IMPROVING THE PERFORMANCE OF A PYRAMID-SHAPED SOLAR STILL

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ABSTRACT

The main goal of this study is to improve the performance of a pyramid-shaped solar still by studying some effective parameters on the still distillate yield and still instantaneous efficiency including solar radiation intensity, brine depth, water salinity, temperature difference between the glass cover and the brine. Thus a simple basin pyramid- shaped solar still with total area of 0. 64 m^2 covered with four triangle clear sheets of glass with 3 mm in thickness without frame was fabricated and tested with auxiliary black materials in basin from 8 am to 6 pm under Zagazig city local climatic conditions (Latitude 30.5° N). The solar still performance was evaluated under three levels of brine depth (4 ,8 and 10 cm),two levels of water salinity (15000 and 35000 ppm) intended to simulate brackish water and seawater respectively using auxiliary black materials including black sponge cubes and black stones. The results showed that around the noon hour, using the black sponge cubes at water depth of 4 cm and water salinity of 15000 ppm gave the highest still instantaneous efficiency of 46.15 %, the highest temperature difference between the glass cover and the brine of 32.40 °C, the highest distillate and accumulated yield of 630.40 ml/h and 3620.45 ml respectively. Hence, it is recommended to operate the solar still at brine depth of 4 cm and water salinity of 15000 ppm using black sponge cubes to obtain the highest values of the distillate yield, accumulated yield and the instantaneous efficiency.

Keywords: *solar still, brackish water, brine, auxiliary, distillate yield .*

INTRODUCTION

It is well known that large areas in arid and semi-arid regions are suffer from the rare, shortage and pollutions of freshwater either the surface sources of water such as; rivers, ponds and lakes or the underground water, especially in deserts, remote, rural and the isolated communities, in addition to the increase of fresh water transporting costs

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to those areas. Thus, it is obvious that it is needed to think about other ways to supply those communities with fresh water. In Egypt, the mean value of energy incidence ranges from 500 to 1400 W/m^2 **(Mosalam, 1997)**.So, such care must be taken to utilize the solar energy for desalinating the seawater or even the brackish water by using solar still that seems a good and economical method to produce drinking water. Solar stills are cheap and having low maintenance costs but the solar still productivity is still low **(Duffle and Beckman, 1991)**, therefore it is important to execute more efforts to increase the production rate of the solar still. **Ernani (1996)** concluded that the distillation rate increases with increasing water temperature and temperature differences. **Ghoneyem and Arif (1997)** studied four stills, three had a glass cover of different thickness (3, 5 and 6 mm), while the fourth cover is plastic. They reported that the daily average product per m^2 of still No.1 (3 mm) is about 0.03 kg higher than that of still No.2 (5 mm) and 0.04 kg higher than that of still No.3 (6 mm), so the thinnest glass cover had shown the highest production rate, up to 16.50%. **Aboul- Enein *et al.*(1998)** indicated that the total daily output of the solar still decreases with increasing water depth, but overnight output increases with an increase in water depth, which contributes considerably towards the total daily output. **Bilal *et al.*(1998)** found that the fresh water productivity by a solar still can be increased by the presence of some absorbing materials such as; rubber. They added that using an absorbing black rubber mat increases the daily water productivity by 38%. **Bekheit *et al.*(2001)** observed that the daily yield per still area in the basin solar still mainly depends on the evaporative area and condensing surfaces. **Fath and Hosny(2002)** mentioned that the glass side cover is inclined with angle equal to latitude of the place to receive the sun rays close to normal and the distance between the cover and basin water is kept minimum ,so that maximum volume of air with vapor purges into the condenser area. **El-Sebaii (2004)** said that there are important parameters affecting the performance of a solar still, such as; solar intensity and the mass of basin water as well as wind speed. **Rajesh and Tiwari (2005)** summarized that with deep basin, the productivity of the still decreases with any increase in depth of water during daylight and the reverse is the case of overnight production. **Kalidasa *et al.*(2008)** indicated that for lower latitude places double slope stills are preferred with south–north orientation. **Kabeel (2009)** studied concave wick pyramid shaped still .He showed that average distillate productivity in day time was 4.10 Lit/m^2 and a maximum instantaneous system efficiency of 45% and average daily efficiency of 30% were recorded. **Yazan and Madhar (2012)** designed a pyramid shaped solar still to increase the area of condensation. Hence, the main objective of the present study is to construct and evaluate a simple basin pyramid-shaped solar still suitable for small farmers in rural, remote and isolated areas to enhance its performance by using auxiliary black materials under the prevailing weather conditions of Zagazig city, Egypt.

