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An Experimental Study of Performance of Water Stirring Solar Still

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ABSTRACT

This paper presents an experimental study of performance of water stirring solar still. The Conventional Solar Still (CSS) has been modified, developed and tested to enhance the performance by using water stirring method. This modification was performed by fixing a mechanical wiper on the bottom of still basin. The experimental results on the modified solar still were analyzed and compared with that of conventional solar still (CSS) that has the same basin area, dimensions, water depth and operating conditions. Results showed that, the accumulated productivity from the water stirring solar still (WSSS) ranges from 3.27 to 3.82 L/m^2 per day at water depth of 2 cm. The corresponding values for (CSS) range from 3.0 to 3.5 L/m^2 per day. The increasing in productivity for WSSS is about 9.14 % more than that of the CSS.
Keywords: Solar energy; Desalination; Solar still; Performance.

1. INTRODUCTION

The need of fresh water is becoming an increasingly important issue in many areas of the world. The shortage of fresh water is the most important problem in the developing countries; therefore, the need for water desalination becomes very important process to save fresh water for peoples. The use of conventional energy sources in water desalination consumes fuel in large quantities causing high pollution rates. However, attention has been given to the use of renewable energy such as solar energy as a source of energy for desalination, especially in remote areas and islands.

The performance of solar stills depends on a number of different parameters such as wind speed, solar intensity, the height of water inside the still and the absorbing surface area. Many of researchers used the theoretical and experimental methods to study the performance of solar still. Among of these experimental studies that conducted by Al-Karaghouli, A. et al., [1].Two solar stills (single basin and double basin) were manufactured and tested experimentally. The results showed that, the monthly average of daily distillate production of the double-basin still is higher than the average distillate production of the single-basin still. El-Sebaii, A. [2] studied theoretically the effect of wind speed on the daily productivity of some designs of basin type and vertical solar still. The results showed that, the daily productivity increases with increasing the wind speed up to a typical velocity beyond which the increase in the daily productivity becomes in significant. Tanaka, H. [3] represented a theoretical analysis of basin type solar still with flat plate external reflector and internal reflectors. The results indicated that, the daily amount of distillate of the still with internal and external bottom reflector is predicted to be 41 % and 62 % greater than that of a conventional basin type still.

The modeling and performance analysis of a single-basin solar still with the entering brine flowing between a double-glass glazing was discussed by Abu-Arabi, M. et al. [4]. The results indicated that, the solar still productivity increased when flowing cooling water between the double-glass cover. Zurigat, Y. et al. [5] evaluated and modeled a regenerative solar desalination unit. The performances of the regenerative and the conventional still were compared with each other under the same weather conditions. The concluded results approved that, the productivity of the regenerative still is 20 % higher compared to the conventional still. The wind speed has a significant effect on the productivity of the stills. Sponges were used by Bassam, A. et al. [6]. Experiments were carried out with various sizes of the sponge cubes, sponge to basin water volume ratio and water depth. It was found that the increase in distillate production of the still ranged from 18% to 73% compared to an identical still without sponge cubes under the same conditions. Kabeel, A. [7] used a concave wick surface for evaporation of a pyramid shaped still was used for condensation. Results showed that average distillate productivity in day time was 4.1 L/m^2; maximum instantaneous system efficiency of 45% and average daily efficiency of 30% were recorded. The maximum hourly yield was 0.5 L/h.m^2 after solar noon.

Tiwari, A. et al. [8] studied the effect of water depth on heat and mass transfer in a passive solar still in summer climatic conditions. In addition, the

