THE EFFECT OF DISTILLER SHAPE FACTOR TO THE DESALINATING WATER BY SOLAR ENERGY

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Abstract

Three experimental distillers were designed, constructed and installed at the Agricultural Engineering Research Institute (AEnRI) in order to desalinate water during May 2003. These units were constructed as box shape with three different tilt angles (20°, 30° and 40°), single and double glass covers. Black basalt stones were used inside the distiller during the distillation experiment to store energy which was absorbed from the sun during the day light and used through the night. Comparative studies were made between the effect of shape factor with different tilt angles and different covers (single & double) in order to assess the desalinating water by using the net energy radiation among distillers' surfaces. The data obtained showed that the salinity of water reduced from 1990 ppm before testing to the range zero to 30 ppm after desalinating. The average discharge of each unit was 3.1, 3.3 and 2.2 l/m^2 and increased to 4.06, 4.2 and 2.4 l/m^2 for tilt angles 20°, 30° and 40°, respectively, when double glass cover and basalt stone were used.

INTRODUCTION

Since 1973, energy conflict became eminent. There has been shortage of fuels in many parts of the world and their prices increased steeply. In addition, combustion of fossil fuels causes serious air pollution with harmful effect on the environment. Now, alternative sources of energy are sought to conserve the environment. Solar energy conversion technologies are different from region to another, partly because of the varying solar intensities, and mainly due to economy and industrial advancement of the country. The solar energy incident on Egyptian land has a magnitude of 3.2 – 4.9 kWh/m^2 per day in winter and 7.8 – 8.8 kWh/m^2 per day in summer, and that sun-shine duration per day extends to about 9.2 – 11 hours (Saad *et al.*, 1992 and Sayigh, 1977).

Hoda (1985) mentioned that the functions of a solar collector are to absorb solar radiation, convert it to heat, and transfer the heat to the transport fluid which moves depending on the environmental conditions, such as : operating temperature, mass flow rate, and design features of the collector.

Faber (1973) summarized the use of solar energy and described the activities of Solar Energy Laboratory of Florida. These activities include converting solar energy to more useful forms of power and devices to produce it in the fewest possible steps by the simplest means. The solar energy was used in different ways in this laboratory as follow: solar water heating, swimming pool heating, housing heating, solar baking, solar refrigeration and air conditioning, solar energy concentration, solar power, solar cooking, solar furnace, converting solar energy into mechanical power, solar water pumps, converting solar energy into electricity, sewage treatment using energy and solar distillation systems.

Kreider and Kreith (1981) reviewed the history of solar energy serving as the foundation for present and future work in the field. People in Western Society have been making use of the sun intermittently over the past 250 years, but it seems that directly there is a correlation between the use of solar energy and the price and availability of other energy sources especially in areas where sufficient amount of solar energy are available. They also illustrated that the flat plate collector is commonly used to convert the sun's radiant energy to heat. The temperature level of this converted energy is the key parameter that must be known to effectively match a conversion scheme to a specific task.

To evaluate the performance of a distiller, the efficiency (η_{dist}) should be calculated. The efficiency is defined as the percentage of the water evaporation energy to the solar radiation falling on the distiller as follows:

$$\eta_{dist} = q_e / G_t \text{ --(1)}$$

Where:

q_e = Is the heat evaporation energy (W/m^2).

G_t = Is the solar radiation energy (W/m^2).

This efficiency is instantaneously measured, so that daily efficiency (η_d) is defined as the daily energy required for water evaporation, and may be calculated as follows:

$$\eta_d = 3600/H_d \int q_e \, dt \text{ ------------------------------------(2)}$$

Where :

t = Is the time measured from the start of operation.

H_d = Is the daily solar radiation.

The internal efficiency of the distiller (η_i) is defined as the useful heat energy in evaporation to the absorbed heat energy by the water and may be represented as follows:

$$\eta_I = q_e / \alpha_w \tau_g G_t \text{ ------------------------------------(3)}$$

Where :

α_w = Is the water absorptivity

τ_g = Is the glass transimitivity.

The internal efficiency was used to evaluate the different heat transfer processes inside the distiller. The main problem statement is that the people in the desert and the remote regions depend upon the underground water which contains salts, hence the objective of the present research is the desalination of water using solar energy through the evaluation of different types of distillers used.

