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Effect of Fine Stone Bed Layer Thickness on the Solar Still Performance

تأثير سمك طبقة الصخور علي أداء المقطرة الأشمسية

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KEYWORDS:
Solar still, Black stones, Desalination

الملخص العربي:-في هذا العمل، تم إجراء دراسة تجريبية على المقطر الشمسي للتحقيق في تأثير سمك طبقات الحجارة على إنتاجية المقطر الشمسي. وتشمل هذه الدراسة التجريبية على اثنين من المقطرات الشمسية المتطابقة: أحدي المقطرات تقليدي والأخرى لديها طبقة من الحجارة الدقيقة على قاعدة المقطر. تم تقسيم الحجارة الدقيقة إلى ثلاث طبقات. تبدأ كل تجربة بدون طبقة حجرية. ثم أخذت القراءات من طبقة واحدة، وطبقتين، وثلاث طبقات من الحجارة توضع في حوض المقطر الشمسي. سمك هذه الطبقات هي 10 مم، 15 مم و20 مم، على التوالي. وأجريت التجارب في جامعة المنصورة، مصر (31 '21 o31,N' 04 o E)، خلال شهر نوفمبر، 2016. وتم تسجيل درجات الحرارة في مواقع مختلفة في المقطر الشمسي (الماء، سطح الغطاء الزجاجي والحجارة وخليط الهواء والبخار) وتقاس مع مرور الوقت. وبالإضافة إلى ذلك، يتم تسجيل الإشعاع الشمسي، ودرجة الحرارة المحيطة وكمية المياه المقطرة خلال التجارب في مختلف أيام التشغيل. وأشارت النتائج الحالية أن تعزيز 3.79٪، 7.06٪ و11.8٪ للطبقة الواحدة وطبقتين وثلاث طبقات من الحجارة، على التوالي من المقطر التقليدي كما تبين أن الكفاءة كانت أعلى مع الحد الأقصى لسمك طبقات الحجارة

Abstract—— **In this work, an experimental study has been conducted on a solar still to investigate the influence of stone bed layer thickness on the productivity of the solar still. These present experimental study involves two identical solar stills: one of the stills is conventional and the other has a layer of fine stones on the base of the still. The fine stones were divided into three layers. Each experiment starts without stone layer. Then readings were taken from the still for one stone layer, two stone layers and three stone layers on the basin. The thicknesses of this layers are 10mm, 15mm and 20 mm, respectively. The experiments were conducted at Mansoura University, Egypt (31° 04 ′N, 31° 21 ′ E), durin g November month, 2016. Temperatures at different locations in the still (water in the still, glass cover surface, stone and air – vapor mixture) are measured and recorded with time. In addition, solar radiation, ambient temperature and amount of distillated water are recorded during the experiments at various operating days. The present results indicated that the enhancement of 3.79%, 7.06% and 11.8% for one, two and three fine stones bed layers, respectively more than the conventional still. Also, it was showed that the efficiency was highest with the maximum stone bed thickness.**

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I INTRODUCTION

THE presence of water is an important element for all organisms that live on the surface of the globe, as well as for the development of the economy of any nation. The percentage distribution of the water on the earth is 2.53% and 96.54% of freshwater and seawater, respectively [1]. The available fresh water for the people is 0.36% of total fresh water [2]. However, the shortage of rainfall and the increase of population create water scarcity in many countries.

Consequently, the major concerns in the world notably the third world at present is to find new resources and new processes of providing cheap fresh water, especially for people in remote areas. One of the options used to obtain fresh water from seawater is to use solar desalination system. The use of solar energy in desalination systems is gaining more momentum especially in the Gulf and Middle East regions where the solar radiation intensity is very high. It is an economical, effective and environment friendly technology.

Solar stills are classified broadly into two categories namely passive and active solar stills. Passive solar stills require solar energy for evaporation of saline water whereas active solar stills require an additional thermal energy by external mode for faster evaporation [3-5].

