

Productivity Amelioration of Solar Water Distillator Linked with Salt Gradient Pond

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Abstract

There is a great need for fresh water in many developing countries. Water sources from, e.g., lakes; rivers and groundwater are often brackish or contain harmful bacteria and should therefore not be used for drinking or irrigation.

In this work a simple solar double sloped basin type still was connected to a solar salt gradient pond. The salinity-gradient solar pond is constructed in such a manner that the convective circulation in the pond is prohibited by making the bottom water much denser than the surface water. In doing so, the solar radiation absorbed in the deep water can be stored; the hot water from the salt pond was used to heat salt water in the stiller, at daylight and night.

The tests were conducted in September and October in autumn season in Baghdad city-Iraq in 2009. The results show development in stiller productivity at daylight and larger productivity increase at night. The stiller productivity increased also with cooling the glass cover from the still outside.

Keywords: Solar water distillation, Salt gradient pond, Productivity, Solar intensity, radiation.

تحسين انتاجية مقطر ماء شمسي مرتبط ببركة متدرجة الملوحة

الخلاصة

تزداد الحاجة الى الماء الصافي بشكل كبير خصوصا في البلدان النامية، ويتوفر الماء من مصادر مثل البحيرات، الأنهار والمياه الجوفية، والتي غالبا ما تكون ملوثة ووسخة، وتحتوي أشكال عديدة من البكتيريا الضارة، ولذلك لا يمكن استخدامها للشرب أو الغسيل.

استخدم في هذا البحث مقطر ماء شمسي بسيط ذو سطحين مائلين متصل ببركة ماء شمسية ذات تدرج ملحي، وقد صممت البركة بطريقة تمنع دورة الحمل الحراري داخلها، وذلك بجعل الجزء السفلي من ماء البركة أكثر كثافة من سطح الماء العلوي، وبهذه الطريقة يمكن خزن الإشعاع الشمسي الممتص في المياه العميقة، واستخدام الماء الساخن من البركة الملحية لتسخين الماء الداخل للمقطر الشمسي خلال الصباح وحتى في الليل.

أجريت التجارب في شهري أيلول وتشرين الأول في خريف عام 2009 في مدينة بغداد- العراق، وبينت النتائج تحسن واضح في انتاجية المقطر في ساعات الصباح، وزيادة أكبر في الانتاجية لساعات الليل، وتزداد انتاجية المقطر بتبريد الغطاء الزجاجي من الخارج.

كلمات دالة: تقطير شمسي للماء، بركة متدرجة الملوحة، انتاجية، شدة الأشعاع الشمسي، الأشعاع.

Nomenclatures

T_w = Brackish water temperature entered to still K.

T_B = Basin water temperature K.

T_{Cm} = Average transparency cover temperature K.

P_B = Partial pressure at basin water temperature Pa.

P_C = Partial pressure at average transparency cover temperature Pa.

q_c = transferred thermal energy by convection between solar still basin and glass cover W/m^2 .

q_e = Transferred evaporating energy between solar still basin and glass cover W/m^2 .

Introduction

There is a growing water demand in the world. Along with the deterioration of existing water supplies, the escalating world population leads to the assumption that two out of three people will lack sufficient fresh water by the year 2025. As competition for fresh water increases, water of lower quality from, e.g., lakes; rivers and groundwater are often brackish or contain harmful bacteria and should therefore not be used for drinking or irrigation^[1 & 2].

Desalination is the only possible way to produce more fresh water. Desalination in solar stills is a technology with long history and installations were built over 200 years ago, although to produce salt rather than drinking water. One of the earliest large-scale solar stills with a capacity of 23 m^3/day during clear weathers to supply a mining community in Chile with drinking water was built in 1872^[3 & 4].

Most of desalination plants are driven by fossil fuels and only 0.02% by renewable energy. A sustainable development requires simple inexpensive desalination systems driven by renewable energies.

The basic solar still can be described as a water container with a transparent cover to solar radiation. The incident solar radiation is transmitted through the cover and absorbed as heat by the insulated metal container in contact with the water to be distilled. The water is thus heated and evaporates to the space

above the water surface. The resulting vapor condenses on the inclined cover and runs down into a gutter from where it is fed to a storage tank^[5 & 6].

