Experimental Study of a Single Slope Solar Still in Jordan

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ABSTRACT

The performance of a single slope solar still using different operational parameters was studied experimentally. The increase in still productivity to about 33% was achieved when the wind speed increases by 50%, this due to the increase in temperature differences between the still cover and water. The ambient conditions were found to have direct effect on the productivity of the still. The study also showed that the daily production of still can be increased by reducing the depth and salinity of water in the basin. It can be concluded that high salinity will create a sharp density gradients which can lead to stratification of different concentrations of salinity, creating trapping energy and preventing convection and reducing the productivity by 22%.

Distilled water by solar stills can be one of the options for providing fresh water (some treatment required) for desert regions communities.

KEYWORDS: Solar energy, Solar still, Distillation, Single slope still.

INTRODUCTION

The availability of potable water is an important problem for the communities who will be lived in the desert regions or especially for people in remote region. These regions are recognized by a high intensity of solar radiation, which makes the direct use of solar energy represents a promising option for these communities to reduce the major operating cost for pumping drinking water.

Most third world countries are suffering from the incapability of supplying pure drinking water to their communities living in the arid regions. Also the availability of clean water is a necessity for reducing the spread of diseases in these countries.

Solar distillation is one of the available methods for water distillation, and sunlight is one of several forms of heat energy that can be used to power that process. Sunlight has the advantages of zero fuel cost but it requires more space (for collection) and generally more equipment.

The solar energy can be utilized to obtain drinkable water from salty or brackish water through the use of solar still to capture the evaporated (or distilled) water by condensing it onto a cool surface (slope), and the output will be clean water.

The operation of the still is very simple. The incident solar radiation is transmitted through the sloped transparent glass cover to the water in the basin that will heat it , so it will evaporate and condense on the inside layer of the glass cover and run down the cover to the channels, where it will be collected at the distillation vessel or tank.

There are various methods of solar distillation, in addition to the original single basin solar still, For example double basin solar still, multiple basin solar still, chimney solar still, etc.

Although the productivity of those methods was improved compared to that of the single basin solar still, but this improvement was obtained with increase in complexity, cost and maintenance (Kalogirou 2004 & 2005, Akash et al 1998 & 2000, and Nijmeh et al 2005, Singh & Tiwari 2004, Tiwari, & Suneja1998, and Samee et al 2007).

From the several types of solar stills, the simplest of which is the single basin still. But the yield of this is low and falls in the range of (3-7) liters per day per m^2 (Akash et al 2000, Nijmeh et al 2005, Al-Hinai et al 2002, and Al-Hayek & Badran 2004, Nafey et al 2001, and Samee et al 2007).

Many experimental and numerical studies have been done on the single slope solar stills, such as those of Badran and Hamdan 1995, Abu Hijleh and Rababa'h 2003, Vorpoulos et al 2001, Al-Hayek & Badran 2004, Malik et al 1982, Tripathi & Tiwari 2004, Badran & Abu-Khader 2006, Badran 2006, and Badran & Al-Tahaineh 2005.

Many parameters can be used to improve the operating efficiencies of various types of solar distillation devices. Forced air circulation is one of many parameters that can be used to enhance the vapor condensation rate in stills. Several investigators have attempted to make use of the latent heat of evaporation in either multiple-effect systems or for preheating the brine to increase the output of still (Tiwari et al 1997, El-Sebaii 2000, Nafey et al 2001, and Badran and Al-Tahaineh 2005). Several large-scale distillation plants and integrated schemes for combining electric power generation and desalination of water have also been suggested as a way of improving the overall operating efficiency of the plant (Malik et al 1982, Duffie and Beckman 1991, and Kalogiru 2005).

Tiwari & Suneja 1998, Kumar & Tiwari 1999, Jubran et al 2000, Al Hinai et al 2002, Singh & Tiwari 2004, and Badran 2006 have investigated the effects of climatic, operational and design parameters on the performance of single, double and multi-effect active and passive solar stills. They have concluded that the productivity increases with the increase of solar radiation, ambient temperature and wind speed. Malik & Tran 1973 and El-Sebaii 2000 have concluded that the increase in wind speed causes increase in productivity.

