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WATER DESALINATION USING THERMAL APPLICATIONS OF SOLAR ENERGY

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ABSTRACT

Desalination of brackish water by solar powered systems is a practical and promising technology for producing potable water in the regions which suffers from water scarcity especially in arid areas. Therefore, a small-scale solar powered desalination system has been constructed and operated for using the desalination solar technology to produce the fresh water, for domestic use. In the present investigation, a parametric study of passive solar still is presented, to improve the solar still performance. To increase the productivity of this solar still, a flat plate solar collector was integrated with the solar still (active solar still). Hence, the present study aims to evaluate and compare between passive and active solar stills based on the productivity values. The obtained data showed that by applying solar still cover cooling, the highest productivity is 7.80 l/m^2.d. when the glass cover inclination is 0.436 rad (25 deg.) and the water basin depth is 1cm for passive solar still. The highest productivity for active solar still is 10.06 l/m^2.d. when the flat plate solar collector inclination is 0.436 rad (25 deg.).

Keywords: Desalination, double slope solar still, flat plate solar collector, solar energy, brine depth, solar insolation.

INTRODUCTION

Water is a nature's gift and it plays a key role in the development of an economy and in turn for the welfare of a nation. Non-availability of drinking water is one of the major problem faced by both the under developed and developing countries all over the world. Around 97% of the water in the world is in the ocean, approximately 2% of the water in the world is at present stored as ice in polar region, and 1% is fresh water available for the need of the

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plants, animals and human life (Vinothkuumar and Kasturibai, 2008).

Alarms have recently been sounded about Egypt's limited water resources. Surface water resources originating from the Nile are fixed at 55.5 billion m^3 a year and are being completely used, whereas non-renewable ground water sources in the western desert are being brought into full production. The situation is worsening by growing water requirements, demanded by a population boom which needs more agricultural areas to produce more food.

As natural fresh water resources are limited, sea water plays an important part as a source for drinking water as well. In order to use this water, it has to be desalinated. So, sea water desalination is a real challenge for eastern civilization. It is therefore beneficial to exploit solar energy directly by installing solar stills. Technologies available for desalination range from family sized solar stills to city sized treatment facilities.

Great efforts have been carried out by some researches, to improve the production capacity of the solar stills by adopting different techniques under proper operational conditions.

Al-Hinai *et al.* (2002) indicated that during the winter months, increasing the cover tilt angles tends to increase the yield of the still with an opposite effect during the summer. The optimum tilt angle of the cover is obtained by taking the average still yield when various cover tilt angles are used over the whole year. The optimum tilt angle in this study is found o.401 rad (23 deg.).

Chaibi (2003) showed that for basin solar stills, glass cover slope higher than o.401 rad (23 deg.) increase productivity in winter and decrease it in summer. For slope of o.785 rad (45 deg.), the productivity increase in winter by 9% and in summer decrease by 6% and the yearly optimal slope is o.611 rad (35 deg.).

Nafey *et al.* (2004) stated the effect of cooling water flow rate on the system productivity at different values of cooling water inlet temperature. They observed that by increasing the cooling water flow rate and decreasing the inlet cooling water temperature, the surface temperature of the air cooler decreased; hence the condensation rate and the unit productivity increased.

Badran and Al-Tahaineh (2005) studied the effect of coupling flat plate solar collector on solar stills productivity. They found that coupling solar collector with solar still increased the productivity by 36%.

Tarawneh (2007) showed that the deciding role of cooling the glass cover was strongly observed on the increased temperature difference (T_w-T_g) as well as on the increased water productivity. The effect of cooling the glass cover shows an increase on the water productivity with about 17-23%.

Tiwari *et al.* (2009) discussed the effect of water depth on the daily yield of the active solar still integrated with a flat plate collector. They showed that the yield decreased with the increased of water mass. The decrease in the yield may be attributed to a higher specific heat capacity of water by the increased water mass.

Sampathkumar *et al.* (2010) showed that the solar distillation systems are mainly classified as passive solar still and active solar still. In a passive solar still, the solar radiation is received directly by the basin water and is the only source of energy for raising the water temperature and consequently, the evaporation leading to a lower productivity. Later, many active solar stills have been developed. Hence, an extra thermal energy is supplied to the basin through an external mode to increase the evaporation rate and in turn improve its productivity.

Velmurugan and Srithar (2011) showed that an enhancement in productivity of the still can be increased by introducing a sprinkler (Cooling film) to the outer layer of the glass cover of the still. This modification will increase the productivity by 22%.

The study aimed to 1. Investigate the performance of the solar desalination system under different operational and design parameters. 2. Evaluate and compare the daily productivity of the passive solar still (Triangular solar still) and the active solar still (Solar still integrated with a flat plate solar collector).