Many researchers [6-9] have provided an experimental and theoretical study for enhancing the performance of solar stills. They concluded that the simplest and least expensive solar stills are passive solar stills in comparison to active solar stills and the productivity depends on climatic conditions and various other parameters. In addition, there are numerous factors affect the performance of a solar still. The design factors such as absorbing material, absorbing area, condensing cover material, cover slope, cooling of cover, water depth, insulation material, insulation thickness, geographical position of the still, sun tracking system, etc. and the climatic factors such as solar intensity, ambient temperature, wind velocity, etc. affect thermal efficiency and the productivity of the solar still [3-4].

A comprehensive review on the thermal performance as well as experimental modifications and various solar still (SS) designs was discussed in the literature [10-19]. Various modifications were applied on the solar still for enhancing the productivity and efficiency of solar still such as using pin finned wick [20], Nano fluid [21], evacuated tube [16], thermoelectric module [22-23] and heat-pipe [24].

Due to the big influence of the availability of the useful energy and exergy from the system on the performance of any solar system, many researchers [25-32] have investigated the energy and exergy analysis to optimize the operating parameters and design.

A double basin double slope solar still was fabricated by Rajaseenivasan et al. [33] in climate conditions of Madurai, India. They concluded that the efficiency of double basin still is higher than the conventional solar still with single basin by 85% for the same basin condition.

Kabeel, et al., [34] studied experimentally a double passes solar air collector–coupled improved solar still, with PCM to enrich the fresh water productivity. It was found that the daily productivity was approximately recorded 9.36 L/m2 for the double passes solar air collector– coupled improved solar still, with PCM, however its value is recorded 4.5 L/m2 for the conventional still.

Deshmukh and Thombre [35] studied experimentally the performance of a single slope single basin solar still with sand and servo-therm medium oil as sensible passive storage material beneath the basin liner. the results indicated that for both, sand and servotherm medium oil, lower storage depths, the productivity was increased compared to conventional still.

Samuel et al., [36] utilized different types of energy storage material to enhance the conventional solar still productivity. Their results showed that the output of freshwater using spherical ball salt storage achieves the maximum productivity of 3.7 kg/m2 as compared to a conventional single slope solar still.

The objective of the present work is to study the freshwater productivity enhancement of single basin passive solar still with stone bed as energy storage medium. The used stone in the present work is basalt rock stone due to its wide availability and low cost. The effect of the thickness of stone bed is experimentally investigated, and the study results are compared with conventional still, to evaluate the enhancement in the solar still efficiency and freshwater productivity.

II EXPERIMENTAL WORKE

In present study, two basin stills were designed, fabricated and constructed at the Mechanical Power Engineering Department, Faculty of Engineering, Mansoura University to compare the performance of the solar desalination system. One of them is a conventional type, and the other is an enhanced type with inserting fine stone bed in basin as shown in Figs. 1 and 2. The conventional still is made from galvanized iron sheet (1 mm thick) with a basin area of 1 m^2 (80 cm × 125 cm). The low-side wall height is kept at 70 mm and the high side wall depth is 320 mm for 17° inclinations. The inclination angle of the glass cover is certain on the basis of previous studies, in which it is stated that the most efficient angle for El-Mansoura city is around 15° [37]. The inner walls of the basin are coated with Black paint to improve the absorptivity. The outside still surfaces are insulated on the bottom and side walls with fiber glass 50 mm thickness to reduce the heat loss from the still to ambient. The basin is covered with a normal glass cover of 4 mm thickness. The gap between the glass cover and the still walls was filled with silicone rubber to prevent leakage to the atmosphere.

The still with stone bed has the same dimensions and construction of conventional still. To study the effect of stone bed thickness, the stills were filled with 1 cm (one layer), 1.5 cm (two layer), and 2cm (three layer) of Stone bed.

A collecting V-trough is used to collect the condensed water into two 3 L capacity containers. The tube exit and flask inlet are covered by plastic sheet to prevent leakage of vapor outside the still. Schematic of the experimental system is illustrated in Fig.1.

To keep the water level in the solar still at a level of 3 cm, each of the solar still units is supplied with a level controller as shown in Fig (2). The main design parameters of the still are presented in Table 1.