The aim of the present paper is to conduct an experimental work for the solar still in passive mode under the Jordanian climate. The passive still with different operational conditions have been proposed to improve its productivity. All the results were compared together to reach to the best operating conditions that can be used in future for solar still augmentation for the production of drinking water to arid regions in the Jordanian desert.

EXPERIMENTAL SETUP

The following experimental components were used in this work: single slope solar still, constant head tank and feeding tank. A frame was built to carry the above mentioned instrumentations.

A single slope solar still shown in Figure (1) has been constructed from a large variety of local materials. The materials selected have generally been based on knowledge of the conditions prevailing in various parts of solar still and an assessment of the material cost and ease of incorporating it in construction. The technical specifications of the solar still are shown in Table (1).

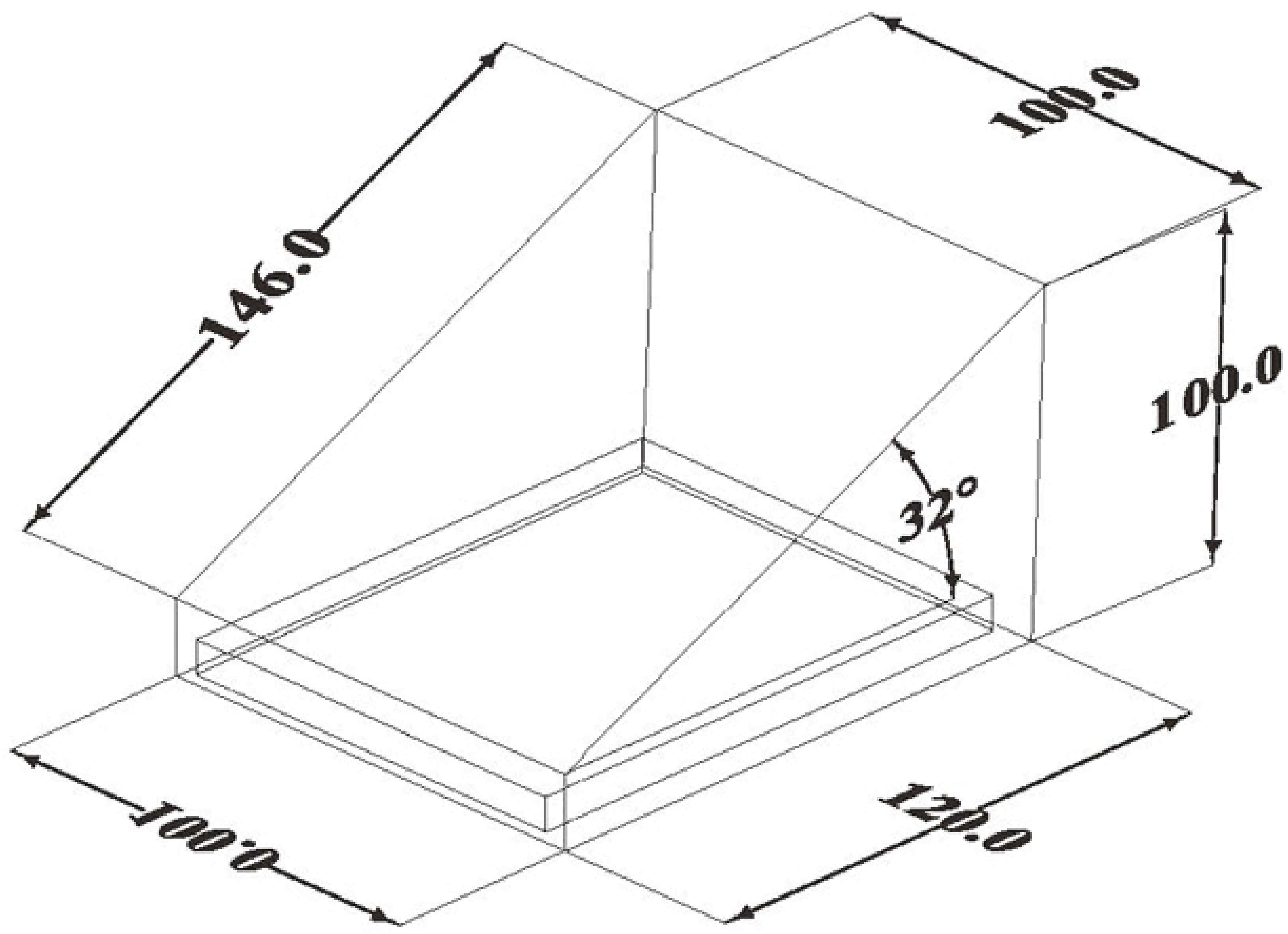


Figure 1. Isometric view of the solar still

Table 1. Technical specifications of the solar still

Specification	Dimensions
Basin area, m^2	1
Glass area, m^2	1.46
Glass thickness, mm	4
Number of glass	1
Slope of glass	32°

BASIN LINEAR

In this work the basin liner made of galvanized iron sheet of 90x110 cm with maximum height of 5cm, and 1.4 mm thickness. It is coated with a fainted black paint layer. This is the major part of the solar still. It absorbs the incident radiation that is transmitted through the glass cover. The basin liner should be resistant to hot saline water, has a high absorbance to solar radiation and resistance to accidental puncturing and in the case of damage (possibly by broken glass), it should be easily repaired.

GLASS COVER

