 2.78 L/m^2 day for the conventional solar still. The daily freshwater productivity for solar still coupled with a solar dish concentrator is 52.9 % higher than that of conventional solar still. The solar still coupled with a solar dish concentrator is superior in daily freshwater productivity (52.2% - 54% improvement) compared to the conventional solar still, during the period from November 2015 to January 2016 under Egyptian conditions.

Keywords: Solar desalination, Solar stills, Solar dish concentrator, Productivityenhancement.

1. INTRODUCTION

In the last 40 years, the problem of pure dranking water shortage has been one of the main challenges in the world for life on earth and developing countries. Although more than two thirds of the earth has been covered with water, but only about 0.014% of global water can be used directly for human and industrial purposes [1]. In addition,with an ever increasing population and rapid growth of industrialization, there is a great demand for pure dranking water, especially for drinking.One of the options used to obtain pure drinking water from sea water is to use solar desalination techniques. Solar stills represent a good option and a simple technique compared to the other distillation systems.

The main problem encountered the solar stills are the low freshwater productivity. Phadatare and Verma [2] studied the peformance of a solar still at different water depth. The results show that the freshwater productivity of the solar still decrease with the increase water depth in basin still. Tripathi and Tiwari [3] experimental studied the effect water depths in the basin still on the productivity for passive and active solar stills. They found that the convective heat transfer coefficient between the inner glass cover and basin water depends on the water depth. Rajamanickam and Ragupathy [4] studied the effect water depths on the productivity for a double slope and a single slope solar still. The results show that, the productivity of the still decrease with increase the depth of water. Abdul and Ahmad [5] experimental studied the impact of water depths on the freshwater productivity of still. The results show that, for increase the water depth from 1 to 10 cm the still productivity decreased by 48%.

Also the productivity of solar still depends on the temperature difference between basin water and glass cover. The still with double glasses [6,7], triple basin still [8] and regenerative still [9] are used to increase the productivity of the still by increasing the difference in temperature between the basin water and glass cover.

The free surface area of the basin water effect on the water evaporation rate. Bassam et al. [10] use the sponge cubes in the basin water to increment the free area of the saline water. The results show that, the freshwater productivity increase for using sponge cubes in the basin water. Velmurugan et al. [11-13] found that in using the sponges in a conventional still and stepped still, the productivity of freshwater increased by 15.3 %.

The evaporation rate in the solar still depend only the amount of the energy input solar still, but in the active solar still by additional some external sources such as solar water heater [14-17], parabolic trough concentrators [18], a flat plate reflector [19], solar collectors and storage tank [20, 21] and pump [22]. These studies showed that, the daily freshwater productivity increases with an increase the thermal energy in the basin still.

Due to the low freshwater productivity of the solar stills, this study aims to improve the productivity of the solar stills by using the solar dish concentrator. The effect of a solar dish concentrator on the performance of solar still coupled with a solar dish concentrator have been experimentally investigated, and the study results is compared with conventional solar still, to evaluate the development in the freshwater productivity for using a solar dish concentrator,in the Faculty of Engineering-Tanta University, Egypt in the period from November 2015 to January 2016.

2. EXPRIMENTAL SETUP

The present experimental workwas designed and fabricated in the Faculty of Engineering-Tanta University, Egypt (Latitude 30.47^{o}N and longitude 31^{o}E) in the period from November 2015 to January 2016. In the present work, two solar stills were designed, fabricated and constructed to compare the freshwater productivity by using the solar desalination technique. One of stills is the solar still coupled solar dish concentrator and the other is the conventional solar still as shown in Figs. 1 and 2.

Figure. 1 shows a schematic diagram of the stills is the solar still coupled solar dish concentrator and the conventional solar still. In addition, Fig. 2 shows a photo of the solar still coupled solar dish concentrator and the conventional solar still.