MATERIALS AND METHODS

The present study was carried out at the Faculty of Agriculture, Zagazig University, Zagazig city (30° 2' N latitude and 31°12' E longitude), in eastern delta, Egypt during the summer seasons of 2009 and 2010.

Materials

A small-scale hydrological cycle can be created in a well designed solar still. The air tightness and the good insulation are two essential design parameters that should be highly considered in order to minimize the vapor leak and heat loss tendencies.

Saline water

The saline water is the fluid that naturally flowed through the desalination process. Also, it is the raw material to produce fresh water. The saline feed water in this work was ground water (TDS of 4.5 dS/m).

The Components of Solar Desalination System

Raw water tank

The water tank located at the highest level of the still unit, saline water flowed from its outlet hole (at its bottom) with feed rate of 0.8 l/h to the flat plate solar collector due to thermosyphon effect, as shown in Fig. 1. The water tank made of 0.2 cm thickness galvanized iron sheet rolled as cylinder then soldered, it has a diameter of 40 cm, a height of 45 cm and its volume is 0.0565 m^3. One black iron screwed pipe soldered as outlet hole controlled by hand valve.

Solar still unit (Triangular solar still)

The solar still has a rectangular box shape. It consists mainly of a black tray as evaporator (170 × 70 cm) which created a net square area of 1.19 m^2. The still unit wall consists of three layers: counter wood of 2 cm thickness, fiberglass of 2.7 cm thickness and galvanized iron sheet of 0.3 cm thickness and the outside height of the basin is 15 cm.

The space above the basin is completely enclosed with four airtight glass covers (0.3 cm thickness) with slope of 0.436 rad (25 deg.), its three views shown in Fig. 2. The glass cover is sloped towards a condensate channels (U-troughs) which run along the lower edges of the glass pan with a small inclination in order to speed up the condensate velocity and to avoid the tendency of re-evaporation. Two sprinklers are constructed and installed on the top part of the solar still in order to ease splashing method and to cool the glass cover.

S.N.	Part name	Material type
1	Triangular solar still	Galvanized iron sheet
2	Flat plate solar collector	Galvanized iron sheet
3	Raw water tank	Galvanized iron sheet
4	Stand	Iron
5	Connecting pipe	Rubber
6	Graduated flasks	Glass

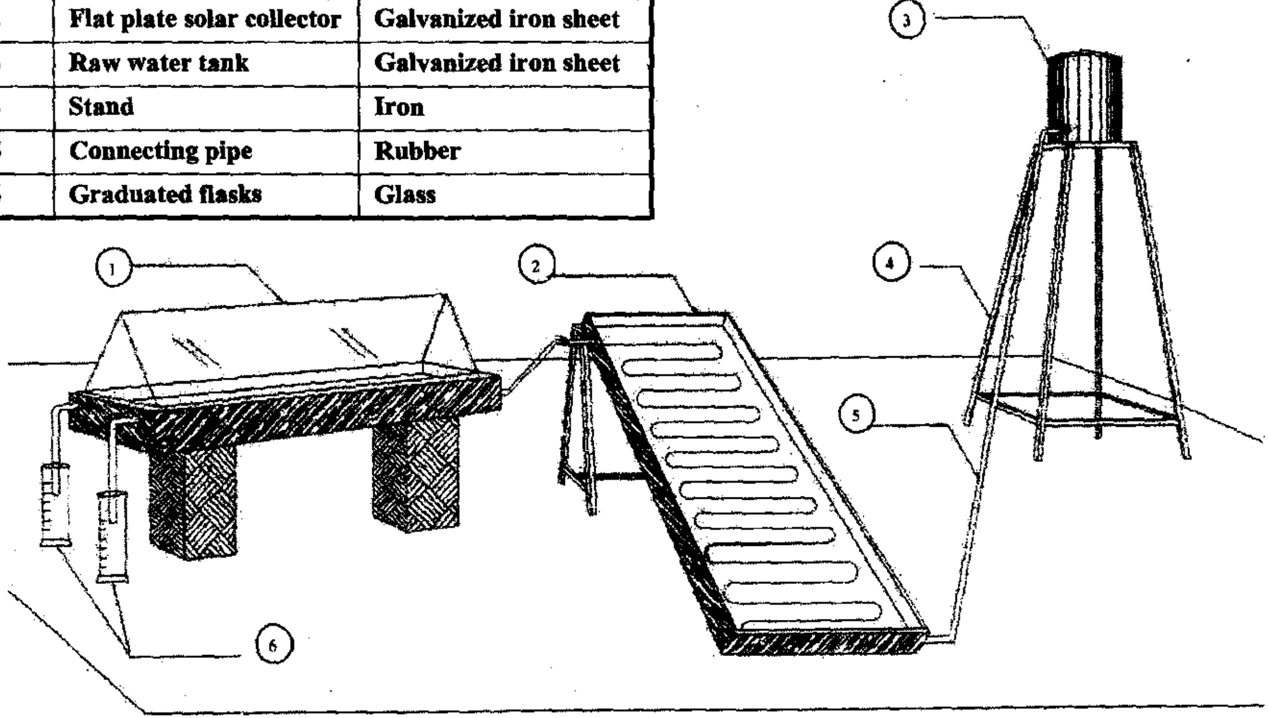


Fig. 1. The schematic diagram of triagram solar still integrated with flat plate solar collector (Active solar still)