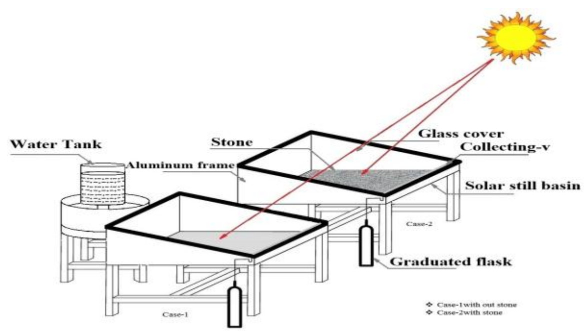


Fig. 1. Schematic of the experimental test unit.

Fig. 2. View of the experimental test units

The atmospheric temperature, solar radiation, basin temperature, stone bed temperature, basin water temperature, glass temperature and distilled water productivity were measured for every half an hour. Solar power meter (TES-1333R) is used to measure the solar radiation intensity with measuring range of 0 – 2000 W/m^2, an accuracy of ± 10 W/m^2 and a resolution of 0.1 W/m^2. The temperatures are measured by using thermocouples of type K with accuracy of 0.5^{o}C and a resolution of 0.1℃.

The daily thermal efficiency of the solar still can be calculated from the following expression;

$$\eta = \frac{m_w \times h_{fg}}{I_s \times A_b} \qquad (1)$$

where (m_w) is the production rate of fresh water in Kg/s, (h_{fg}) is the latent heat of water evaporation at an average water temperature in kJ/kg, (A_b) is the basin area for each m^2 and (I_s) is the solar radiation intensity in W/m^2. In calculation of the daily efficiency, latent heat of evaporation is taken as an average value of 2257 kJ/kg, and basin surface area is 1 m^2.

III RESULTS AND DISCUSSION

Fig (3-a) shows the temperature variation at different locations (glass surface, basin, stone surface and air–vapor mixture) for the solar still with the absence of fine basalt rock bed. The temperatures measured for one day were noted to be a similar pattern of the amount of solar intensity. It is clear that the temperature increased as the solar intensity increased during the day. The solar intensity reached its maximum about mid of the day but the temperature reached its maximum about 1.00 p.m. This is due to the time lag between the energy supplied for vaporization and condensate collected. During the time from 12:30 p.m. to 1:30 p.m., the reduced solar intensity increased the temperature difference between the seawater and glass cover, and resulted in more condensation of water vapor.

Fig (3-b) shows the variation of temperatures at different locations (glass surface, basin, stone surface, air–vapor mixture and water) of solar still with basalt rock stone bed. The energy stored in the stone bed was given to the seawater during late evening hours, which increased the yield of the still. There was a steep increase in yield of the still till 12.00 p.m. and there was a steep decrease in yield of the still after 2.00 p.m. The same trend has been observed for two and three stone layers as shown in Fig (4-a), (4-b), (5-a) and (5-c).

TABLE I
STILL DESIGN PARAMETERS

Basin dimensions, mm	800 × 1250
Glass cover angle, deg.	17o
Insulation thickness, mm	50
Thickness of the layers of stones used, mm	10, 15, 20
Water Level in the basin, mm	30