MATERIALS AND METHODS

A-Materials

In present study, a glass pyramid-shape solar still was fabricated and assembled at a private workshop. The practical experiments were carried out from 1 to 22 of April 2012 at Zagazig City (Latitude of 30.50º N).

-The experimental setup

The construction features and main components are shown schematically in Fig. (1).The construction of these components can be described as follows:

The container of the solar still is a square wooden box with 0.8 m length, 0.80 m width and 0.15 m depth, where the wooden box surfaces were painted from inside and outside using a black matt paint. The bottom and the sides of the wooden box were insulated with 50 mm layer of glass wool. The basin is a fixed plate on the bottom of container which made from 3 mm steel sheet and painted with a matt black paint with overall dimensions of 600×600×100 mm. Four triangle clear sheets of glass with inclination angle of 45º (according to preliminary tests), 3 mm thickness and transmittance of 0.90 were used as a cover for the still where the glass sheets were sealed together with silicon rubber sealant to give the pyramid shape without frame. The vertical distance between the cover peak points to top edge of the container is 400 mm and to the basin bottom is 500 mm. The total area of the container of still has the same area of the glass cover of 0.64 m^2 .The glass sheet supplied with distillate troughs at the bottom edge which made of reinforced plastic. The container has two holes with 38 mm in diameter for the input and output plastic pipes. The solar still has three graduated tanks with volumetric capacity of 10 Lit, one for the saline water and the other for receiving the fresh water. The solar still was supported with square poles at height of 200 mm above the ground with north-south orientation with about 10° tilt angle to permit the condensate droplets to slide in the collecting trough towards the outlet pipe as shown in Fig. (1).

B-Methods:

The procedure of experiment

The practical experiments were executed during month of April which started at 8 am to 6 pm and all readings of temperatures and solar radiation were recorded every 15 minute time interval and manual cooling on the outer surface of glass each 30 min. Every test was performed along one day. The investigation tests were carried out to evaluate the still performance using the following variables:

1-Three different levels of brine depth of 4, 8 and 10 cm.

2-Two levels of water salinity of 15000 and 35000 ppm intended to simulate the brackish water and seawater respectively.

With three different treatments of : *A*) without material, *B*) black cubes of sponge (Length of the side of sponge cube 100 mm according to preliminary tests) and *C*) black stones ranging from 20 to 30 mm in diameter.

Instrumentation and Measurements

1-The weather station:

A weather station (Watchdog, model 900 ET) was used to measure wind speed (0-175 mph) ± 5%, wind direction (2° increments) ± 7°, temperature (-30° : 100° c), relative humidity (20-100%) ± 3%, rainfall (0.01-0.25 cm) ± 2% and solar radiation (1- 1250 W/m^2). Data were recorded each 15 minutes and averaged for each hour.

2- Thermocouples:

Thermocouples (type-K) that contacted with digital thermometer was used to measure the temperatures at various places inside the solar still such as, the glass, the brine, the black materials in basin. The accuracy of this device is 0.1°C for the temperature measurements between 1 and 100°C.

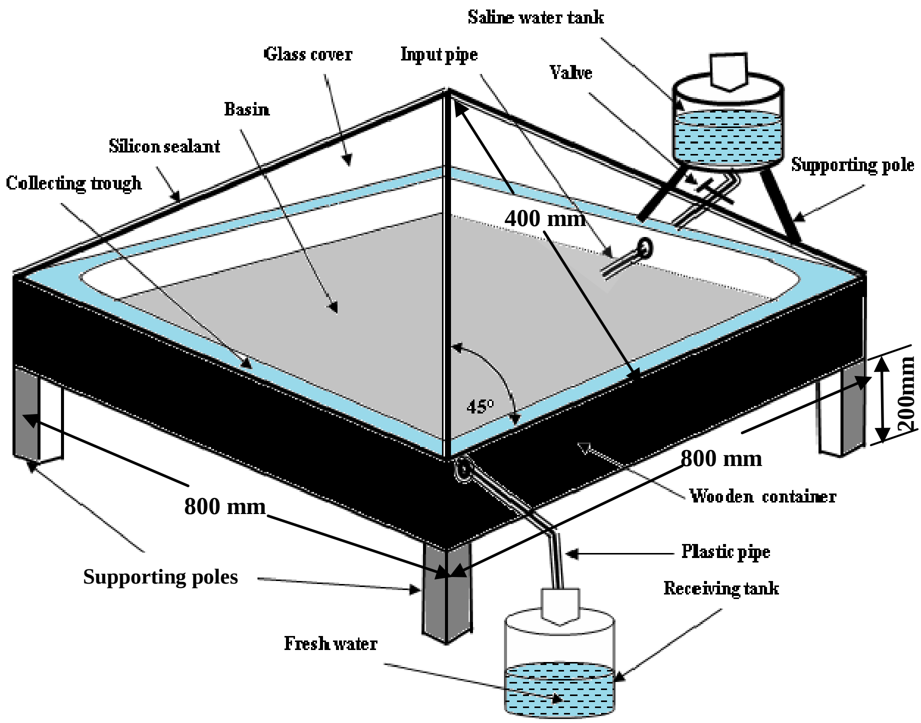

Fig.(1): Schematic diagram of the pyramid-shaped solar still .