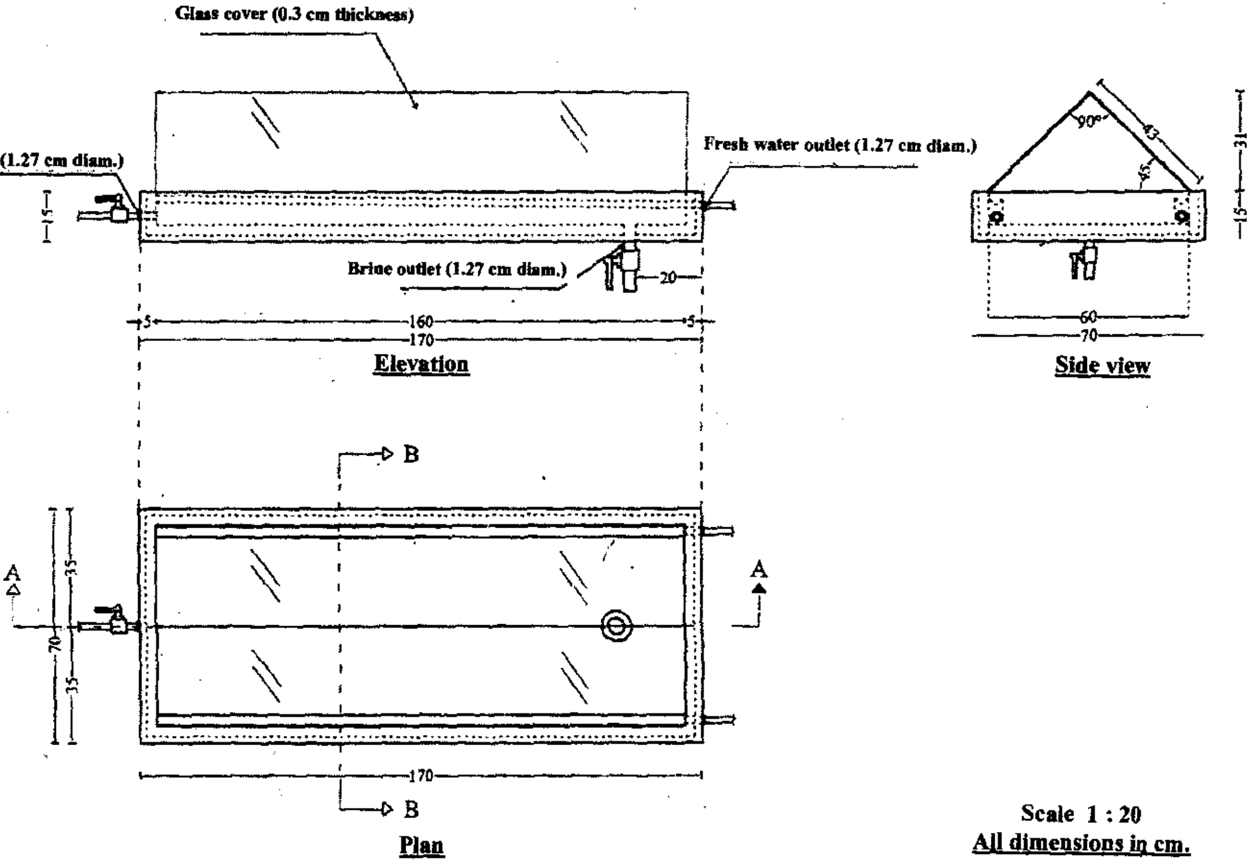


Fig. 2. The three views of the triangular solar still

Flat plate solar collector

The flat plate solar collector is designed of rectangular section shape (180 × 75 cm). It fixed inside external body made of wooden sheet (2 cm thickness), its absorber plate and sidewalls are made of galvanized iron sheet (0.3 cm thickness), painted with black painter to maximize solar energy absorption and insulated from heat losing by fiberglass insulation (2.7 cm thickness), as shown in Fig. 3.The absorber plate soldered with 19 horizontal copper pipes and flat glass cover (0.3 cm thickness), it was south facing and inclined of 0.523 rad (30 deg.) with horizontal (equal to the latitude of the place, where the latitude of Zagazig is 30° 2' N.