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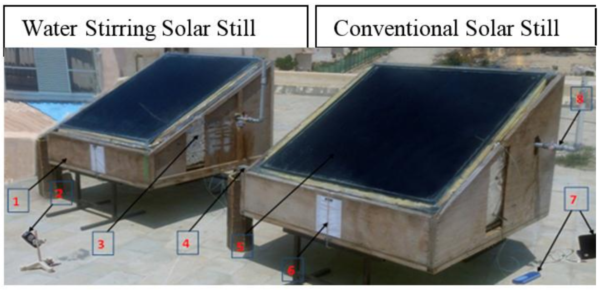
performance analyses for six different water depths in a single slope passive solar still of cover inclination of 30° were studied. Increasing the water depth decreases the yield of the still up to depths of about 0.1 m but greater depths over this have negligible effect on the yield. Sadineni, S. et al. [9] studied theoretically and experimentally the performance of a weir-type inclined solar still. The average distillate productivities for double and single pane glass covers are approximately 2.2 and 5.5 L/m^2/day in the months of August and September in Las Vegas, respectively. The transient performance of an active single basin solar still integrated with a thin layer of sand as a storage material was studied by El-Sebaii, A. et al. [10]. The results showed that, an estimation of daily productivity of 4.005 L/m2/day with an average daily efficiency of 37.8 % has been acquired using 10 kg of sand compared to 2.852 L/m2/day with average daily efficiency of 27% when the still utilized without sand. A single-slope single-basin solar still integrated with a shallow solar pond was studied by El-Sebaii, A. et al. [11]. The results showed that, the annual average values of the daily productivity and efficiency of the still with shallow solar pond were found to be higher than those obtained without the solar pond by 52.36% and 43.80%, respectively. Corrugated wick type solar still and simple basin solar still type were manufactured and tested to compare the enhancement of the corrugated wick type still with the simple still by Matrawy, K. et al. [12]. An improvement of around 34% was recorded in the productivity for the proposed wick type solar still when compared with the simple basin solar still case.

The theoretical and experimental performance of an inclined solar still with and without baffles were investigated by Nagarajan, P. et al. [13]. The yields were 5.4 kg/m2.day ± 3.6% for still with baffles and 3.4 kg/m2.day ± 3% for still without baffles in April month with total daily intensity of 8.125 kWh/m^2. The yield of solar still is enhanced by 1.68 times the solar still without baffles. Single slope solar still has been modified by Guptaa, B. et al. [14]. The modifications in conventional single slope solar still include inside walls painted with white colour and attachment of water sprinkler with constant water flow rate of 0.0001 kg/s on the glass cover. Water productivity of single slope solar still increased by 20% and the overall efficiency increased by 21% over the conventional solar still. The thermal performance of a finned single basin solar still was investigated experimentally and theoretically by El-Sebaii, A. et al. [15]. The results indicated that the price of 1 L of fresh water equals 0.28 and 0.31 LE for the still with and without copper fins. For finned basin liner made of glass and mica, it was found that the price of 1 L of fresh water was found to be 0.21 and 0.20 LE, respectively. Dimri, V. et al. [16] studied the effect of condensing cover material on yield of an active solar still. Higher yield was observed for an active solar distillation system as compared to the passive mode. From the previous review, most of researchers focused on improving the performance of solar stills using different methods such as increasing the surface area of the heat transfer, using solar concentrators or other methods. Increasing the evaporation from the basin will increase the productivity of the still. Therefore, the main objective of the present work is to study the performance of the solar still using water stirring system. Designing and manufacturing two solar stills with the same dimensions were performed. The first one is a conventional solar still and the other contains mechanical wiper to stir the water inside the solar still. The various parameters such as the irradiance, water temperature, space temperature, glass temperature, accumulated water quantity and climatic parameters (wind velocity and ambient temperatures) were recorded throughout the experimental work.

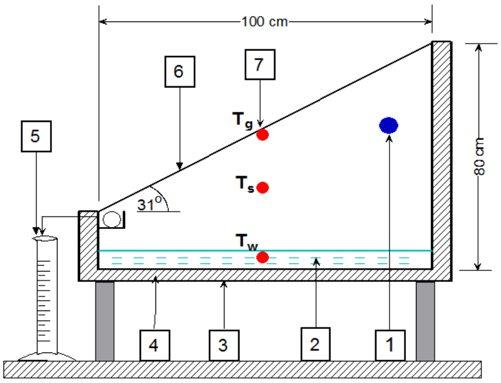
2. EXPERIMENTAL SETUP

The experimental setup of the solar stills was designed, installed and tested in Energy Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Sinai University, Al-Arish city-Egypt. The layout of the experimental setup is shown in Fig. 1. The first still is a conventional solar still (CSS). The second still named, water stirring solar still (WSSS), the design modification is accomplished by using mechanical wiper. The stills are made of steel sheets with thickness of 2 mm and mounted on a wood frame. The sides and the base of solar still are painted black to increase the solar absorptivity. The two stills have the same basin area (A = 1 m2), the same inclination angle of transparent cover and insulation material. Figure 1 show calibrated glass tubes fixed in front wall of solar stills to adjust the water level. Three thermocouple sensors are connected in each solar still to measure the water (Tw), space (Ts) and glass (Tg) temperatures. The temperature sensors are connected with data logger to record the temperatures every 15 minutes as a time interval from 9.00 AM to 5.00 PM. The wiper worked by small 12V DC motor. The work theory of the mechanical wiper is the as the washing wiper fixed on the glass of the cars. Figures 2 and 3 show schematic diagrams for the two stills individually used to obtain the experimental results.