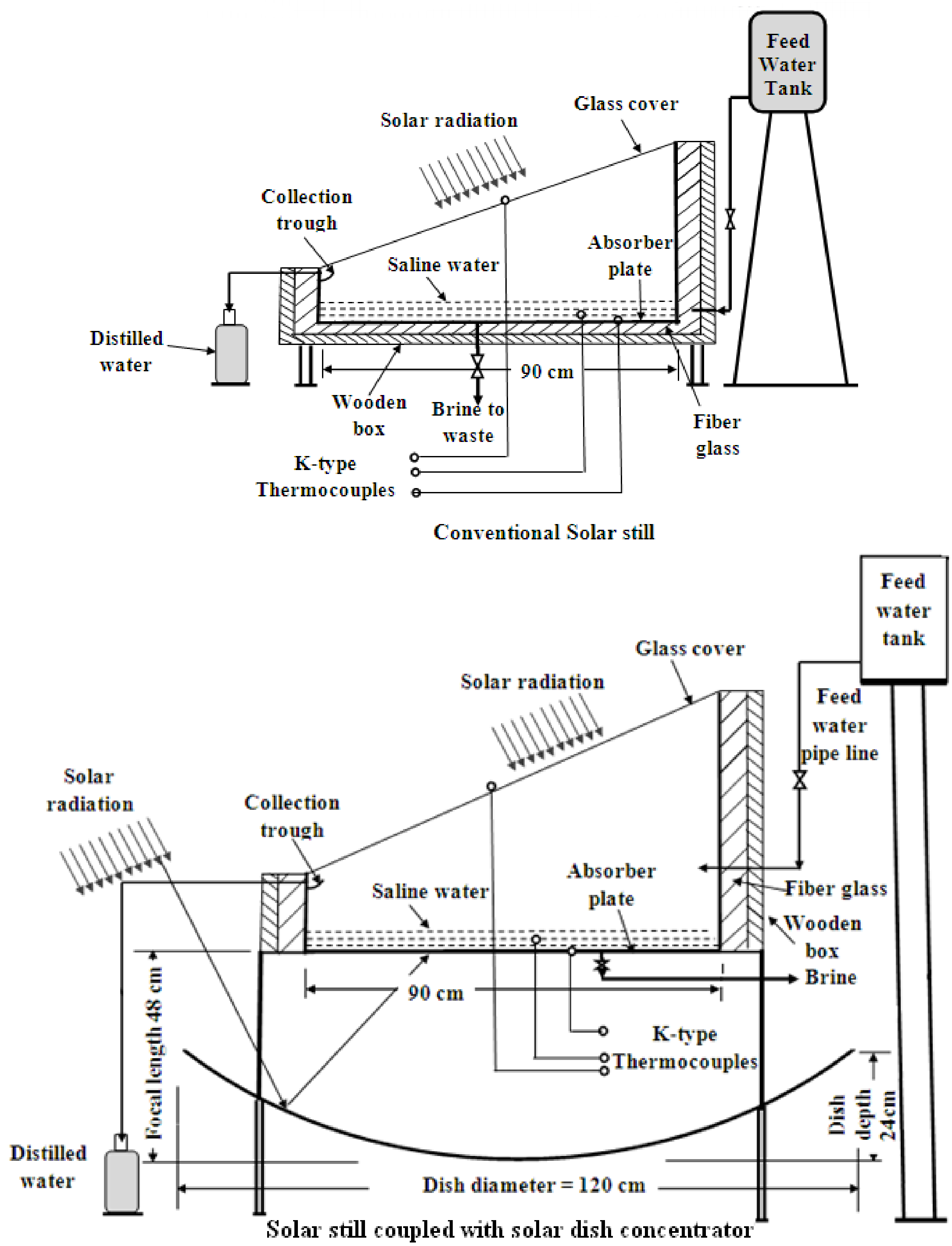

Fig. 1 A schematic diagram of the stills is the solar still coupled solar dish concentrator and the conventional solar still