Saline water flowed to the flat plate solar collector from the raw water tank then heated by solar radiation in its copper pipes, raised up and exited from the flat plate solar collector to the solar still unit.

Connection piping

The connection piping is made from rubber tubes fixed with all inlet and outlet pipes with metal seal and insulated with sticking rubber tube to prevent any heat losing through saline water flow. Also, it associated with hand valves made from galvanized steel to shut and open any part and measure flow rate at some points.

Methods

The experiments of the solar desalination system were conducted from 9 a.m. to 5 p.m., the productivity of passive and active solar stills were measured with hour intervals to choose the proper conditions which accompanied with highest productivity under four water depths of 1, 2, 3 and 4 cm, three different rates of cooled water to cool the glass cover under control with continuous flow of 2.5, 5 and 7.5 l/h, then water cooling has been carried out in flash tactic (the cooling done from time to time in) every 5 minutes (five minutes on and five minutes off), this method was iterated but every 10 and 15 minutes and three inclination angles of glass cover of 0.436, 0.611 and 0.785 rad (25, 35 and 45 deg.).

The effect of the flat plate solar collector and its inclination on the productivity was also considered to compare between the performance of passive and active solar stills and to determine the optimum inclination angle of the flat plate solar collector on the productivity using three inclination angles of 0.436, 0.523 and 0.611 rad (25, 30 and 35 deg.).

RESULTS AND DISCUSSION

The obtained results were discussed as follows:

The Effect of Operational Parameters on the Productivity

Water brine depth

As shown in Fig. 4, the increase of the water depth from 1 to 2 cm followed with a productivity decrement by 4.39% (from 6.38 to 6.10 l/m^2.d.) and by 4.69% (from 8.52 to 8.12 l/m^2.d.), the increase of brine depth from 1cm to 3 cm was followed with a reduction in the still productivity by 10.34% (from 6.38 to 5.72 l/m^2.d.) and by 12.44% (from 8.52 to 7.46 l/m^2.d.), while the increase of brine depth up to 4cm caused a decrease in the still productivity of fresh water by 17.40% (from 6.38 to 5.27 l/m^2.d.) and by 23.94% (from 8.52 to 6.48 l/m^2.d.), for passive and active solar stills, respectively. That may be because of the increase of the solar radiation absorbed by the bases, which decreases the overall thermal capacity of the still.

For both the passive and the active solar still, as the basin water depth increase the daily productivity decrease due to thermal storage effect and are in its peaks at a basin water depth of 1cm, which is the lowest basin water depth can be reached to prevent dry spots. But this decrease is greater for the active solar still than that for the passive solar still because of the greater thermal storage in the basin water and greater thermal energy could be lost to ambient as shown in Fig. 5.

Solar still cover cooling

Data show that using water cooling increases the fresh water output, because by flowing thin film of cooled water over the still cover, the cover surface temperature decreased, as a result, the condensation rate and the productivity are increased. It is observed from Fig. 6 that using water cooling increases the fresh water output, whereas by using continuous flow with 2.5 l/h the productivity improved from 6.38 (nature cooling) to 6.80 l/m^2.d. and from 8.52 (nature cooling) to 8.90 l/m^2.d. for passive and active solar stills, respectively.

By increasing the flow rate from 2.5 to 5 l/h decreases the productivity by 8.82% (from 6.80 to 6.20 l/m^2.d.) for passive solar still and 8.99% (from 8.90 to 8.10 l/m^2.d.) for active solar still. Whereas by increasing it from 2.5 to 7.5 l/h decreases the productivity by 11.76% (from 6.80 to 6.00 l/m^2.d.) and 13.48% (from 8.90 to 7.70 l/m^2.d.) for passive and active