1- Wooden frame 2- Solar wattmeter
3- Glass wool insulation still
4- Measuring flask 5- Glass cover
6-Water glass tube
7- Data logger and Computer 8- Water input

Fig.1: Photograph of the experimental setup.



1-Water inlet 2-Water
3-Wooden frame 4-Insulation
5-Measuring flask 6-Glass cover
7- Thermocouples sensors

Fig.2: Schematic diagram of the conventional solar still.

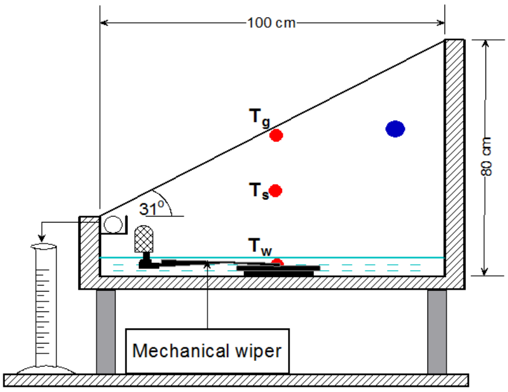


Fig.3: Schematic diagram of the water stirring solar still.

3. RESULTS AND DISCUSSION

A comparison between the two conventional stills at the same operating conditions is conducted to calibrate and determine the deviation of solar stills performance. The weather characteristics such as the ambient temperatures; dry bulb temperature (T_{db}) and wet bulb temperature (T_{wb}), global solar radiation (I) and the wind velocity were recorded every 30 minutes. Figure 4 presents the variations of ambient temperature and global solar radiation during the working period that started at 9:00 AM till 5:00 PM. The maximum value of the global solar radiation in this day was 1100 W/m^2. The wind velocity also was measured along the day; the wind velocity ranged between 1 m/s and 3 m/s.

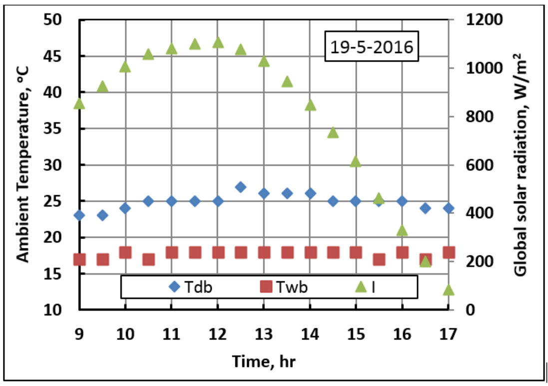


Fig.4: Variation of ambient temperature and global solar radiation with time.

The two stills have the same area and adjusted for the same water depth (H = 2 cm) and worked at the same operating conditions as conventional solar stills. Figures 5 to 8 represent the variation of water temperature, space temperature, glass temperature, production rate, productivity, and still thermal efficiency for the two stills, respectively. It can be seen that the two stills with no modifications give approximately the same water, space and glass temperatures and the maximum value of water temperature is 71 °C for the two stills and occurs at noon time. Also the Maximum values for the space and glass temperatures are 69 and 64 °C, respectively, at noon time. There is a considerable agreement in production rate for the two stills as shown in Fig.6. For the accumulated productivity, CSS gives 3.27 L/m^2 and WSSS gives 3.20 L/m^2. The two stills have the same accumulated productivity nearly as shown in Fig.7 in case for working without any modification. The same results of still thermal efficiency which is defined as $\eta = \frac{m \cdot \times h_{fg}}{A \times I(t)}$ were observed as shown in Fig. 8. In general, this experiment indicates that the two stills are working without any modification and have the same behaviour resulting in a considerable agreement between the performances of the two stills.

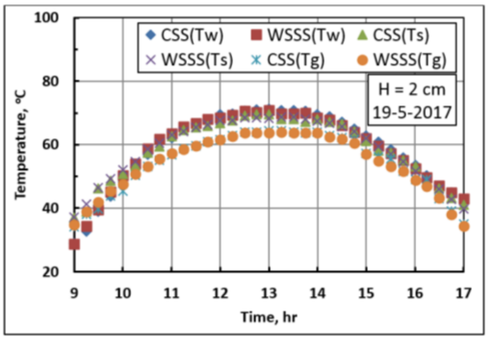


Fig.5: Variation of water temperature with time for two solar stills.