Fig. 2 A photo of the solar still coupled with a solar dish concentrator and the conventional solar still

The conventional solar still was made of galvanized sheet with 1.5 mm thick and has a basin area of 0.81 m^2 (0.9 m × 0.9 m). The basin still is coated with black paint to increase the absorptivity of solar radiation. The height of high-side and the low-side walls of the basin are 65 cm and 20 cm, respectively. The single slope basin was covered with glass sheet of 3 mm thick inclined at nearly 30.47^o horizontally, which is the latitude of Tanta City, Egypt. Also, the basin of the conventional solar still is insulated through the side and the bottom with low thermal conductivity 5 cm fiber glass insulation to reduce the loss in heat energy from the conventional solar still to the ambient. The condensed water was collected trough the lower end side of the glass cover. The silicon is used as a bonding material to prevent any leakage between the basin box and the glass cover.The feed water tank is placed 1 m above the still to feed the saline water to the still basin. The feed water tank is connected to basin still by water pipe line. A check valve is integrated at the pipe line entrance to regulate the saline water flow rate.

The solar still coupled solar dish concentrator consists of single slope basin solar still and the solar dish concentrator. The single slope basin solar still wasmadeof galvanized sheetwith0.0015 mthickandhas a basin area of 0.81 m^2 (0.9 m × 0.9 m). The height of low-side and high-side walls of the basin is 20cm and 65 cm, respectively. The basin still is coated with black paint from inside and outside to increase the absorptivity of solar radiation. The single slope basin was covered with glass sheet of 3 mm thick inclined at nearly 30.47^o horizontally, which is the latitude of Tanta City, Egypt. Also, the side walls of the single slope basin solar still are insulated with low thermal conductivity 5 cm fiber glass to reduce the loss in heat energy from the side walls to the ambient. The silicon is used as a bonding material to prevent any leakage between the basin box and the glass cover.The feed water tank is connected to basin still by water pipe line. A check valve is integrated at the pipe line entrance to regulate the saline water flow rate.
The parabolic solar dish concentrator system used to collect energy from the sun. The solar dish concentrator made fromgalvanized sheet with 0.5 mm thick with 120 cm in dish aperture diameter, the dish depth 24 cm and the focal length 48 cm. The dish surface was covered with highly reflective glass mirror strips of 4 mm thickness. In this experimental work, a newly adapted single slope basin solar still was designed and mounted at the concentrator focus. The receiver (single slope basin solar still) is optimized to be just large enough to admit most of the concentrated sun-light but small enough to limit radiation and convection losses.

3. EXPERIMENTAL PROCEDURE

The experimental work were designed and constructed in Faculty of Engineering-Tanta University, Egypt.The experiments were carried out from 8:00 am to 5:00 pm during the period from November 2015 to January 2016. For the solar still coupled solar dish concentrator, the dish-shaped concentrator reflects and concentrates incoming direct normal insolation to a receiver and distilled water temperature. The measurements are taken each hour. The collected freshwater productivity is also measured each hour. For both solar still coupled solar dish concentrat(single slope basin solar still) located at the focal point of the dish. Inside the single slope basin solar still, the basin water is vaporized by the intense heat created by the concentrated sunlight on the bottom and by the intensity solar radiation absorbed in absorber plate from top. The following parameters are measured during the experiments, the intensity solar radiation, ambient temperature, glass cover temperature, saline water temperature, absorber plate temperature or and conventional solar still, the depth of the saline water remains constant at 2 cm during the experiments. All experimental measurements are aimed to evaluate the performance of both stills under the atmospheric conditions of Tanta City- Egypt. The experiments show the effect of a solar dish concentrator on the fresh water productivity of the solar stills.