A window glass of 4mm thickness was used and its average transmissivity (τ) of 0.88, it was fixed at an angel 32° with the horizontal as shown in Figure (1). Glass cover has been sealed with silicon rubber, which is the most successful because it will make strongly contact between the glass and many other materials. The sealant is important for efficient operation. It is used to secure the cover to the frame, take any up difference in expansion and contraction between dissimilar materials.

INSULATING MATERIAL AND MIRRORS

The insulating material is used to reduce the heat losses from the bottom and the side walls of the solar still. The insulating material is a rock wool of 5cm thickness and $0.045 W/m^{2}{}^\circ C$

thermal conductivity. Mirrors fixed inside the solar still on the inner sides walls which are useful, because the mirrors increase the reflectance that occur for incident solar radiation in the solar still.

THE DISTILLATE CHANNEL AND SIDE COMPONENTS

The distillate channel used to collect the condensate from the lower edge of glass cover and carry it to storage, it was made of aluminum sheet of (U) shape, and the side walls made of wood of 16 mm thickness.

MEASURING DEVICES

a. Wind Speed

The device used to measure wind speed is a digital anemometer. During the experimental work the wind speed was in the range of 2.5-5 m/s.

b. Temperatures

The temperature at various locations in the still were measured by thermocouples (type-k) coupled to digital thermometer (its range from -50 to 150 C°). Five thermocouples probe were used to measure the following temperatures:

Basin, glass (in), vapor, water, glass (out). And a thermometer is used to measure: collector, inlet and outlet and ambient temperature. Figure (2) shows the locations of these thermocouples and thermometers. The accuracy of this device is in the range of 1°C for the temperature measurements "between" 1 to 99°C.

SOLAR RADIATION

In the present study a Heliometer is used to measure the solar radiation, this device measures the instantaneous intensity of radiation in (kW/m^2) (its range from 0 to 1.2 kW/m^2).