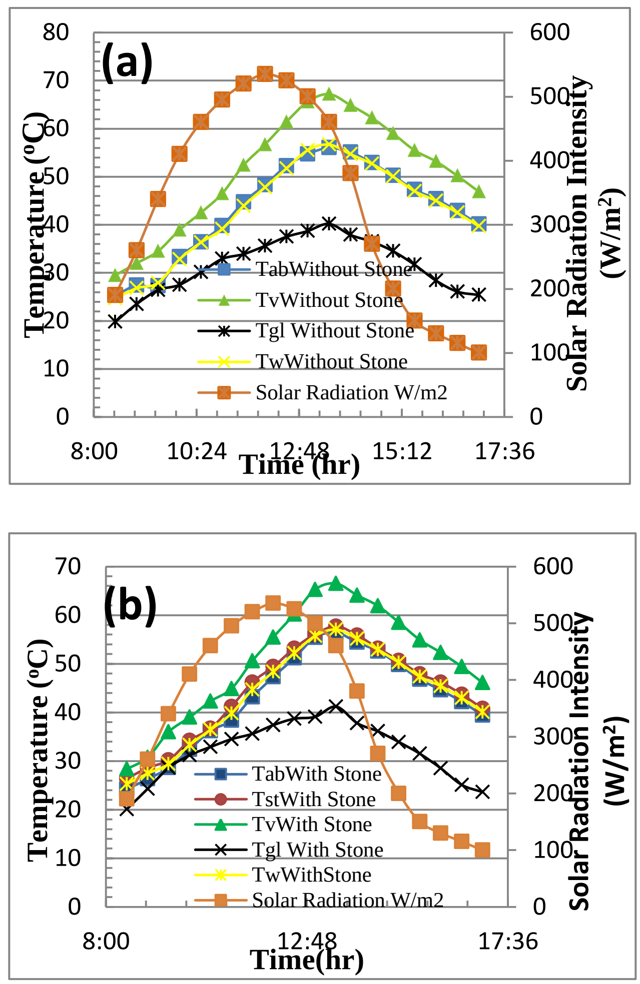
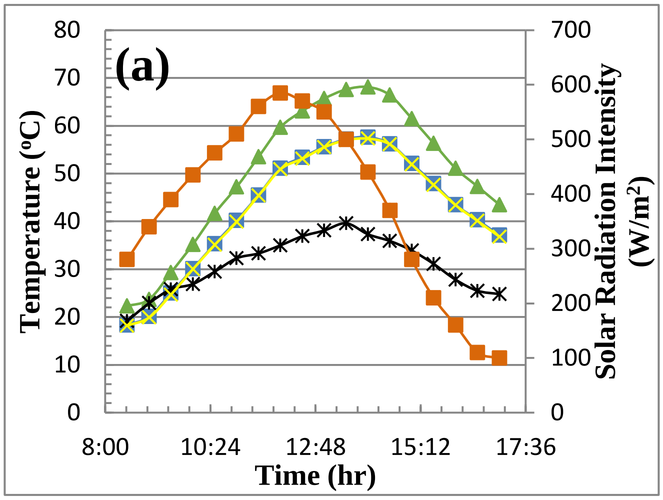


Fig (3) Variation of temperatures with time for date 1/11/2016 for angel 17^o one layer (a)with Stone, (b) without Stone



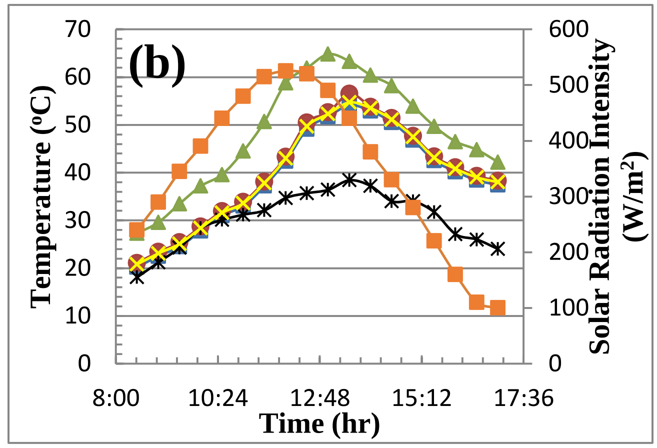


Fig (5: a,b) Variation of temperatures with time for date 5/11/2016 for angel 17° three layers (a)With Stone, (b) Without Stone.