4. ERROR ANALYSIS

During the experiments, several parameters were measured in order to evaluate the system performance. The ambient temperature, glass cover temperature, saline water temperature and absorber plate temperature were measured by K-type thermocouples which integrated with a PLC. Total solar radiation was measured on the same level of still glass cover bya solarimeter. Wind speed was measured by a vane anemometer. The amount of freshwater productivity measured by a calibrated flask. The accuracy, range and errors that occurred in measuring instruments are shown in Table 1. The errors are calculated for solarimeter, thermocouples, vane anemometer and calibrated flask. To estimate the uncertainties in the results presented in this work, the approach described by Barford [23] is applied. The uncertainty in the measurements is defined as the root sum square of the fixed error of the instrumentation and the random error observed during different measurements. Accordingly, the resulting errors of the calculated amount of daily productivity is ±0.6%.

Table 1 Experimental uncertainty errors

Device	Accuracy	Range	Error
Solarimeter	± 1 W/m^2	0 – 5000 W/m^2	0.153 %
Thermocouples	± 1 ^oC	-200: 1250 ^oC	1.78 %
Vane anemometer	± 0.1 m/s	0.4 – 30 m/s	3.57 %
Calibrated flask	± 5 ml	0 – 2000 ml	1.176 %

5. RESULTS AND DISCUSSION

Depending on the state of the climate conditions the intensity of the solar radiation varied from 190 to 845 W/m^2 and the wind velocity varied from 0.8 to 6.4 m/s. The performance of the solar still coupled with a solar dish concentrator and the conventional solar still are tested at the same basin water depth of 2 cm and under the same ambient conditions.

The performance of the solar still, mainly depends on the intensity of solar radiation absorbed by the absorber plate. From the Figs. 3 and Fig. 4 , it is observed that both solar radiation intensity and ambient temperature increases to the maximum value at the midday and decrease after that gradually.Also, Figs. 3

and Fig. 4 show the variation of basin water temperature and the glass temperature according to time for the solar still coupled with a solar dish concentratorand the variation of basin water temperature and glass temperature according to time for the conventional solar still. Fig. 3 shows that, for the solar still coupled with a solar dish concentrator, the maximum basin water temperature about 71^{o}C, while the glass temperature in the range of 30 – 39^{o}C. On the other hand, for the conventional solar still the maximum basin water temperature about 55^{o}C, while the glass temperature in the range of 29 – 36^{o}C. Also, Fig. 4 shows that, for the solar still coupled with a solar dish concentrator, the maximum basin water temperature about 70^{o}C, while the glass temperature in the range of 30 – 38^{o}C. On the other hand, for the conventional solar still the maximum basin water temperature about 53^{o}C, while the glass temperature were in the range of 28 – 35^{o}C. The previous results indicate that,the temperatures of measured points are gradually increased until they reach their maximum values at 1:00 pm and decrease after that gradually. This mainly because the intensity of solar radiation increases in the morning and its decreses in the afternon.

The basin water temperature of the solar still coupled with a solar dish concentratoris higher than that of the conventional solar still by about 6-16^{o}C, this mainly because that, the solar dish concentratorincrease the amount of the solar energy absorbed by the absorber plate.