3-The instantaneous efficiency (η_i)

The instantaneous efficiency of the still at any time is defined as the ratio of the heat transfer in the still by evaporation-condensation to the radiation on the still. The instantaneous thermal efficiency (η_i) can be calculated using the equation given by **(Duffie and Beckman, 1991)** as follows:

$$\eta_i = \frac{m_D h_{fg}}{AgG} \times 100 \ ,(\%)$$

Where:

m_D= production rate of the solar still, (Kg/h)

h_{fg}=water latent heat of evaporation, (kJ/kg)

G = solar radiation flux, (kJ/m^2 .h)

Ag =the glass collecting area, (m^2)

RESULTS AND DISCUSSION

1-Distribution of hourly total solar radiation

The obtained results show that the day of April,17 has the maximum value of the hourly solar radiation (*G*) of 665.47 W/m^2. For the mentioned day, the hourly solar radiation in W/m^2 and temperature differences in degrees were plotted against the time of the day as shown in Fig.(2) and Fig(3) respectively. It is very clear that hourly total solar radiation value increased in the morning hours till it reaches the maximum value around noon hour, then the incident hourly radiation value starts to decrease rapidly in period from afternoon to the sunset hours. Also, the same trend was found in all experimental days. Fig.(3) illustrates the distribution of values of ambient temperature (T_a), glass temperature (T_g) and brine temperature (T_b) during the maximum hourly radiation day. It is obvious that the maximum values of T_a, T_g and T_b are 30.31, 36.54 °C and 57.43°C respectively, were recorded around the noon hour. It was noticed that the glass cover temperature (T_g) reached its maximum value before the brine temperature and a clear gap in temperature values between the glass cover temperature (T_g) and brine temperature (T_b). This phenomenon may be attributed to the fact that the glass cover has lower heat capacity compared with the brine. Hence, it can be expected that using the solar still around noon hour may improve its performance.

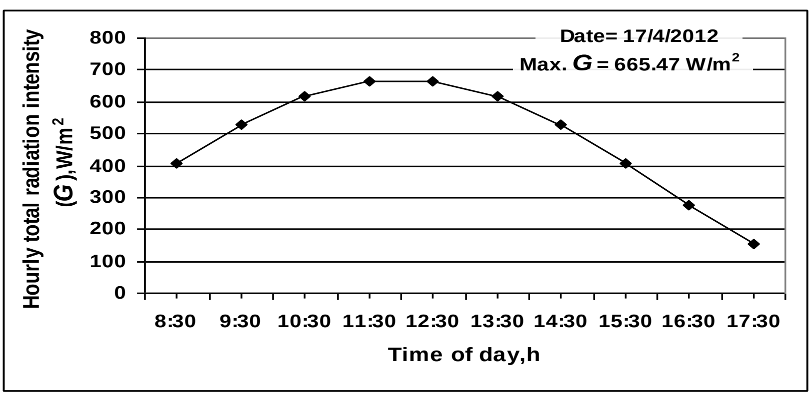

Fig.(2): Hourly total radiation intensity distribution during the maximum hourly radiation day.

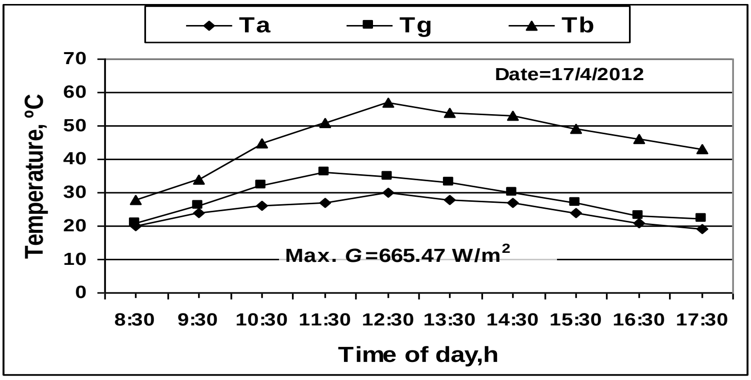

Fig.(3): Variation of ambient temperature (T_a), glass temperature(T_g) and brine temperature(T_b) during the day of maximum radiation.