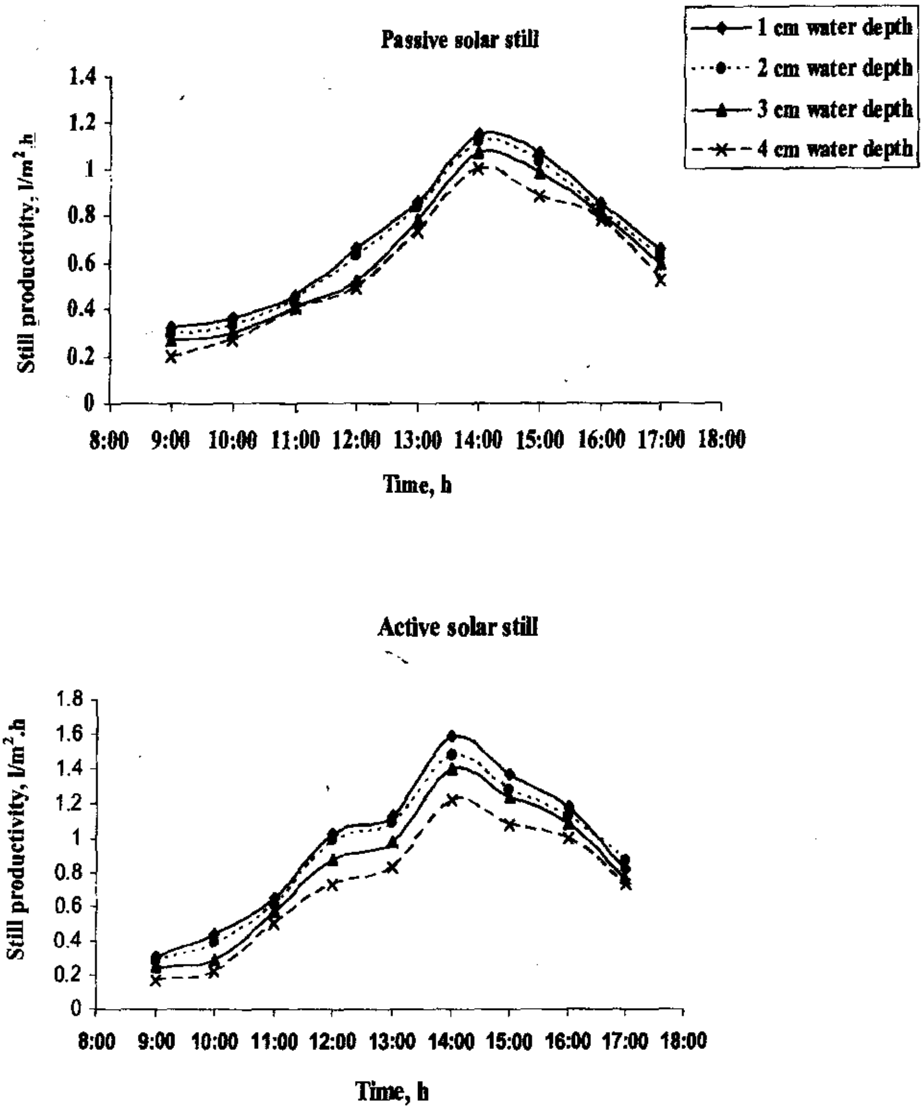


Fig. 4. Effect of water brine depth on the passive and active solar stills hourly productivity

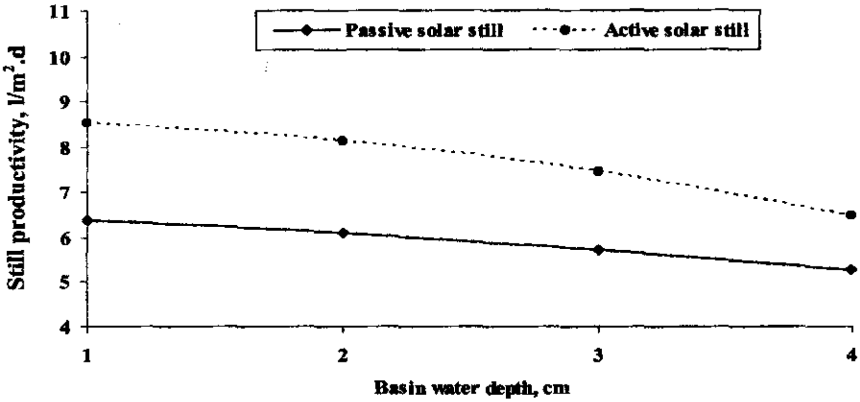
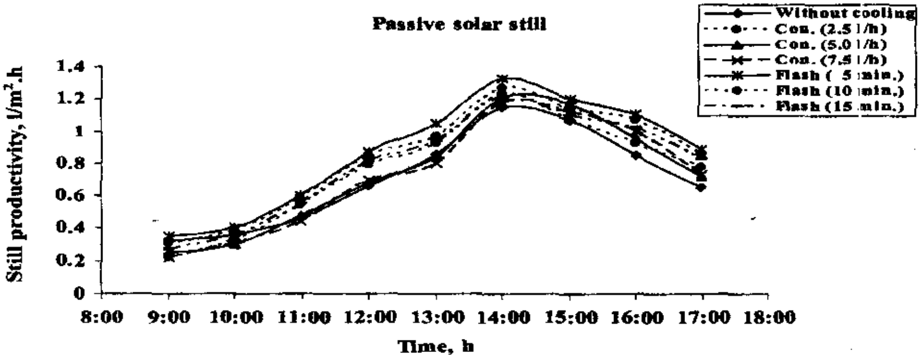