MATERIALS AND METHODS

1- Distiller construction

It is important to design the system as simple as possible so that it is easy to operate and can be manufactured locally by using the available raw materials. The design was based on the basin distiller type. The collector was made of steel sheets 0.8 mm and insulated with 25 mm thicknesses insulation and covered from outside by wood. The inner surface was painted black. The saline water was stored in a 200 litter tank and fed to the distiller through pipes. The water level inside the distiller was controlled by floating and kept at 3 cm height. The fresh water was collected in plastic bottles outside the distiller through u shape channel. And the distiller covered by 3 mm thick glasses Fig. (1) illustrates a sketch of three distillers used and shows the saline water feeding and the fresh water collection.

2- Measurements:

In order to evaluate the performance of the distiller, the temperatures are recorded at the glass surface, the back of the distiller, the air inside, the water, and the ambient air temperature. The temperatures are measured by using calibrated thermocouples type (T) connected to data collection system (KAYE – DIGISTRIP II) with 48 channel. Also the water salinity is measured before and after testing. A Japanese made solar meter with range measurement 0–2 $cal/cm^2 min$,100mV/cal cm^2 min^{-1} ,and accuracy ± 5% is used to measure the solar intensity during sun shine.

The shape factor represents that fraction of the total energy emitted from a surface and intercepted by another surface. This factor was calculated based on the following equation (Holman, 1981):

$$q_{1\leftrightarrow 2} = (E_{b1} - E_{b2}) \int A_1 \int A_2 [\cos\theta_1 \cos\theta_2 \, dA_1 \, dA_2 / \pi R_2] \text{ --- (4)}$$

Where:

$q_{1\leftrightarrow 2}$ = The net heat exchange between two surfaces 1 and 2.

E_{b1}, E_{b2} = Energy emitted from surfaces 1 and 2, respectively

dA_1, dA_2 = The differential areas of the two surfaces 1 and 2

θ_1, θ_2 = The angles between the normal line on differential areas dA_1, dA_2 and the line between the two differential areas dA_1 and dA_2

R_2 = The line between the two differential surfaces dA_1 and dA_2

$\int A_1 \int A_2$ = The double integration may be written as $A_1 F_{1\rightarrow 2}$ or $A_2 F_{2\rightarrow 1}$ and

F_{12} = Is called the shape factor or configuration factor based on A_1.

RESULTS AND DISCUSSION

Solar energy has the potential for providing a significant portion of required energy used in the desalinating water. The energy source for desalinating water is dependent upon the development of solar energy distillery that has optimum performance, good reliability, and economic characteristics.

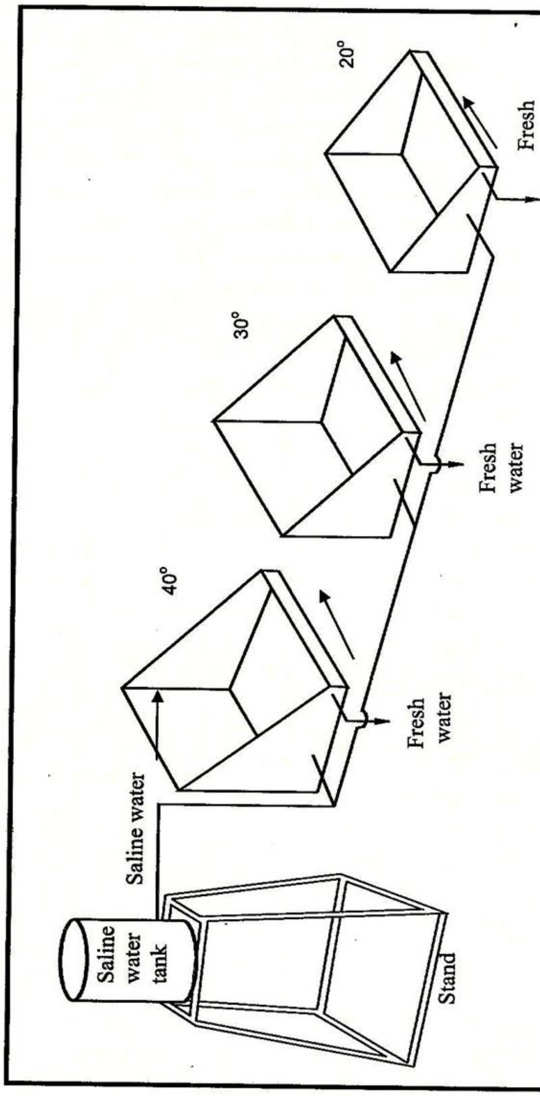

Fig. 1. A sketch illustrating the system components

Using the basalt stones inside the distillery raised the distillery efficiency and raised the water evaporation inside the distillery at the glass surface (it increases the water discharge from the distillery).Also using double glass covers (the air between the two glass covers worked as isolation) reduced the temperature losses from the top of the distillery.