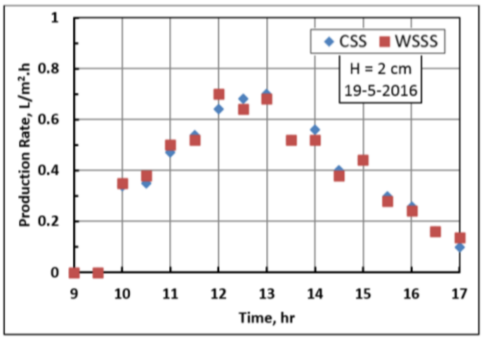


Fig.6: Variation of production rate with time for two solar stills.

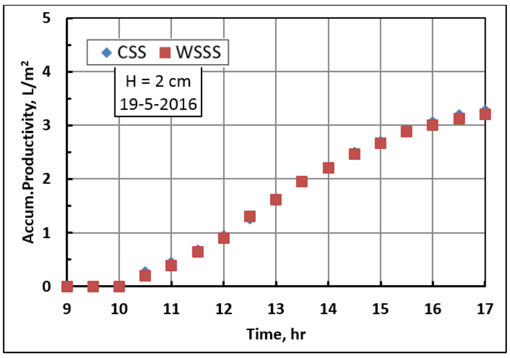


Fig.7: Variation of productivity with time for two solar stills.

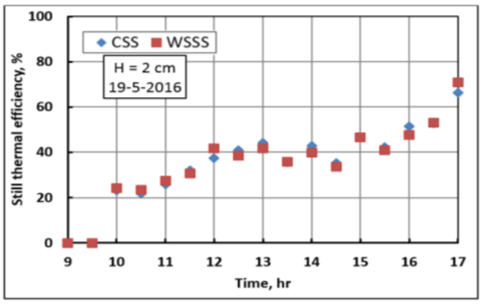


Fig.8: Variation of still thermal efficiency with time for two solar stills.

Clear sky days are selected to study the performance of the modified solar still. The mechanical wiper in the (WSSS) is running from the beginning to the end of experiment. The two stills: CSS and WSSS have the same water depth (H= 2cm). Figures 9 to 12 show a comparison of water temperature, production rate, accumulated productivity and still thermal efficiency of the two types of solar still. Due to movement of surface water in WSSS the productivity showed increasing tendency. This is due to the increase of evaporation rates to the air inside the still (see Figs 10 and 11). From Fig. 9 it can be seen that the maximum values of water temperatures for CSS and WSSS are 73.0 and 71.5 °C, respectively. It can be concluded that the WSSS type has almost low temperatures compared with that in the CSS type. The previous behaviour is due to the increase of the rate of makeup water to keep the water level constant at 2 cm inside the still, as a result of increasing the evaporation rate.

Fig. 10 shows a comparison between the production rate for the two stills through the day time, it can be seen that the WSSS has the highest values. A comparison between accumulated productivity for CSS and WSSS is shown in Fig. 11. The accumulated productivity for CSS and WSSS are 3.5 and 3.69 L/m^2 respectively. The WSSS gives 0.19 L/m^2 more than the conventional solar still. Fig. 12 shows a comparison between still thermal efficiency for CSS and WSSS. The figure indicates that the WSSS has the highest still thermal efficiency. The mean value still thermal efficiency for CSS and WSSS are 39.42 and 44.25 % respectively.

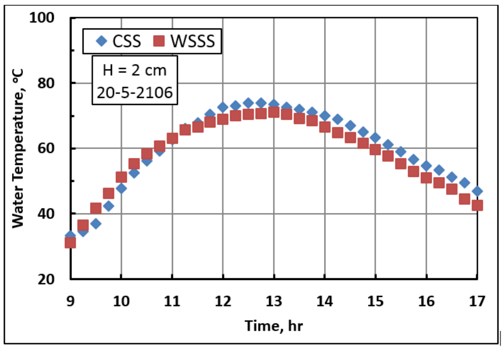


Fig.9: Variation of water temperature with time for the two solar still types.