Fig. 5. Comparison between the passive and the active solar still daily productivities under different basin water depths



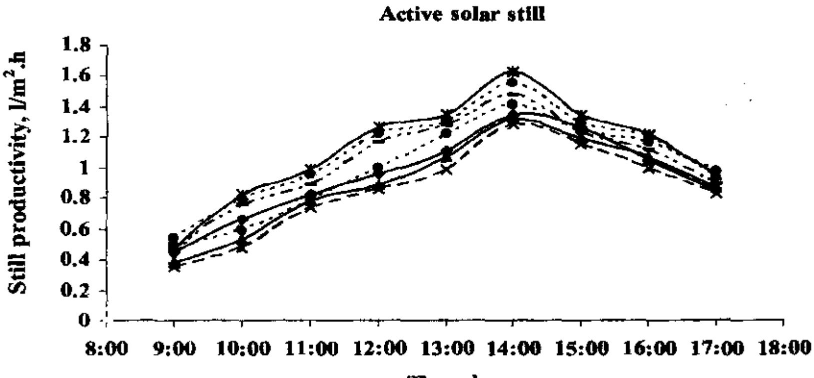


Fig. 6. Effect of cover cooling on the passive and active solar stills hourly productivity

solar stills, respectively, because the water film descended over the cover reflects part of the solar radiation addition to this continuous water film decreases the cover temperatures more than needed and absorb the heat from the still components causing energy losses, hence it decreases the thermal retention, so as the flow rate of cooling water increased, the fresh water output decreased.

It is observed that the use of flash flow by descending water film with flow rate of 2.5 l/h within 5 minutes and shut for other 5 minutes caused an increase in the daily productivity from 6.38 $l/m^2.d.$ under nature air cooling to 7.80 $l/m^2.d.$ with increment about 18.21% (passive) and from 8.52 $l/m^2.d.$ under nature air cooling to 10.06 $l/m^2.d.$ with increment about 15.31% (active). On the other hand by iterating this method but every 10 and 15 minutes, the result obtained showed that the daily productivity improved by 14.36 and 10.14% (passive) and by 13.06 and 8.39% (active), respectively, comparing with natural cooling. The productivity from the 5 minutes flash demarche increased by 4.49 and 8.97% (passive) and by 2.58 and 7.55% (active), respectively, comparing with the 10 and 15 minutes flash demarche.

It is observed that from the obtained result that the active solar still performed better under the flash cooling than under traditional cooling (natural air and continuous flow) wherein the flash cooling insures a good thermal retention which increases the evaporation rate, combined with decreasing the cover temperature which increases the condensation rate, hence increases the distillate output.

Fig. 7 shows a comparison between the passive and the active solar still daily productivities under different cover cooling treatments. It is observed that the water cooling showed better performance than without cooling and the 5 minutes flash cooling comparing with all other treatments insured the best operation conditions and obtained the greatest amount of fresh water.

The Effect of Design Parameters on the Productivity

Glass cover slope

Results obtained show that for both passive and active solar stills, the daily productivity is higher for glass cover inclination of 0.436 rad (25 deg.) and the lower for 0.785 rad (45 deg.). It is observed that the daily output decreased by 6.27% (from 6.38 to 5.98 $l/m^2.d.$) and 11.44% (from 6.38 to 5.65 $l/m^2.d.$) for passive solar still and

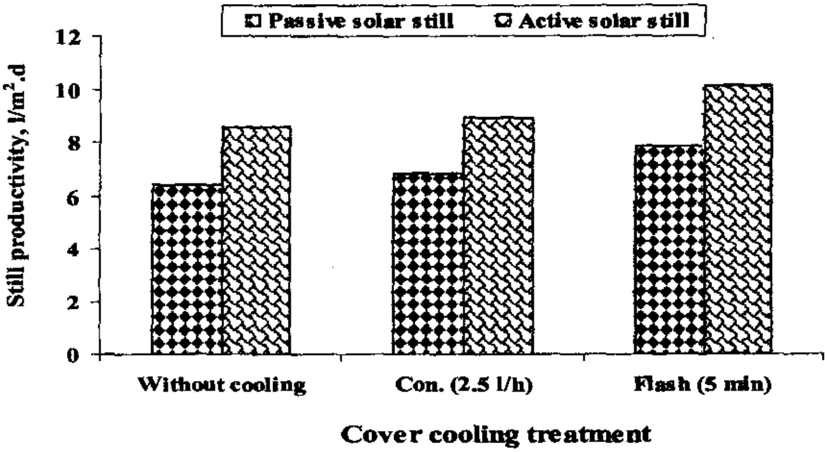


Fig. 7. Comparison between the passive and the active solar still daily productivities under different cover cooling treatments

by 3.76% (from 8.52 to 8.20 l/m^2.d.) and 4.34% (from 8.52 to 8.15 l/m^2.d.) for active solar still when glass cover inclination increased from 0.436 to 0.611 rad and from 0.436 to 0.785 rad (from 25 to 35 deg.) and from (25 to 45 deg.), respectively, as shown in Fig. 8. Generally, increasing glass cover inclination creates big internal volume which caused less heat storage capacity and low evaporation rate.