The method of direct solar desalination is mainly suited for small production systems, such as solar stills, in regions where the fresh water demand is less than 200 m^3/day ^[7 & 8]. This low production rate is explained by the low operating temperature and pressure of the steam.

One of the main setbacks for this type of desalination plant is the low thermal efficiency and productivity. This could be improved by a number of actions, e.g. injecting black dye in the sea water, reducing the heat conduction through basin walls and top cover or reusing the latent heat emitted from the condensing vapor on the glass cover. Another solution would be to separate the solar collector and the saline water so that corrosion damages, and thereby efficiency losses are avoided^[9 & 10].

The salinity-gradient solar pond is constructed in such a manner that the convective circulation in the pond is prohibited by making the bottom water much denser than the surface water. In doing so, the solar radiation absorbed in the deep water can be stored^[11 & 12]. The general solar pond consists of three layers of different temperature and salt content (fig. 1).

The top layer, usually about 0.8 – 1 meter deep, is at atmospheric temperature and has a low concentration of salt. The second layer is the so-called gradient zone. Here the temperature and

salt concentration increase with the water depth, which usually is 1 – 2 meters. The bottom layer in the solar pond, also called the storage zone, is the dense water beneath, convection is prevented and the heat is stored in the storage zone. The Solar ponds require plenty of land area, water and salt. That's why it is reasonable to locate them in wastelands or in deserts, close to salt works. To use solar ponds instead of fossil fuel for heating the desalination plants would mean significantly lower production costs ^[16].

The aim of this article was making use of the storage heat of solar pond in improving productivity of solar distiller.

Experimental work

A. Land required for proposed demonstration project.

The solar pond site selection is very important; the ideal solar pond site should have several essential characteristics:

- Easy access to water to fill the pond and for operation and maintenance.
- Access to salt and free salt available to reduce costs.
- Dry soil to minimize thermal losses.
- Free from moving water table to minimize heat losses.
- Easily compacted soil and with good cohesion for wall and structural stability.

Often some of these items are contradictory; in fact, for example, if the soil is good for draining, it has low cohesive properties and then it is difficult to compact for berm construction, but in any case it is possible to reach a compromise.

To fulfill these requirements or most of them, the solar pond was constructed in Al-Fadelia area in Baghdad city. Its measures were 5m length, 4m width and 1.5m depth. Constructed by brick and cement with 25cm thickness consists of

very dense and is heated up to 100°C^[13 & 14]. Since the water in the gradient zone cannot rise, due to the light water on top, and cannot fall, due to two layers of brick with 10cm thickness for each one. The layers were separated by polyethylene thermal insulator 5cm thickness. The inner surfaces were attired with cement, and then painted by dia eboccy used in damps pelvis painting to plug existing pores, and to increase solar radiation absorption. The pond's bottom was made of a concrete base of 25cm thickness. A pebbles layer was put under it, and its outer surface was covered by asphalt layer to prevent water leakage from and to the pond, and to give it the black color. The pond was supplied with transparency plastic cover. This was used when it was necessary, at dusty and windy days, to avoid water mixing, and to prevent dirt falling inside it. The pond was supplied with several thermocouples type (K) to measure water temperatures on many elevations.

Salt solution was formed using local sodium chloride (NaCl). Sodium chloride was used because of its availability and cheap prices. Salt purity was checked in Geological and Metal Investigation Department laboratories, Baghdad. Salt quantity was calculated due to wanted concentrations in storing and gradation zones. The method mentioned in ref (Weinberger H, 1963)^[17] was used to construct the solar pond salt layers. Storage and gradient zones height were chosen equal to 0.7 m, while the top layer height was 0.1 m. These dimensions were used due to the limited height of the constructed pond. Increasing the pond depth was restricted by groundwater.

Daily observations to the pond temperatures were recorded for all the tested period. The salt concentrations in pond's layers were tested periodically by

taking several samples from a number of different depths in various time periods.