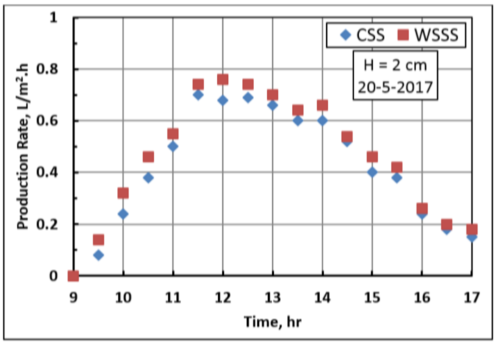


Fig.10: Variation of production rate with time for the two solar still types.

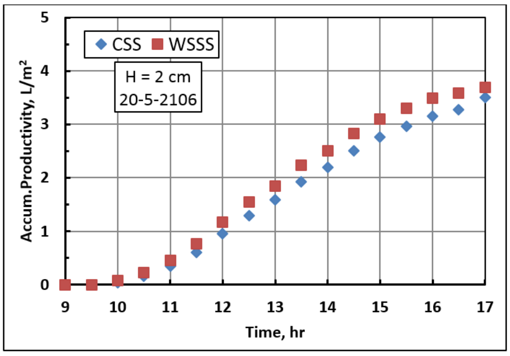


Fig.11: Variation of productivity with time for the two solar still types.

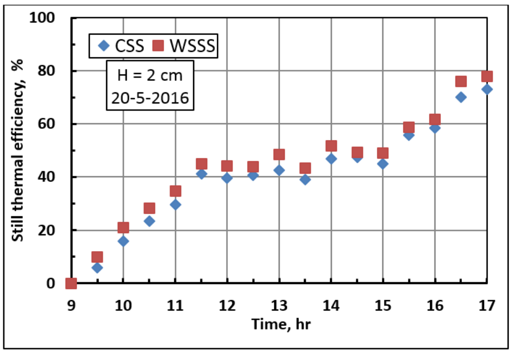


Fig.12: Variation of still thermal efficiency with time for the two solar still types.

In order to insure the results, the experiment with the same operating parameters is repeated in different days. The same performance trend is obtained at different day's weather condition. Also the same results are compared and analysed in the same manner.

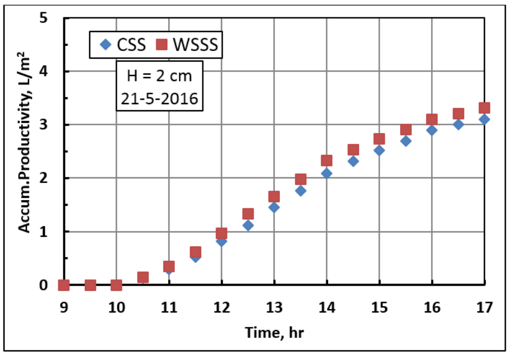


Fig.13: Variation of productivity with time for the two solar still types.

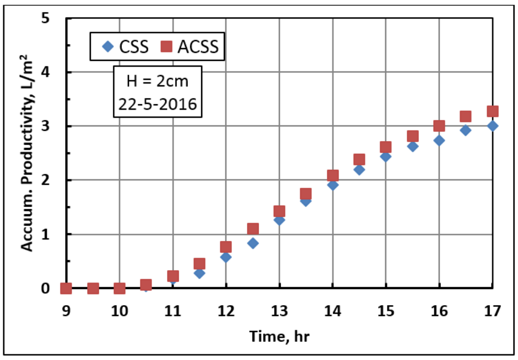


Fig.14: Variation of productivity with time for the two solar still types.

4. ECONOMIC STUDY OF SOLAR STILLS

The main purpose for solar stills is to produce fresh water in remote areas with minimum cost. The capital recovery factor (CRF), the fixed annual cost (FAC), the sinking fund factor (SFF), the annual salvage value (ASV), average annual productivity (AAP) and annual cost (AC) are the main calculation parameters used in the cost analysis of the desalination unit. The annual maintenance operational cost (AMC) of the solar still is required for regular filling of water, collecting the distilled water. As the system life passes on, the maintenance on it also increases. Therefore, 10% of net present cost has been considered as maintenance cost [17]. The cost of distilled water per liter (CPL) can be calculated by dividing the annual cost of the system (AC) by annual average productivity of solar still (AAP).The above mentioned calculation parameters can be reviewed in reference [17].