The Effect of the Flat Plate Solar Collector and its Inclination on the Productivity

To show the effect of coupling the flat plate solar collector to the solar still or the productivity difference between the passive solar still and the active solar still, their productivities during the day hours were compared as shown in Fig. 9. The daily productivity of the passive solar still and the active solar still are 6.38 and 8.52 l/m^2.d. The productivity ratio between active solar still and passive solar still (active solar still productivity/ passive solar still productivity) was calculated during the day hours, the productivity ratio is about 1.34. The productivity ratio is 0.97 after the sunrise and moves up until the noontime it is 1.56, then it moves down and up until the sunset it is 1.26. These values show that the productivity of the active solar still equal (1.34 × the productivity of the passive solar still) during the day hours, because of the thermal energy added during the day hours until the sunset.

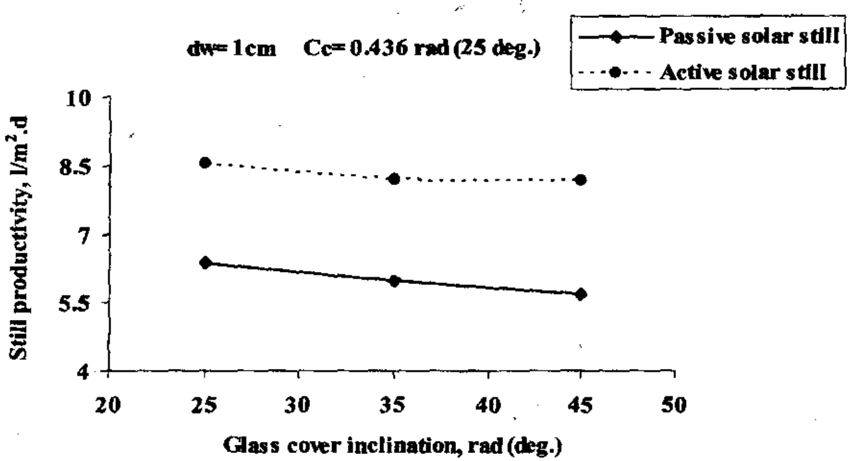


Fig. 8. Effect of glass cover inclination on the daily productivity of the passive and active solar stills

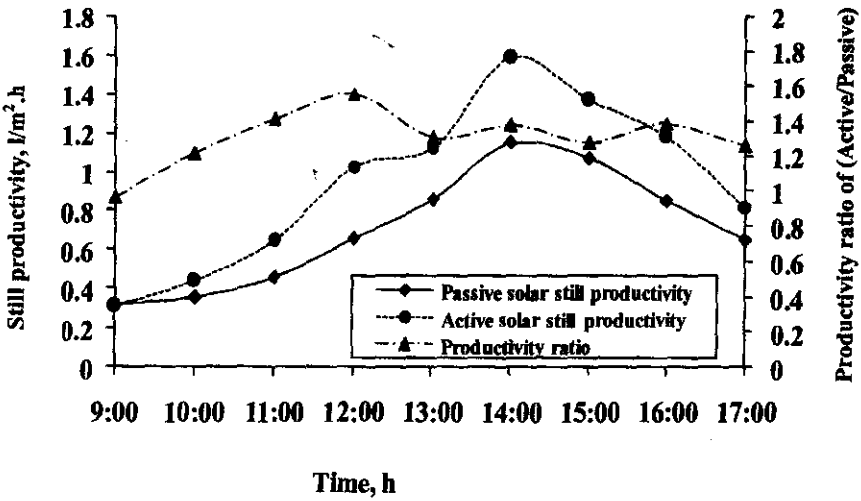


Fig. 9. Comparison between the hourly productivity of the passive and the active solar still

It was noticed that for each glass cover inclination the daily productivity is higher for flat plate solar collector inclination of 0.436 rad (25 deg.) and the lower is for flat plate solar collector inclination of 0.611 rad (35 deg.). the obtained Results show that when the flat plate solar collector inclination increased from 0.436 to 0.523 rad (from 25 to 30 deg.), the daily output decreased by 2.93%, and when it increased from 0.436 to 0.611 rad (from 25 to 35 deg.), the daily output decreased by 3.99 %. Fig. 10 illustrates that the productivity is maximum at flat plate solar collector inclination and glass cover inclination of 0.436 rad (25 deg.) for both of them.