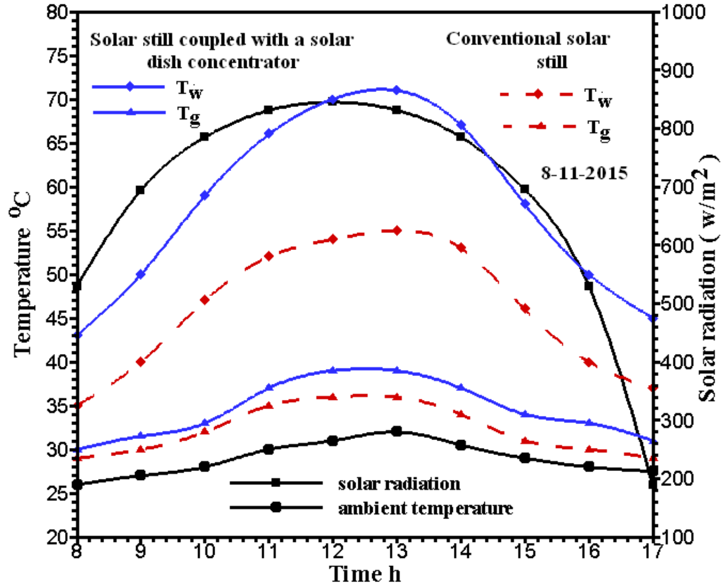

Fig. 3.Hourly solar radiation and temperature variations for the solar still coupled with a solar dish concentrator and conventional solar still, 8-11-2015.

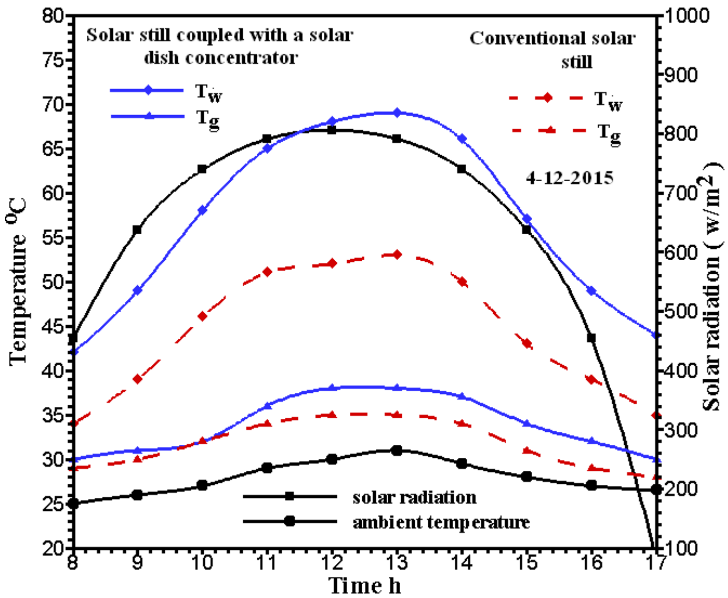

Fig. 4.Hourly solar radiation and temperature variations for the solar still coupled with a solar dish concentrator and conventional solar still, 4-12-2015.

Comparisons between the hourly productivity for both solar still coupled with a solar dish concentratorand conventional solar still during the period from 8:00 am to 5:00 pm are shown in Figs. 5 and Fig. 6. This figure show that, the hourly productivity increases from zero value in 8:00 am to the maximum values in 1:00 pm. The increase in the hourly productivity due to the increase of water evaporation rate and condensation rate. The rate of condensation depend on the difference in temperatures between the outer glass cover and the basin water. The hourly productivity in the solar still coupled with a solar dish concentratoris higher than that of the conventional solar still, because of the higher basin water temperature. For the solar still coupled with a solar dish concentrator the solar dish concentrator increase the amount of the solar energy absorbed by the absorber plate Also, Fig. 5 shows the freshwater productivity in 8-11-2015. The productivities of the two stills were arround 0.0 at 8:00 am, while their value recorded 0.76 L/m^2. hour and 0.58 L/m^2. hour as a maximum freshwater productivity at 1:00 pm for solar still coupled with a solar dish concentrator and conventional solar still, respectively. Fig. 6 shows the freshwater productivity in 4-12-2015. The productivities of the two stills were arround 0.0 at 8:00 am, while their value recorded 0.74 L/m^2. hour and 0.56 L/m^2. hour as a maximum freshwater productivity at 1:00 pm for solar still coupled with a solar dish concentrator and conventional solar still, respectively.