2- Effect of brine depth, water salinity and the auxiliary black materials in basin on the hourly distillate and accumulated yield

The solar still was tested with sprayed black sponge cubes, sprayed black stones and without any material in basin under three brine depths of 4, 8 and 10 cm with two concentrates of saline water of 15000 and 35000 ppm depending upon the fact that the black surface is the best solar radiation absorbing material to the both of evaporation and condensation processes.The effect of mentioned variables on the distillate and the accumulated yield is shown graphically in Fig.(4) and Fig.(5).It is clear that the distillate yield attained its maximum value at the noon hour and the distillate yield rate remained high at the afternoon hours as shown in Fig.(4) ,this may be due to the accumulative and the stored energy at this period compared to the rates before noon period and may be for the same reason the accumulated yield increased slightly at afternoon hours because it is considered a direct function of distillate yield as shown in Fig.(5).It is obvious that the highest values of distillate yield rate are 630.40, 510.30 and 460.6 ml/h for black sponge cubes, black stones and without material respectively at brine depth of 4 cm and water salinity of 15000 ppm. Also, the highest value of the accumulated distillate yield of 3620.45 ml was recorded under the previous variables using the black sponge cubes. This may be attributed to that the projected area of evaporation increased and the surface tension of brine decreased so, the strength of bonds among molecules may reduce by using black sponge cubes especially at shallow depths, hence, the evaporative water rate and the distillate yield increased. On the other hand, the increase of water salinity from 15000 to 35000 ppm at brine depth of 4 cm was followed with a clear decrease in distillate yield at noon hour by 7.93, 10.71 and 13.04% for the black sponge, black stones and without material respectively. This is can be due to the increase in water mass by increasing water salinity resulting in high thermal heat capacity then a reduction in evaporating rate may occur. The same trend was found with the accumulated distillate yield. As a result, operating the solar still at brine depths of 4 and 8cm gave good values of the hourly and the accumulated distillate yield by using black sponge cubes under all studied parameters.

3- Effect of brine depth, water salinity and the auxiliary black materials in basin on the still instantaneous efficiency

Fig.(6) depicts the hourly variation of the solar still efficiency under three brine’s depths of 4,8 and 10 cm and two concentrates of saline water using auxiliary black materials in still’s basin. It was noticed that the distribution of the still efficiency has the same trend of distillate yield and the hourly total solar radiation. Fig.(6) illustrates that still instantaneous efficiency starts increasing till attain its maximum value at the noon hour and remained higher at the afternoon hours compared to the before noon period under different brine’s depths , especially depth of 4 cm, despite the reduction that occurred in hourly total solar radiation at afternoon period as shown in Fig.(6).This may be attributed to the accumulative and the stored energy in brine water at this period compared to the morning hours.As display in Fig.(6),it was noticed that the instantaneous efficiency decreases as the brine depth increased. The obtained results showed that, the increase in brine depth from 4 to 10 cm the still efficiency decreased by 36.95% at noon with water salinity of 15000 ppm.This may be attributed to the decrease occurred in brine temperature as the water depth increased due to the increase of the heat capacity of brine. Furthermore, the instantaneous efficiency decreases as the water salinity increased. The obtained results showed that, the increasing of water salinity from 15000 to 35000 ppm decreased the still efficiency by 23.91% at noon with brine depth of 4 cm and the same trend was observed at all brine’s depths. The