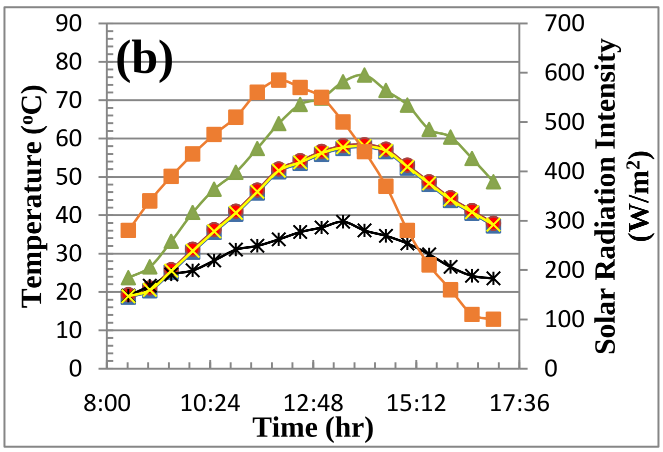
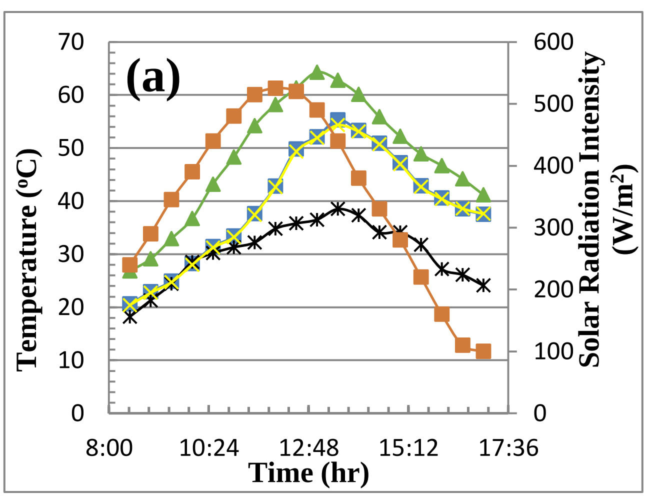
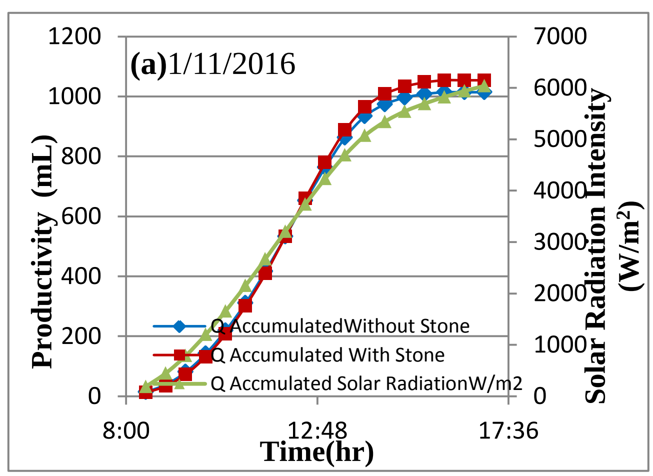


Fig (4) Variation of temperatures with time for date 2/11/2016 for angle 17° two layers (a)With Stone, (b) Without Stone

Variation of the cumulative daily amount of distillate per unit area as well as the cumulative daily amount of solar radiation incident on a 1 m2 basin area at three different stone bed thickness as (one stone layer of thickness of 1 cm, two stone layers of thickness of 1.5 cm and three stone layers with thickness of 2 cm) is presented in Fig (6). The productivity is enhanced when inserting the stone bed layer in the basin for each thickness (one, two, and three stone bed layers) as shown in Figs. (6-a), (6-b), and (6-c); respectively. It was due to the fact that more energy was absorbed from the sun radiation and stored by the stone bed and the same energy was made use of more fresh water where most of heat absorbed in water layer is consumed in the evaporation of water vapor. Another most remarkable result observed is that the productivity increases with an increase in the stone bed thickness as shown in Figs. (6-a), (6-b), and (6-c). It has been found that using stone bed gives an enhancement of 3.79 %, 7.06 % and 11.8 % for one, two and three stone bed layers at days of 1, 2 and 3 /11/2016, respectively.