As the result from the previous steps, it was found that the air temperature inside the distillery was increased very fast. This raised the amount of the daily water distillation from 3.1, 3.3, and 2.2 L/m^2 for single glass cover to 4.06, 4.2 and 2.4 L/m^2 by using double glass covers for tilt angles 20°, 30° and 40°, respectively.

The results of the shape factor calculations indicate that the heat energy transmitted by radiation between the back surface and the water is very small compared with those transmitted from the back surface and the glass and the water and the glass. The shape factor doesn't change when using double glass covers because it equals unity between parallel glass covers. The shape factors between the distillation surfaces were calculated using equation (4) and listed in the following table:

Table 1. The shape factor values among the different parts of the distillers.

Tilt Angle	$F_{g\to b}$	$F_{b\to g}$	$F_{g\to w}$	$F_{w\to g}$	$F_{b\to w}$	$F_{w\to b}$
20°	0.25	0.40	0.33	0.33	0.11	0.07
30°	0.25	0.33	0.34	0.37	0.09	0.07
40°	0.32	0.38	0.34	0.45	0.07	0.08

But the amount of energy transferred between distillatory parts by radiation was different because the amount of energy increased with the temperature rise between the distillery parts. Therefore, the minimum temperature was found between the water surface and the back surface, where the maximum temperature was found between the water surface and the glass surface in the distillatory.

The relationship of the heat transfer by radiation between the glass cover and the water surface was a linear equation given by:

$$q_{net} = a\,\Delta T - b \text{ ------------------ } (5)$$

Where:

a = represented the line slope and

b = is a constant and equals the cut part from (Y) axis.

The correlation factors (R^2) were about 97.8% 98.22%, and 90.9% for the different angles 20°, 30° and 40°, respectively, as shown in Figs. (2), (3) and (4).

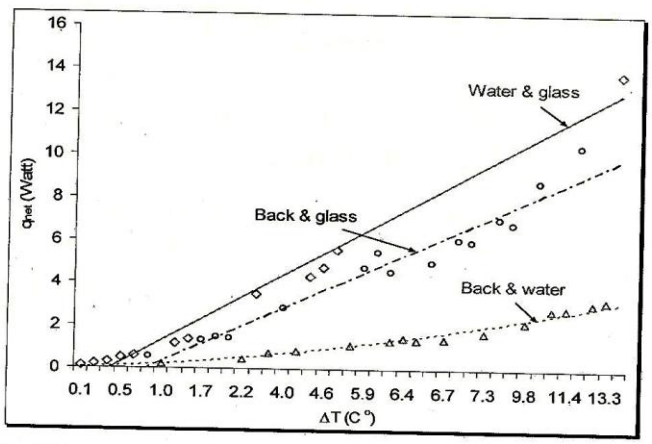

Fig. 2. Energy transmitted among solar collector components at tilt angle 20°.

Also the heat transfer by radiation between the glass surface and the back surface to the distillatory follow the same equation with some difference of the constants (a) and (b) and the correlation factor (R^2) 73%, 95% and 78% for the angles 20°, 30° and 40°, respectively, as shown in Figs. (2), (3) and (4).

But the lowest value of the heat transfer has been found between the water surface and the back surface; it follows the power equation:

$$q_{net} = c\,(\Delta T)^{d} \text{ ------------------- } (6)$$

Where (d) and (c) are constants and the correlation factor (R^2) is 83%, 98.3% and 89% for the angles 20°, 30° and 40° respectively and it is shown in Figs. (2), (3) and (4).

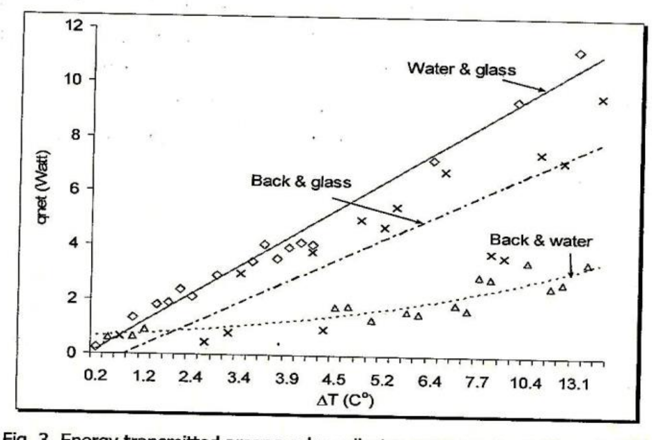

Fig. 3. Energy transmitted among solar collector components at tilt angle 30°.