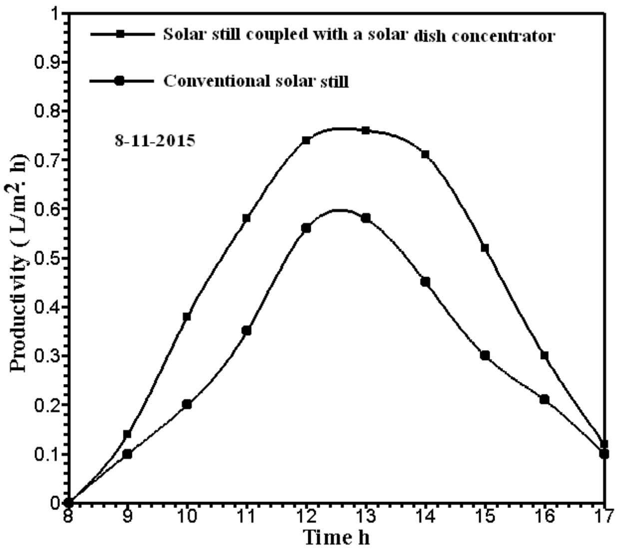

Fig. 5 Variation of hourly productivity for solar still coupled with a solar dish concentratorand conventional solar still, 8-11-2015

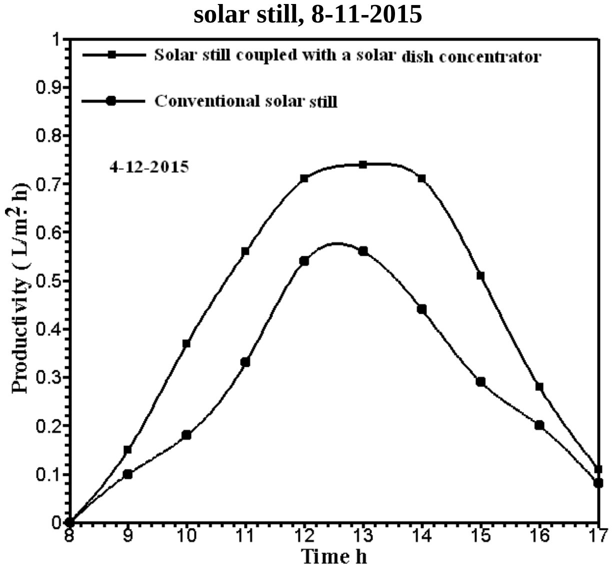

Fig. 6 Variation of hourly productivity for solar still coupled with a solar dish concentratorand conventional solar still, 4-12-2015

Figure 7 and Fig. 8 show a comparison between the accumulated freshwater productivity for the solar still coupled with a solar dish concentratorand the conventional solar still. The results of this figure show that the accumulated freshwater productivity for solar still coupled with a solar dish concentratoris higher than that of conventional solar still along the day. As shown previously in Fig. 7 the accumulated freshwater productivity up to almost 4.25 L/m^2 day for the solar still coupled with a solar dish concentratorwhile its value was 2.78 L/m^2 day for the conventional solar still. The increase in accumulated freshwater productivity for still coupled with a solar dish concentratoris 52.9% higher than that of conventional solar still. Also, Fig. 8 shows that, the accumulated freshwater productivity up to almost 4.19 L/m^2 day for the solar still coupled with a solar dish concentratorwhile its value was 2.72 L/m^2 day for the conventional solar still. The increase in accumulated freshwater productivity for solar still coupled with a solar dish concentratoris 54 % higher than that of conventional solar still.