Conclusion

From the conducted experiments and the obtained results, it can be concluded that the highest productivity can be achieved under the following conclusions: for passive solar still, the highest productivity of 6.38 $l/m^2.d$. was obtained when the glass cover inclination was 0.436 rad (25 deg.) and the water basin depth was 1cm (without applying solar still cover cooling). By applying cover cooling, the highest productivity was 7.80 $l/m^2.d$.

For active solar still, the highest productivity of 8.52 $l/m^2.d$. was obtained when the flat plate solar collector and the glass cover inclinations were 0.436 rad (25 deg.) for both of them and the water basin depth was 1cm (without applying solar still cover cooling). By applying cover cooling, the highest productivity was 10.06 $l/m^2.d$.

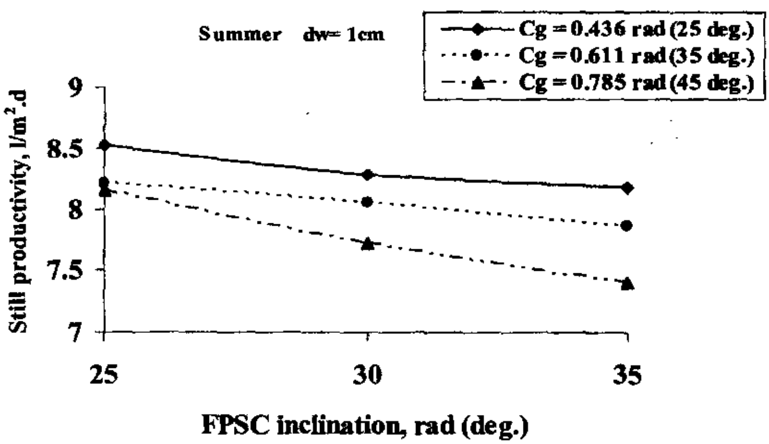


Fig. 10. Effect of the flat plate solar collector inclination on the daily productivity at different glass cover inclinations

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تحلية المياه باستخدام التطبيقات الحرارية للطاقة الشمسية

هند أحمد مجدى المغاورى – محمد قدرى عبد الوهاب

محمود عبد الرحمن الشاذلى

قسم الهندسة الزراعية – كلية الزراعة – جامعة الزقازيق

تعتبر عملية تحلية المياه الجوفية والمياه المالحة (مياه البحر) باستخدام أنظمة الطاقة الشمسية تقنية عملية واعدة بامكانية انتاج المياه الصالحة للشرب في المناطق التي تعاني من ندرة المياه وخاصة في المناطق الجافة. لذلك فقد تم تصنيع وتشغيل نظام لتحلية المياه باستخدام الطاقة الشمسية بغرض توفير المياه العذبة. وقد أجرى هذا البحث بمدينة الزقازيق (٢' ٣٠° خط عرض و ١٢' ٣١°خط طول)، أثناء موسمي صيف ٢٠٠٩ و ٢٠١٠. وشملت الدراسة العوامل المؤثرة على انتاجية المقطر الشمسي (غير الفعال) وكيفية تحسين معدل أداء المقطر الشمسي و زيادة انتاجيته عن طريق توصيله بمجمع شمسي مستوي (مقطر فعال)، ومن ثم فقد استهدف هذا البحث تقييم ومقارنة أداء كل من المقطر الشمسي غير الفعال والمقطر الشمسي الفعال مع عوامل التشغيل المتباينة قيد البحث. ومن أهم النتائج التي تم الحصول عليها يتبين أن: بالنسبة للمقطر الشمسي غير الفعال تم الحصول على أعلى انتاجية (٦,٣٨ لتر/م٢. اليوم) عندما كانت زاوية ميل الغطاء الزجاجي ٠,٤٣٦ نقية (٢٥°)، عمق الماء في الحوض ١سم (بدون اجراء عملية تبريد غطاء المقطر الشمسي). وباجراء عملية تبريد غطاء المقطر وصلت أعلى انتاجية الى (٧,٨٠لتر/م٢. اليوم). بالنسبة للمقطر الشمسي الفعال تم الحصول على أعلى انتاجية (٨,٥٢ لتر/م٢. اليوم)، عندما كانت زاوية ميل المجمع الشمسي المستوي ٠,٤٣٦ نقية (٢٥°)، زاوية ميل الغطاء الزجاجي أيضا ٠,٤٣٦ نقية (٢٥°) وعمق الماء في الحوض ١سم (بدون اجراء عملية تبريد غطاء المقطر الشمسي). باجراء عملية تبريد غطاء المقطر وصلت أعلى إنتاجية إلى (١٠,٠٦ لتر/م٢. اليوم).