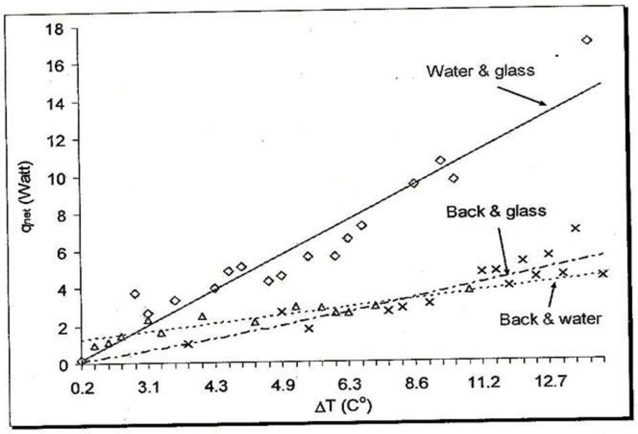

Fig. 4. Energy transmitted among solar collector components at tilt angle 40°

Using equations (1), (2), and (3) the different efficiencies were calculated. The average instantaneous efficiencies were 31.2%, 30.8% and 19.7% with tilt angles 20, 30 and 40 degrees, respectively. White, the average daily efficiency was higher for the tilt angle 30 degree (25.5%) while was 24.9% and 15.4% for 20 and 40 degrees, respectively. The average internal efficiency was 39.3% with tilt angle 20 degrees and 38.9% with tilt angle 40 degrees while was 24.9% with tilt angle 30 degrees. These results indicated that using tilt angle 20 degrees is better in summer because the angle of the sun is high and need a tilt angle more likely close to earth to receive the solar radiation. White 40 degrees tilt angle in winter is available since the angle of the sun is low and need a tilt angle more likely away from earth to receive the solar radiation. So 30 degrees tilt angle is preferred all over the year which represents the altitude angle of the test area.

CONCLUSION

1. The highest energy have been transferred between the water surface and the glass surface.
2. Using the basalt stones help the distillery to store the temperature and use it during the day night to raise the efficiency of the distillery at night time.
3. The water distillation efficiency was 23%, 35% and 27% at the different tilt angles 20°, 30° and 40°, respectively.

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تأثير عامل الشكل للمقطر المائي على تحلية المياه باستخدام الطاقة الشمسية

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تم تصميم ثلاث نماذج تجريبية للمقطرات بقسم بحوث القوى و الطاقة بمعهد بحوث الهندسة الزراعية مركز البحوث الزراعية فى شهر مايو ٢٠٠٣ . هذه المقطرات من النوع الصندوقى ذات السطح المائل و كل نموذج له زاوية ميل مختلفة على السطح الافقى و هى ٢٠ ، ٣٠ ، ٤٠ ° على الترتيب وتزويد الاسطح المائلة بغطاء وغطائين من الزجاج. وقد تم تزويد المقطرات باحجار البازلت وذلك لتخزين الطاقة الشمسية نهارا واعادة استخدامها ليلا لرفع كفاءة المقطر.

تم عمل دراسة مقارنة بين تاثير عامل الشكل والزوايا المختلفة مع تغيير عدد الاغطية الزجاجية و ذلك لرفع كفاءة المقطر.

اوضحت النتائج ان نسبة الملوحة فى الماء انخفضت من ١٩٩٠ وحدة فى المليون قبل التقطير الى متوسط من صفر الى ٣٠ وحدة فى المليون بعد عملية التقطير. و كان متوسط الانتاجية للمقطرات على الترتيب ٣,١ - ٣,٣ – ٢,٢ لتر/متر^{٢} و قد ارتفعت الى ٤,٠٦ – ٤,٢ – ٢,٤ لتر/متر^{٢}/يوم على الترتيب للمقطرات الثلاثة ذات ميل ٢٠° ، ٣٠° ، ٤٠° مع استخدام سطح زجاجى مزدوج.

وقد اوضح عامل الشكل ان اعلى كمية تبادل للطاقة داخل المقطر كانت بين سطح الماء والسطح الزجاجى. وان استخدام احجار البازلت داخل المقطرات ادى الى زيادة الطاقة المخزنة داخل المقطر وادى ذلك الى ارتفاع الكفاءة الكلية للمقطرات. وكانت متوسط الكفاءة اليومية للمقطرات الثلاث هى ٢٣% ، ٣٥% ، ٢٧% على الترتيب.