A mesh system constructed from polyethylene pipes was used to withdraw the thermal energy from the pond. This material was used to prevent corrosion happens in metal pipes due to saline solution. The pipes diameter was 2.5 cm and 90 m total length. It worked as heat exchanger sunken in pond solution. The outlet and inlet ports were connected to metal pipes linked to a water rotating pump outside the pond. The water was directed towards heat exchanger submerged in water treasurer. The heat exchanger inside this box was from polyethylene pipes because the water inside this box was brackish and salty. The heat transferred from heat exchanger was absorbed by the brackish water. The water treasurer was fixed higher than the distiller, so water was descended to the distiller. The treasurer diameter was 50 cm, and 150 cm height, and it was covered with glass wool insulator 10 cm thickness.

B. Solar distiller

Two sloped double effect horizontal basin type solar still was manufactured and used in this work. The solar still basin was made from fabricated plate, with base area 1 m length, 0.4 m width and 36 cm height from the middle. Two small channels were welded to collect the slipping distilled water from the transparency cover. This channel extended longitude on two sides, and with 5 degrees inclined from distiller side to the other side. The two stiller edges were 11 cm height; the stiller top was with 30 degree inclined from the horizontal. The upper edges were bended horizontally by 1cm width at each edge, to fix the glass (transparency) cover on it. To insure of steam complete blockade inside the stiller and preventing its leakage to outside, a plastic stuffing was

used, with 1 cm width and 3 mm thickness. This substance was fixed with silicon material to assure total adherence of the plastic stuffing on the upper edge. The glass cover was adhered on the stuffing material. The inner surface of the metal basin was colored with non shiny selective black color, to increase solar absorption.

The hot water flowed to solar still basin by means of polyethylene pipes connected to the water treasurer. A float inside the solar stiller was used to control the flow. The continuous flow maintained the basin water level at 1cm height.

The slipping distilled water from the transparency cover was collected in inclined collecting channel. The distilled water departed the distiller by means of an orifice fixed in one side of the distillator, connected by a polyethylene pipe 1.27cm (1/2 in) dia. The pipe was extended inside the collecting channel to insure steam remaining inside the still without any leakage from the exit opening to the outside. A wooden box was manufactured to put the metal basin inside it. The box was built from wood boards 2 cm thicknesses each. A thermal insulator (glass wool) was used to insulate the basin. Two fans (6 in dia and 100 W) were used to cool distillator cover. The air flow was directed over the distiller glass cover, each fan cooled one slope.

Several thermocouples type K (copper constantan/copper alumel) were used to measure varied temperatures. These thermocouples were calibrated by comparing their readings with a calibrated mercury thermometer. To get complete distribution of temperatures for all the transparency cover area four thermocouples were fixed on the condenser glass surface. Two thermocouples fixed on the outer surface

and two on the inner surface. The average of these thermocouples readings were taken to represent the average cover temperature. Another thermocouple was fixed in the distiller basin bed to measure its temperature. The temperature of the water coming from the tank to the distiller was measured by means of a mercury thermometer fixed in the connecting pipe. The surrounding temperature was measured by a thermometer placed in shadow.

The gathered water quantities were measured by means of cylindrical vessel 10 liters capacity. The gathered water was measured every hour and in the beginning of the new day. Fig. 2 represents a scheme of the distillation system connected to solar salt gradient pond, while Fig. 3 represents a scheme of two slope double effect solar basin with its details.

The following equations were used in calculating convection and evaporation energies [18, 19 & 20]:

$$q_c = 0.884[(T_B - T_{Cm}) + \frac{(P_B - P_{Cm}) \times T_B}{268 \times 10^3 - P_B}]^{\frac{1}{3}} (T_B - T_{Cm}) \text{ W/m}^2 \dots (1)$$

Where:

T_B = Basin water temperature K.

T_{Cm} = Average transparency cover temperature K.

P_B = Partial pressure at basin water temperature Pa.

P_C = Partial pressure at average transparency cover temperature Pa.

q_c = transferred thermal energy by convection between solar still basin and glass cover.

$$q_e = 4.52 \times 10^{-3} \left[q_c \frac{P_B - P_{Cm}}{T_B - T_{Cm}} \right] \text{ W/m}^2 \dots (2)$$

Where:

q_e = Transferred evaporating energy between solar still basin and glass cover.