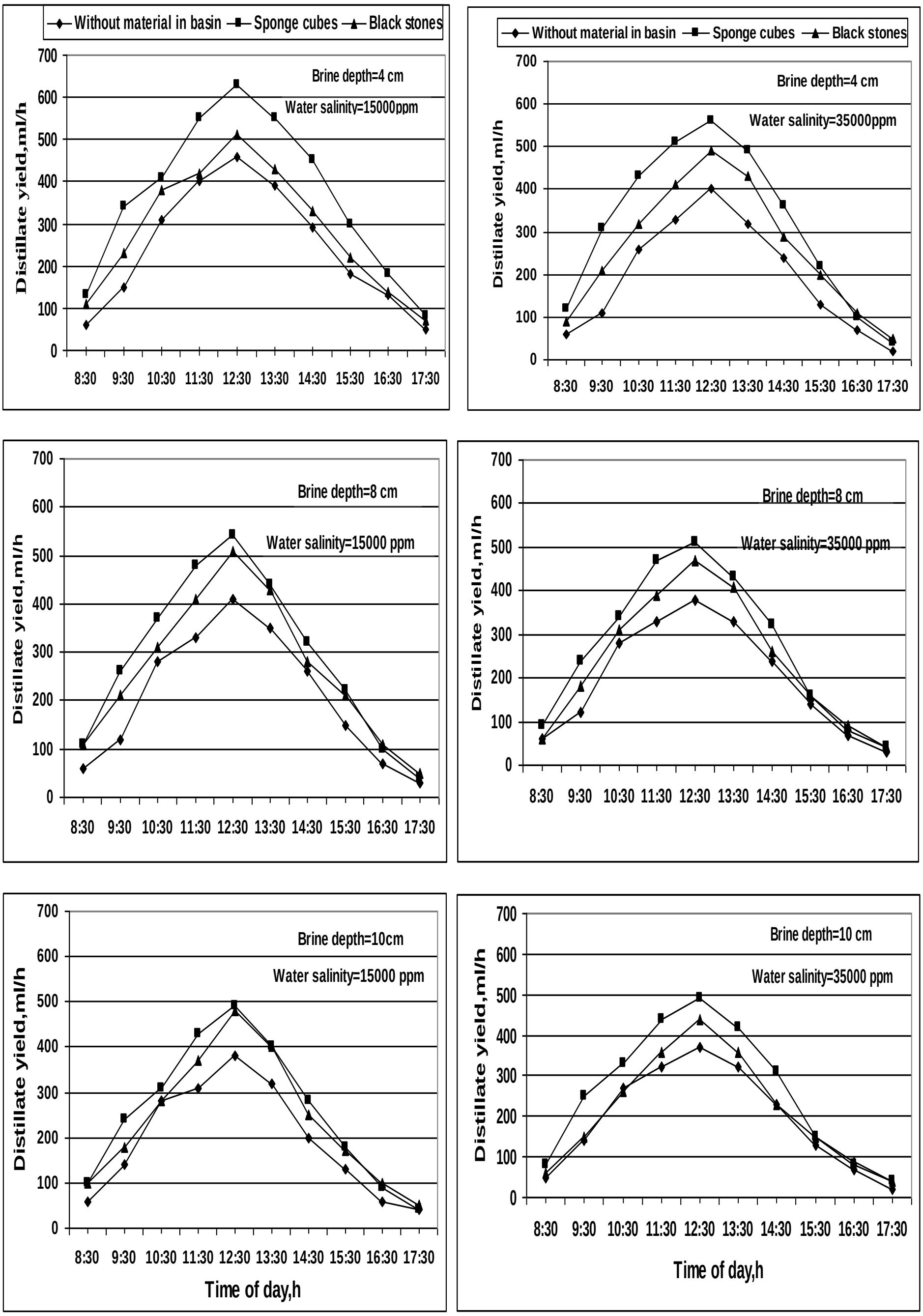

Fig.(4): Effect of brine depth , water salinity and the auxiliary black materials in basin on the distillate yield during time of day.