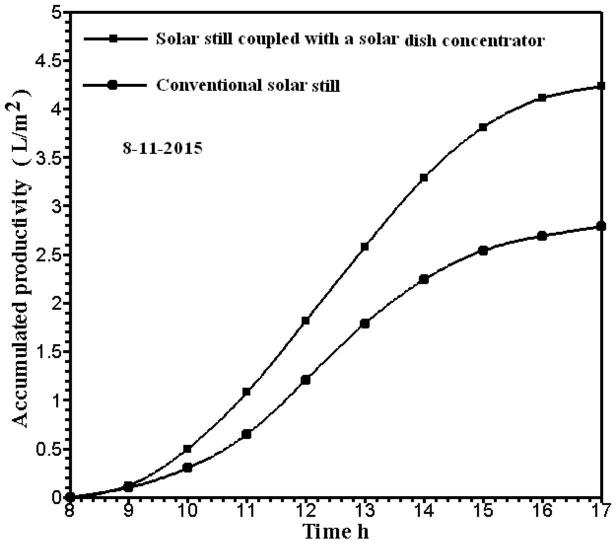

Fig. 7.The accumulated freshwater productivity for solar still coupled with a solar dish concentrator and conventional solar still, 8-11-2015

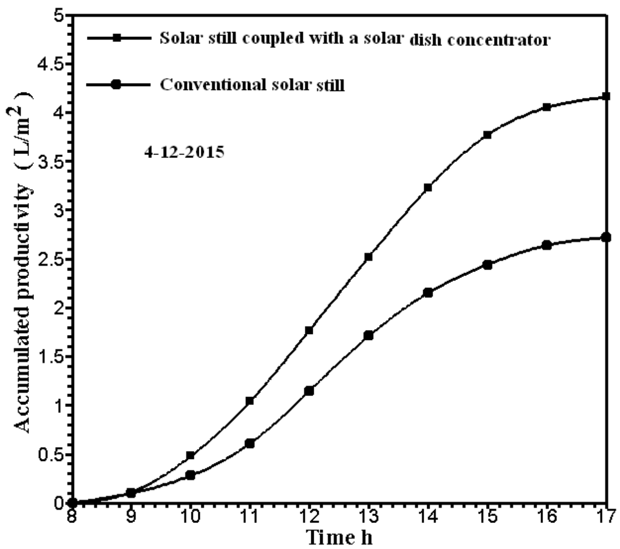

Fig. 8.The accumulated freshwater productivity for solar still coupled with a solar dish concentrator and conventional solar still, 4-12-2015

Table 2 shows the daily freshwater productivity for the solar still coupled with a solar dish concentrator and conventional solar still, the precentage increase in daily freshwater productivity. From Table 2, the daily freshwater productivity reaches4.25 and 2.78 L/m^2 day for solar still coupled with a solar dish concentrator and conventional solar still, respectively. The percentage increases in daily freshwater productivity for the solar still coupled with a solar dish concentrator was in the range 52.2 % - 54 % compared to the conventional solar still, this change due to the change in the ambient conditions.

Table 2 Daily freshwater productivity and daily productivity rise

Date	Daily productivity (L/m^2)		Daily productivity rise (%)
	Conventional solar still	Solar still coupled solar dish concentrator	
8-11-2015	2.78	4.25	52.9
15-11-2015	2.75	4.22	53.4
25-11-2015	2.76	4.2	52.2
4-12-2015	2.72	4.19	54
20-12-2015	2.73	4.18	53.1
5-1-2016	2.78	4.24	52.5

6. CONCLUSIONS

In this work, the effect of a solar dish concentrator on the performance of solar still coupled with a solar dish concentratorwas experimentally investigated under the ambient conditions of Tanta city (Egypt). The rise in the basin water temperature for the solar still coupled with a solar dish concentratoris due to the high amount of the solar radiation intensity absorbed by the absorber surface.The experimental results showed that the daily freshwater productivity for solar still coupled with a solar dish concentratoris higher than that of conventional solar still. The freshwater productivity reached approximately 4.25 L/m^2 day for the solar still coupled with a solar dish concentrator while its value was 2.78 L/m^2 day for the conventional solar still. The daily freshwater productivity for solar still coupled with a solar dish concentrator is 52.9 % higher than that of conventional solar still. The solar still coupled with a solar dish concentratoris superior in daily freshwater productivity (52.2% - 54% improvement) compared to the conventional solar still, during the period from November 2015 to January 2016 under Egyptian conditions.

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