Discussion

Figs. 4 to 7 show the temperature distribution (or variation) in distiller, starting from sunrise to the beginning of sunset. In these figures the modes of temperatures like T_B , T_w , T_{Cm} and T_a are plotted. All temperatures increase starting from first daylight to reach its maximum value at period after mid day. They started to decrease with sunset because of the radiation reduction on distiller's part.

In Fig. 4, where distillation happened without cooling the transparency cover. It can be noticed that cover temperature was high and the difference between T_B and T_{Cm} relatively low. Although the brackish water comes from heat exchanger one can see that T_w behave according to solar intensity variation inside the distiller. Hot water will absorb the incident solar radiation through the glass, and will act according to it in increment and reduction.

In Figs. 5 and 7, where the transparency glass cover was cooled, a high variation between T_{Cm} and the T_B was achieved, causing higher productivity. The salt thermal pond rotating water heats the brackish water in the heat exchanger. This water was hotter than all distiller components. This made the (evaporator) temperature high all day time till evening. This difference between it and the condenser (glass cover) temperature was retained, improving the produced distilled water quantities.

Fig. 6 represents the temperature distribution without cooling the glass cover at daytime. The curves act similar to solar intensity behavior. It increased starting from sunrise to reach its peak at 1 to 2 PM then it start to decline. T_w that comes from the heat exchanger has the

maximum temperature while T_a has the minimum ones. It can be observed that T_w and T_B beak temperatures shift about half an hour from T_a and T_{cm} peak temperatures. This is due to the greenhouse effect of distiller glass that store higher energy for longer time.

Fig. 8 demonstrates the distiller productivity for the four tested days, the productivity increased with day beginning, reached its maximum value after midday, and then started to reduce because of declined radiation abatement on distiller basement. In general, the still productivity in the four days was high, because of using hot water (ready to evaporate) flowed from salt gradient solar pond. The results show that distiller productivity in September days slightly higher than that in October days due to higher solar intensities in these days.

The nightly productivity (which didn't appear in the figures, was measured from the evening start to the next day morning), was very good. The supplied water temperature to the still basement wasn't equal to the temperature supplied from the pond, due to losses in pipes and the lower efficiency of the heat exchanger. The cover was cooled at night because of sun radiation absence, in addition to reduction in air temperatures which cooled the cover. All these factors caused the deference in temperature between the cover and basement to continue. This led to continuing condensing water on glass cover, and improving still productivity all the night highly. The improvements in productivity with cooling the cover compared to non-cooling were 33.79% & 26.7% for Sep. & Oct. tests respectively.

Figs. 9 to 12 present the transferring energies between still base and the glass cover (q_c and q_e). These figures show the variation mode for day hours. These energies increased slowly at day

beginning, and then they increased in accelerated figures to reach its maximum values. Then it started to reduce at sunset. The figures show that the evaporation energy sent out from the basin to the cover q_e was obviously higher than q_c . The evaporation energy which was responsible of mass transfer from still basin to the cover caused vapor condensing on cover. Whenever this energy was increased the still productivity increased.

The still productivity started to reduce after sunset, because of sun radiation disappear and air temperature reduction as well as other losses from solar basin different parts. This resulted in cooling the metal basin which contained hot water coming from the heat exchanger. An increment in energy losses by radiation and convection to ambient air was occurred. Although hot water was entering the distiller basin, yet the decrement of vaporization energy reduced the resulted productivity. It continued production in small quantities, because of the temperature differences between the cold distiller transparency cover and hot water inside its basin. This is what Fig. 13 shows. Also the continuous distiller productivity increased with cooling the glass cover more than the uncooled cover. The increments for Sep. test were 78.72%, while for Oct. test was 68.03%.

Despite the low night productivity of this system, it can be considered high compared with approximately non-exist productivity resulting from a still system lack to hot water as that coming from the salt gradient solar pond in present work.