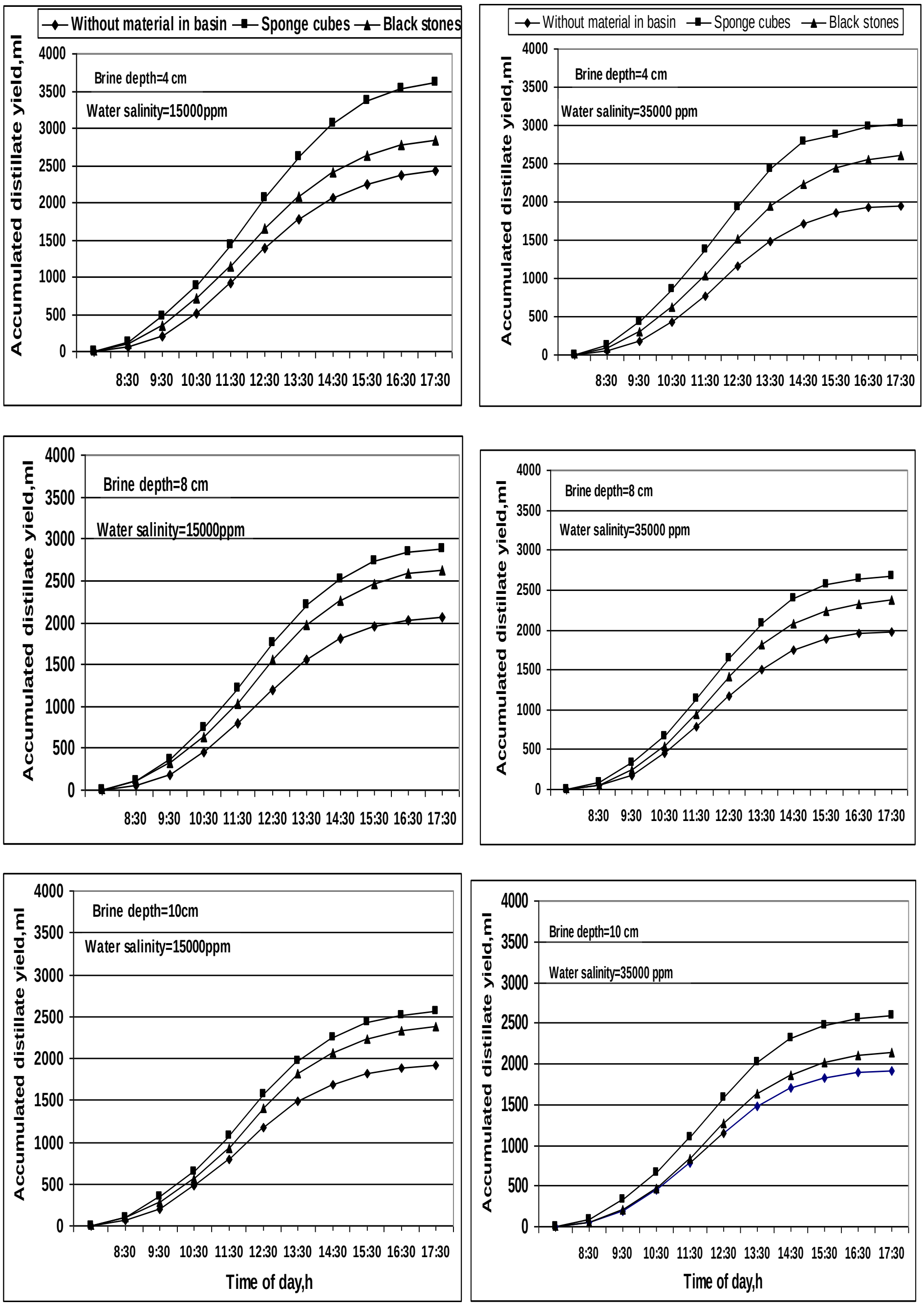

Fig.(5): Effect of brine depth , water salinity and the auxiliary black materials in basin on the accumulated distillate yield during time of day.