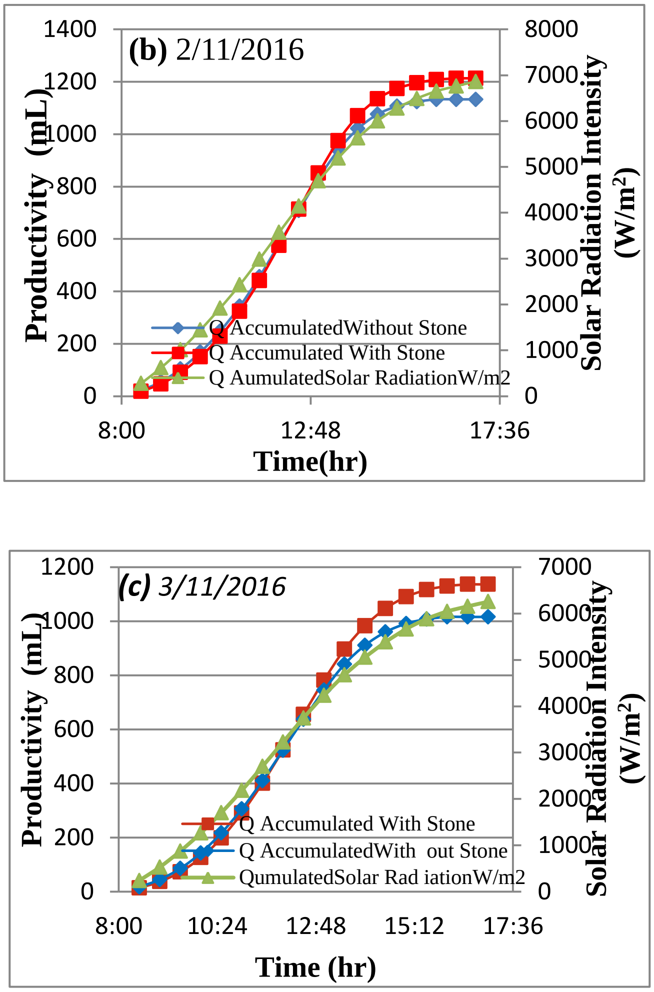


Fig (6: a,b & c) Accumulated values of solar radiation and distillate with time for three different days

The hourly variation of thermal efficiency which calculated based on the instantaneous yield using the Equation (1) has been shown in Fig. (7). It has been observed that the minimum efficiency values of the systems for one-layer stone bed and still without stone are 17.73% and 18.35%, respectively at 08:30 am o'clock as shown in Fig. (7-a) and the maximum efficiency values for one-layer stone bed and still without stone are 36.89% and 34.17%, respectively at 1:30 pm o'clock. For two-layers stone bed, the minimum efficiency values of the systems were 16.01% versus 19.57% for conventional still at 08:30 am o'clock and the maximum efficiency values for one-layer stone bed and still without stone are 38.98% and 33.63%, respectively at 01:30 pm o'clock as shown in fig. (7-b). Finally, from fig. (7-c), the minimum efficiency values of the systems for three-layers fine stone bed and the other still without stone are 17.79% and 14.53%, respectively at 08:30 am o'clock the maximum efficiency values for one-layer stone bed and still without stone are 40.98% and 34.51%, respectively at 01:30 pm o'clock.