Conclusions

A salt gradient solar pond was constructed at Al- Fadelia area. This pond was used to heat rotating water that transfers heat to heat exchanger. The heat exchanger was insulated and filled

with brackish water. The brackish water was heated and entered to simple solar distiller. The experiments were conducted in Baghdad city weathers at September and October 2009. Conclusion can be summarized as:

1. Salt gradient solar pond supply the simple distiller with water had high temperatures. These high temperatures enhanced the distillation process. If the system continues the solar pond will store more and more energy and higher temperatures at heat exchanger will be achieved.
2. Distiller productivity increased by cooling the transparency cover. The maximum improvement reached was 33.79%.
3. Distiller productivity increased with brackish water pre-heating in the heat exchanger.
4. The night productivity of distiller increased with brackish water pre-heating in the heat exchanger. The maximum improvement reached was 78.72% in Sep. nights.
5. The results indicate that for areas where salt gradient solar pond can be constructed, establishing a distillation system with low expenses and high productivity is possible and reasonable.

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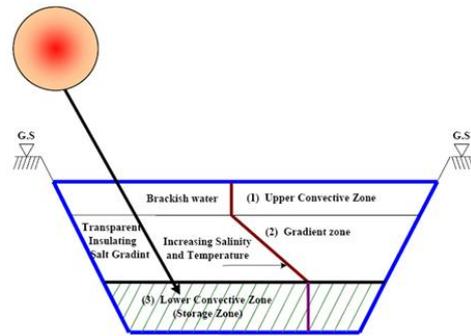


Fig. 1, Typical salinity-gradient solar pond (Hussain, 2003)