$CRF = i\,(1+i)z / [(1+i)z - 1]$ (1)

$FAC = PCC\,(CRF)$ (2)

$SFF = i / [(1+i)z - 1]$ (3)

$S = 0.2\,(PCC)$ (4)

$ASV = (SFF)\,S$ (5)

$AMC = 0.15\,FAC$ (6)

AC = FAC + AMC – ASV (7)
CPL = AC / AAP (8)

Where, S is constant, (PCC) is the present capital cost of desalination system, i is the interest per year which is assumed as 12%, z is the number of life years, which is assumed as 10 years in this analysis.

Table (1) shows the cost comparison between water stirring solar still and conventional solar still such as, present capital cost of desalination system (PCC), the CRF, the FAC, the SFF, the ASV, the AMC, AC, average annual productivity (AAP) and CPL. From the table it's clear that the WSSS solar still gives the highest accumulated productivity and the minimum values of the CPL.

Table (1) the cost comparison between water stirring solar still and conventional solar still

Still type	PCC, $	AAP L/m²	CRF	FAC	SFF	S	ASV	AMC	AC	CPL $/L/m²
CSS	168	11220	0.177	29.74	0.057	33.6	1.92	4.46	32.28	0.00288
WSSS	180	12240	0.177	31.86	0.057	36	2.05	4.78	34.59	0.00283

5. ERROR ANALYSIS

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. It is very important to estimate the accuracy of the measured and calculated parameters in order to make a correct analysis of the experimental results. The measured parameters include time, hourly productivity, and instantaneous efficiency.

5.1 Uncertainty in Time

Digital stop watch is used to measure the working time periods. The watch has a least count of 1 s. Furthermore, the maximum value of measured time was 30 minutes hence the uncertainty is equals to ±0.055 %.

5.2 Uncertainty in Hourly Productivity

The water productivity is calculated from following equation

$$m^{\cdot} = \frac{m}{t} = \frac{\rho V}{t} \quad (9)$$

Then uncertainty in hourly productivity can be calculated by as follows,

$$W_{m^{\cdot}} = \sqrt{\left(\frac{\partial m^{\cdot}}{\partial V} W_V\right)^2 + \left(\frac{\partial m^{\cdot}}{\partial t} W_t\right)^2} \quad (10)$$

Then the uncertainty in hourly productivity is equal to ±1.0%.

5.3 Uncertainty in Thermal Efficiency (η)

The thermal efficiency of the still is calculated using the following equation,

$$\eta = \frac{m^{\cdot} \times h_{fg}}{A \times I(t)} \quad (11)$$

The uncertainty of the still thermal efficiency can be written as

$$W_\eta = \sqrt{\left(\frac{\partial \eta}{\partial m^{\cdot}} W_{m^{\cdot}}\right)^2 + \left(\frac{\partial \eta}{\partial I(t)} W_{I(t)}\right)^2} \quad (12)$$

Then the uncertainty in the still thermal efficiency is equal to ±1.0008%.

6. CONCLUSIONS

In the present study, the performance of a simple basin single slope solar still was experimentally examined. New enhancing modification is proposed and tested along 3 days. The modification has been conducted by fixing small mechanical wiper on the still basin to stir the water of the still. The experimental results on the modified solar still have been collected and compared with that of conventional one for the same design and operating condition. It can be concluded that,

- The experimental results showed that, the accumulated productivity from WSSS increases by 9.14 % compared with that of CSS at water depth of 2 cm.
- The maximum water temperature for WSSS is smaller than that of CSS.
- The cost per liter of WSSS is lower than that of CSS.
- The still thermal efficiency of WSSS is higher than that of CSS.

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عنوان الرساله
دراسة عمليه لأداء مقطر شمسى ذو مقلب للماء
الملخص العربي

تقدم هذه الورقه البحثيه دراسه عمليه لاداء مقطر شمسى ذو مقلب للماء الذى بداخله. تم تعديل وتطوير واختبار المقطر العادى لتحسين اداءه عن طريق تقليب الماء باستخدام جهاز تقليب الماء الذى تم تثبيته فى قاع المقطر الشمسى. تم تحليل ومقارنة نتائج المقطر المحسن بالمقطر الشمسى العادى الذى كان له نفس تصميم المقطر الشمسى المحسن. وضحت النتائج تحسن فى انتاجية المقطر الشمسى المحسن ذو مقلب الماء بداخله فى اليوم عن انتاجية المقطر الشمسى العادى بنسبه 9.14 %
كلمات البحث: الطاقة الشمسيه - التحليه - المقطر الشمسى - الاداء