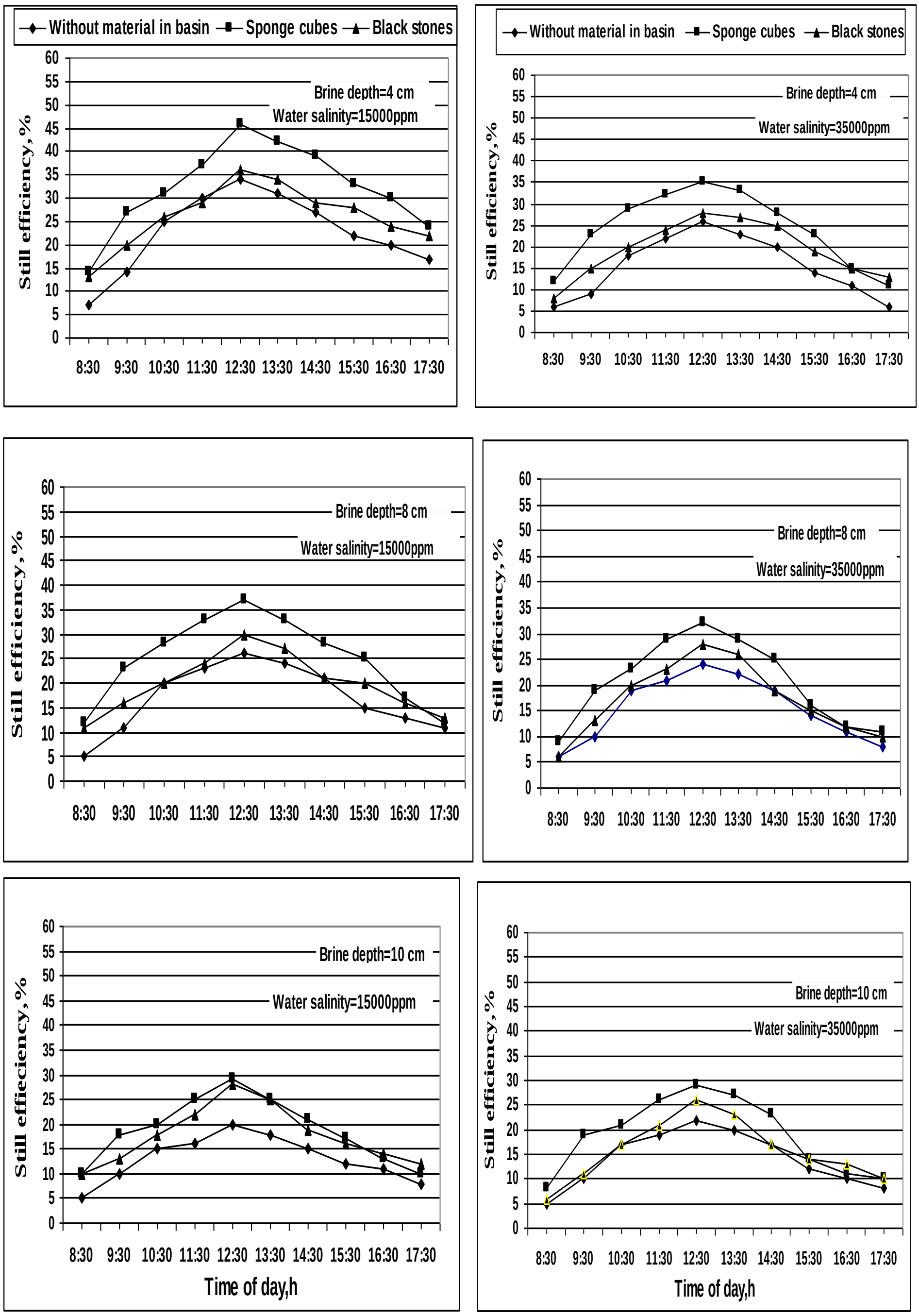

Fig.(6): Effect of brine depth , water salinity and the auxiliary black materials in basin on the still instantaneous efficiency during time of day.

brine density increases as the saline water concentrate increased, thus the heat capacity of water mass will increase leading to lower temperature and evaporation rate. Fig.(6) illustrates that the black sponge cubes gave the highest values of still efficiency compared to the black stones and without auxiliary material in basin under all studied parameter. Operating the solar still at brine depths of 4 and 8cm gave good values of the instantaneous efficiency by using black sponge cubes under all parameters, but using black sponge cubes with brine depth of 4cm and water salinity of 15000 ppm gave the highest still efficiency of 46.15 %.

4- Effect of brine depth, water salinity and auxiliary black materials in basin on temperature difference between the glass cover and brine at noon hour.

Fig.(7) show the effect of using the auxiliary materials in basin ,brine depths and level of water salinity on temperature difference between the glass cover and brine at noon hour. Based on the fact that the evaporation rate increases as the temperature difference between the glass and brine increased. As shown in Fig.(7), the temperature difference between glass cover and the brine decreased as both of brine depth and salinity increased. It was noticed that using black sponge cubes were achieved the highest temperature difference of 32.40 °C between glass cover and the brine compared with black stones (30.30 °C) and without material (26.10°C) at water depth of 4 cm and water salinity of 15000ppm at noon. This can be attributed to the important rule of the capillary effect in shallow depth that allow the water to rise up in short distance and reduce the surface tension of water, thus increasing the evaporating rate. Furthermore, the black sponge can store large amount of heat of solar radiation especially in afternoon period because its thermal capacity and conductivity is very low thus, the temperature of the cubes increased and consequently the brine temperature increased, while the black stones gave a good differences in temperature at the lower brine depths of 4 and

8 cm because at these depths, the voids between stones can make a thin layer of water above stones ,so the evaporation will increase and the contrarily occurred at brine depth of 10 cm also, without material in basin treatment recorded the lowest differences in temperature under all depths and levels of salinity. The results showed that, by increasing the water salinity from 15000 ppm to 35000 ppm, the temperature differences between the glass and brine temperature at noon hour decreased by 6.25, 9.00 and 11.53% for black sponge cubes, black stones and without material respectively at brine depth of 4 cm, while the difference decreased by 10.34, 11.53 and 13.04% for black sponge cubes, black stones and without material respectively at depth of 8cm. At depth of 10cm, the difference decreased by 13.46, 15.9 and 17.50% for black sponge cubes, black stones and without material respectively. From previous discussion, it can be concluded that using black sponge cubes at brine depth of 4 cm and the lower water salinity of 15000 ppm gave the highest temperature difference between the glass cover and brine, resulting in increasing the evaporating rate.

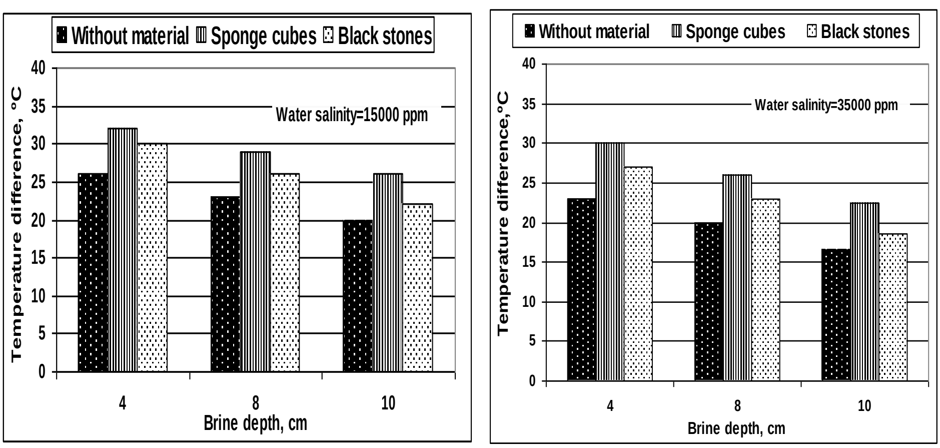

Fig.(7): Maximum temperature difference between the glass cover and brine under the studied variables at noon hour.