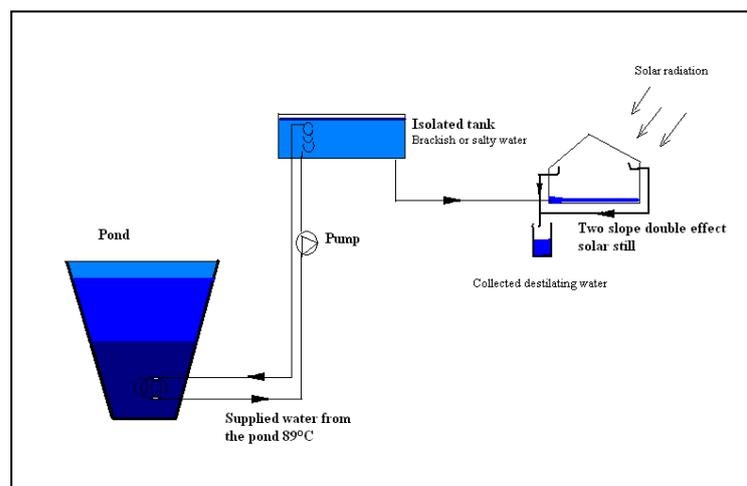


Fig. 2, Distillation operation using solar salt gradient pond scheme

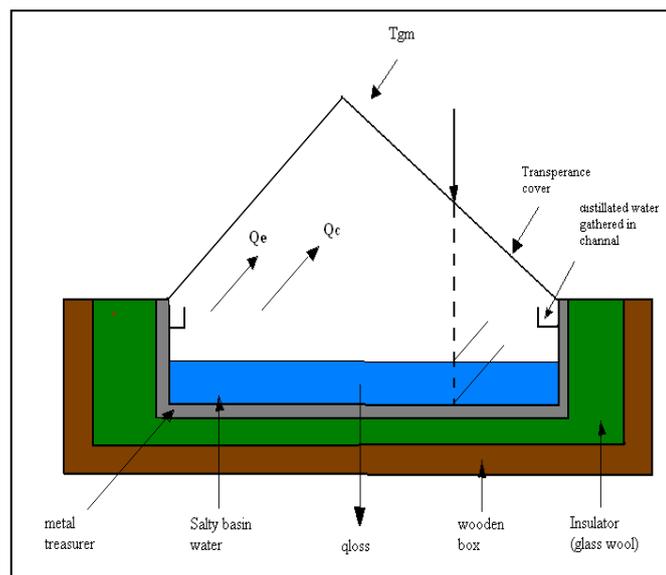


Fig. 3, two slope double effect solar basin scheme

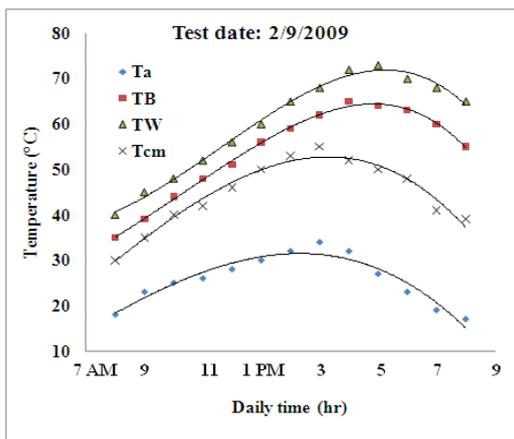


Fig. 4, temperatures distribution for the solar distiller without cooling the glass covers at day time.

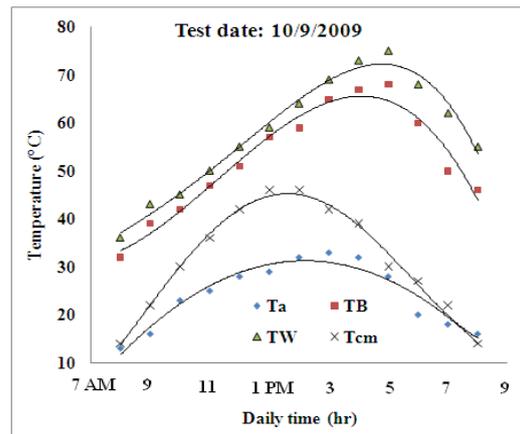


Fig. 5, temperatures distribution for the solar distiller with cooling the glass covers at day time.

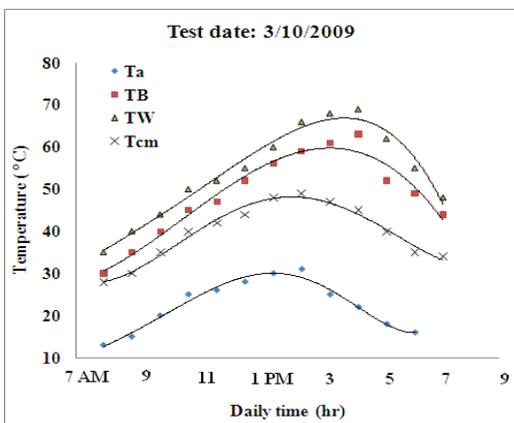


Fig. 6, temperatures distribution for the solar distiller without cooling the glass cover sat daily time.

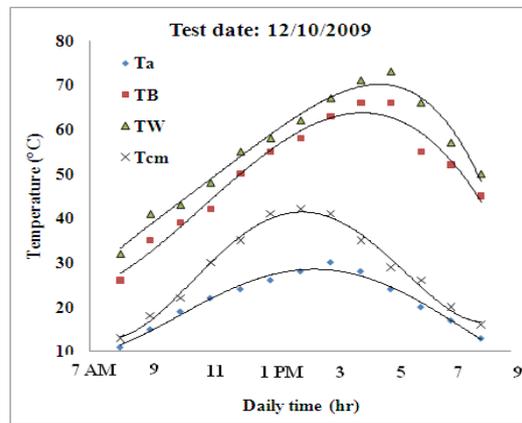


Fig. 7, temperatures distribution for the solar distiller with cooling the glass covers at daily time.