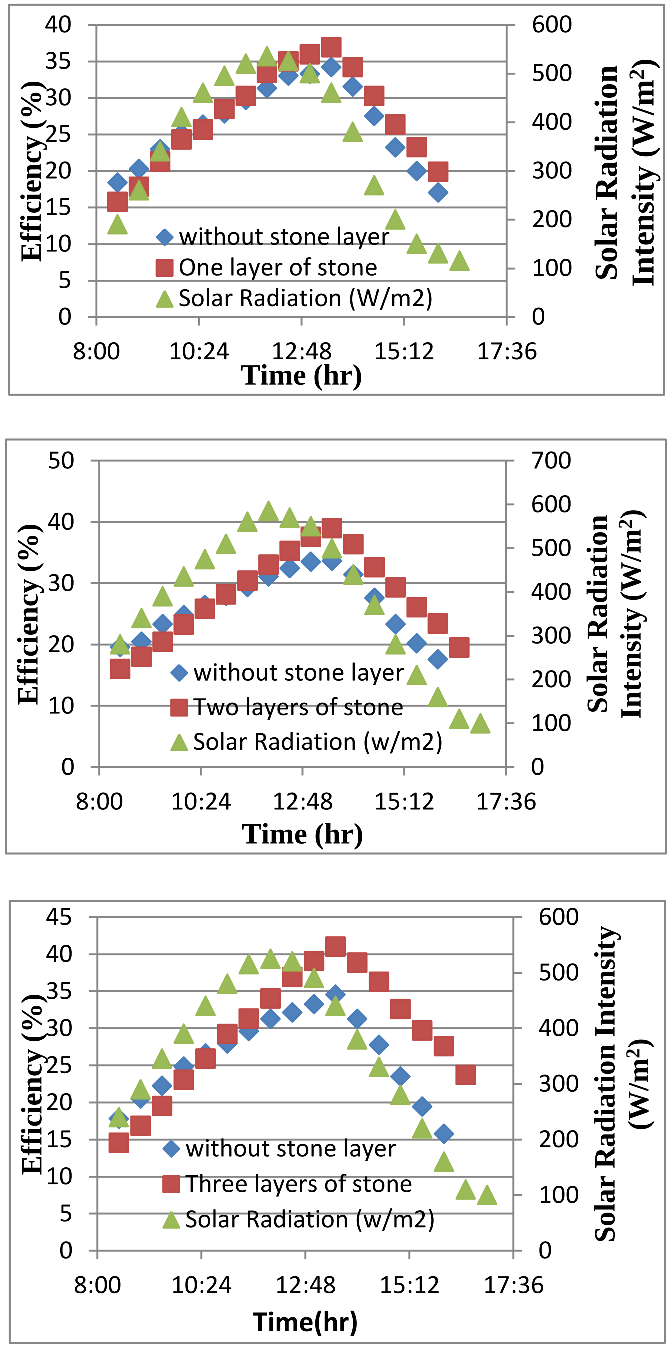


Fig. (7) Comparison between the hourly efficiency and solar radiation with time

Figure (8) shows the overall thermal efficiency of the solar still for all cases of stone bed. The efficiency of the still with the one, two and three stone layers was noted to be 21.9%, 22.15% and 22.8%, respectively, whereas the efficiency of the still without stone was noted to be 20.37%. The increase of efficiency was because of the larger temperature variance maintained between the basin seawater surface and inner surface of the glass cover and the reduction of energy losses by the still.

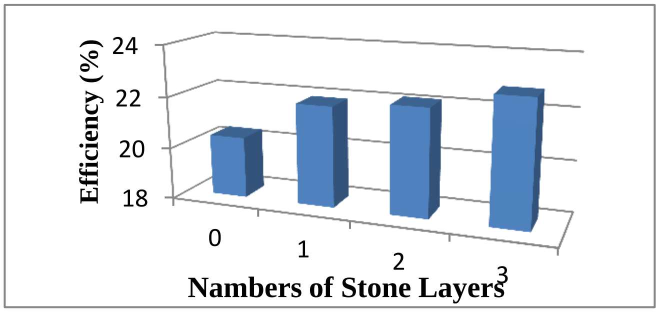


Fig (8) Comparison of overall thermal efficiency with number of layers

IV CONCLUSIONS

An experimental work has been performed on the solar still with basalt rock fine stones bed as an energy storage medium. Two identical experimental units have been designed and experimentally tested to study the performance of the still with this modification. One of the two units is a conventional still which is used as a reference unit, while the other one is enhanced with fine stone bed layers. The effect of thicknesses of the stone bed on the performance of the solar still was experimentally investigated under the atmospheric conditions. The following conclusions have been drawn:

1- Inserting the stone bed layers in the solar still basin could enhance the still productivity and efficiency.

2- The solar still productivity and efficiency were enhanced with increasing the thickness of the stone bed.

3- The productivity of the solar still for one, two and three stone bed layers enhanced by about 3.79 ,7.06 and 11.8%, respectively than the conventional solar still.

4- The efficiency of the solar still with the one, two and three stone layers was noted to be 21.9%, 22.15% and 22.8%, respectively, whereas the efficiency of the solar still without stone was noted to be 20.37%.

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