CONCLUSION

The obtained results revealed that:

1- The distillate yield attained its maximum value at the noon hour .The highest distillate and accumulated yield are 630.40 ml/h and 3620.45 ml respectively were achieved at brine depth of 4 cm and water salinity of 15000 ppm using black sponge cubes.

2- The still instantaneous efficiency decreases as the brine depth and water salinity increased, where the black sponge cubes gave the highest value of still instantaneous efficiency of 46.15 % at brine depth of 4cm and water salinity of 15000 ppm .

3- The temperature difference between glass cover and brine decreased as the both of brine depth and salinity increased. The black sponge cubes at noon achieved the highest temperature difference of 32.40 °C at water depth of 4 cm and water salinity of 15000 ppm, where the black stones gave a good difference in temperature at the lower brine depths of 4 and 8 cm by decreasing voids between stones to make a thin layer of water above stones.

4- The main problem of this still is the accumulation of condensate droplets in the trough of the triangle glass sheet at the inclined side direction, so a slight tilt angle towards one of the both sides of still may be the best solution for this problem.

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الملخص العربي

تحسين أداء جهاز تحلية المياة الشمسي ذو الشكل الهرمي

محمد على توفيق*

الهدف الرئيسي لهذة الدراسة هو تحسين أداء جهاز التحلية الشمسي ذو الشكل الهرمي وذلك من خلال دراسة بعض العوامل المؤثرة علي إنتاجية و كفاءة الجهاز التي تشمل شدة الأشعاع الشمسي،عمق المحلول الملحي، درجة ملوحة المياة وفرق درجات الحرارة بين كل من الغطاء الزجاجي و درجة حرارة المياة المالحة بحوض الجهاز. لذلك تم تصنيع جهاز بسيط لتحلية المياة بالطاقة الشمسية ذو شكل هرمي بمساحة كلية ٠.٦٤ م^{٢} مزود بأربع شرائح من الزجاج الشفاف بسمك ٣ مم مجمعة بدون إطار حيث أختبر الجهاز مع إضافة مواد ذات أسطح سوداء ماصة للحرارة لحوض الجهاز وذلك من الساعة الثامنة صباحاّ إلي السادسة مساءاّ .تم تقييم أداء الجهاز وذلك بإستخدام ثلاث أعماق للمحلول الملحي وهي ٤، ٨ ، ١٠سم مع درجتين لتركيز الأملاح و هي ١٥٠٠٠ و٣٥٠٠٠ جزء في المليون وهي تناظر كل من المياة الغير عذبة و مياة البحر علي التوالي وذلك في وجود مواد ذات أسطح سوداء ماصة للحرارة وتشمل مكعبات من الأسفنج الأسود و الحصي الأسود. وقد أوضحت نتائج الدراسة أنه حول ساعة الظهيرة فأن إستخدام مكعبات الأسفنج الأسود عند عمق ٤سم للمحلول الملحي داخل حوض الجهاز و التركيز الأقل للملوحة وهو١٥٠٠٠ جزء في المليون أعطت أعلي كفاءة لحظية (٤٦.١٥ %) و أعلي فرق في درجات الحرارة بين كل من الغطاء الزجاجي و المحلول الملحي(٣٢ درجة مئوية) وكذلك أعلي إنتاجية للساعة (٦٣٠,٤٤ مل/ساعة) وأعلي أنتاجية تراكمية في اليوم (٣٦٢٠,٤٥ مل) وذلك إذا ما قورنت بالمعاملات الخاصة بالحصي الأسود أو المعاملات التي لم تستخدم فيها أي مواد مضافة للحوض. نخلص من هذه الدراسة إلى التوصية باستخدام مكعبات الأسفنج الأسود مع أقل عمق للمياة المالحة داخل الحوض (٤سم) مع أقل تركيز للمحلول الملحي (١٥٠٠ جزء في المليون) للحصول علي أعلي إنتاجية يومية وكفاءة لحظية للجهاز .

*** مدرس الهندسة الزراعية – كلية الزراعة – جامعة الزقازيق- مصر.**