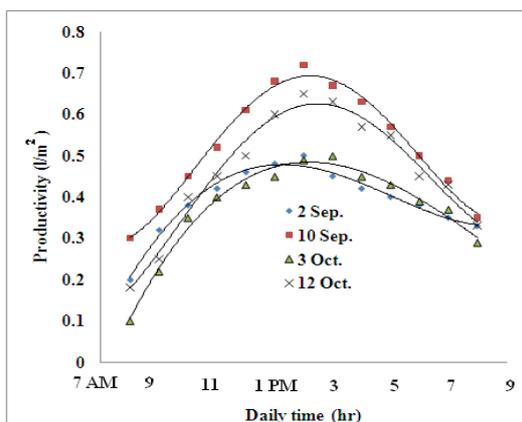


Fig 8, solar distiller productivity by day

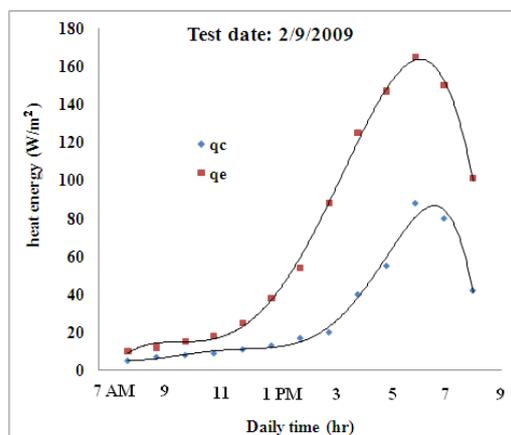


Fig. 9, the transferred energies between distiller basin and the transparency cover

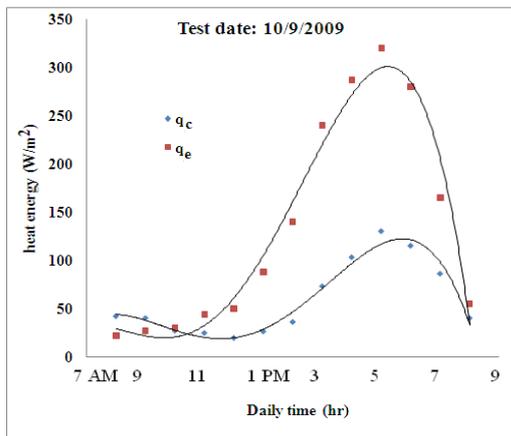


Fig. 10, the transferred energies between distiller basin and the transparency cover

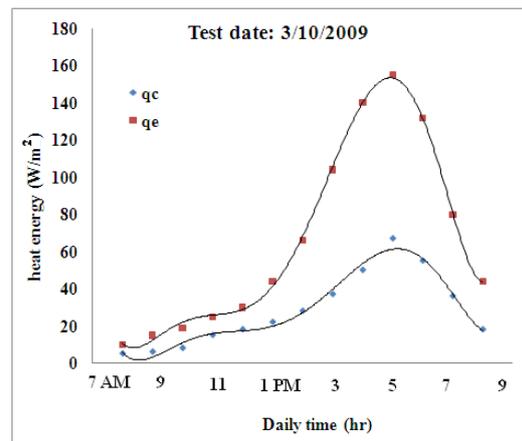


Fig. 11, the transferred energies between distiller basin and the transparency cover

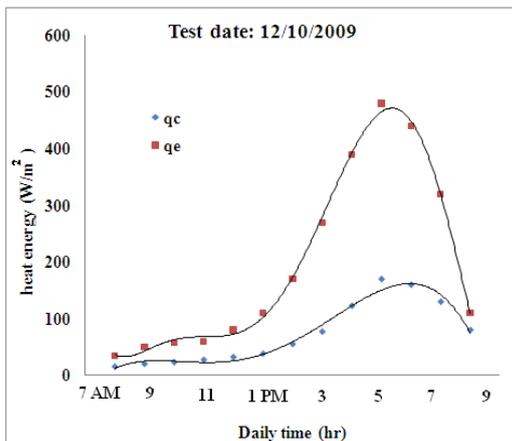


Fig. 12, the transferred energies between distiller basin and the transparency cover

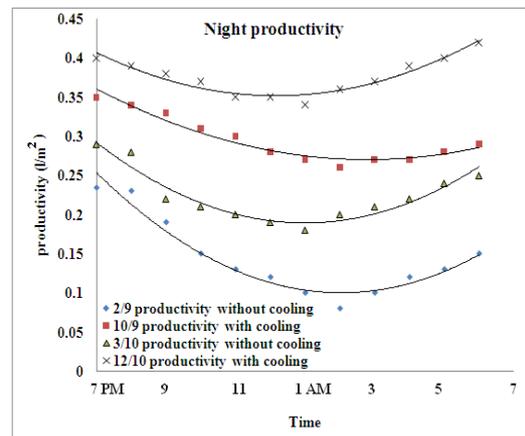


Fig. 13, the night productivity in liter/ m^2 for the solar still area