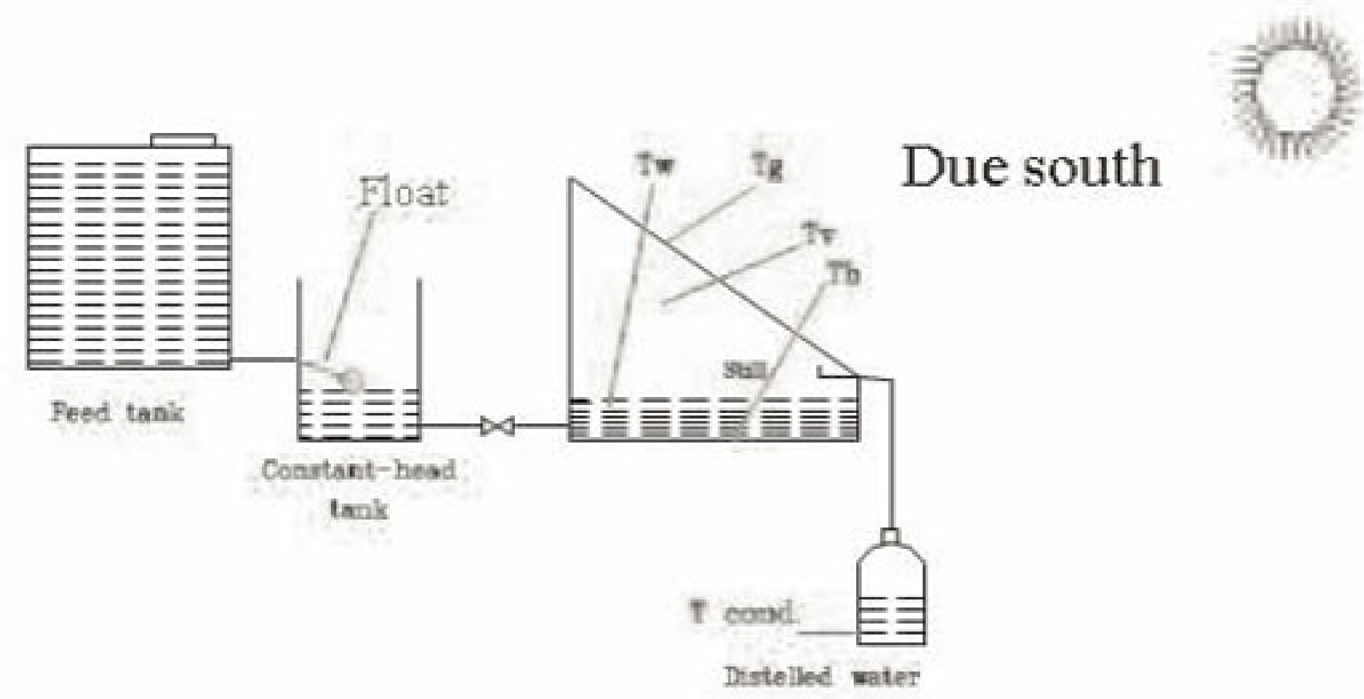


Figure 2. Overall schematic diagram of the solar still.

RESULTS AND DISCUSSION

This section will present the influence of different conditions in the productivity of the solar still, such as ambient temperature, different water depths, and wind effect and salinity concentration. Different variables were measured hourly such as inner glass temperature (Tg,in), outer glass temperature (Tg,out), ambient temperature (Ta), water temperature (Tw), basin temperature (Tb), vapor temperature (Tv), solar radiation (I), wind speed (Vw), productivity (Pr). The optimum depth of the water of 2 cm is used through out the experiments. Figure (3) shows the variation of different variables of solar still, it can be seen that the temperature of the vapor is the maximum followed by the temperature of water that has been heated by the basin in a convection process due to incident rays, then the temperature of the inner glass where the condensation occur, then the outer glass that transmit the incident rays, and it is in contact with the surrounding, and the minimum temperature will be the ambient temperature.

The solar radiation and the productivity for the conducted experiments are shown in Figures (4) and 5. The maximum yield occurred during the time period 13.5 pm and 16 pm corresponding to a high solar radiation interval (Figure (4)). It can be seen from Figure (5); that the highest productivity will be in the afternoon due to lower heat capacity of the water in the basin, and the decrease of heat loss from the still to the ambient, also the decrease of water temperature drop in the basin with time.

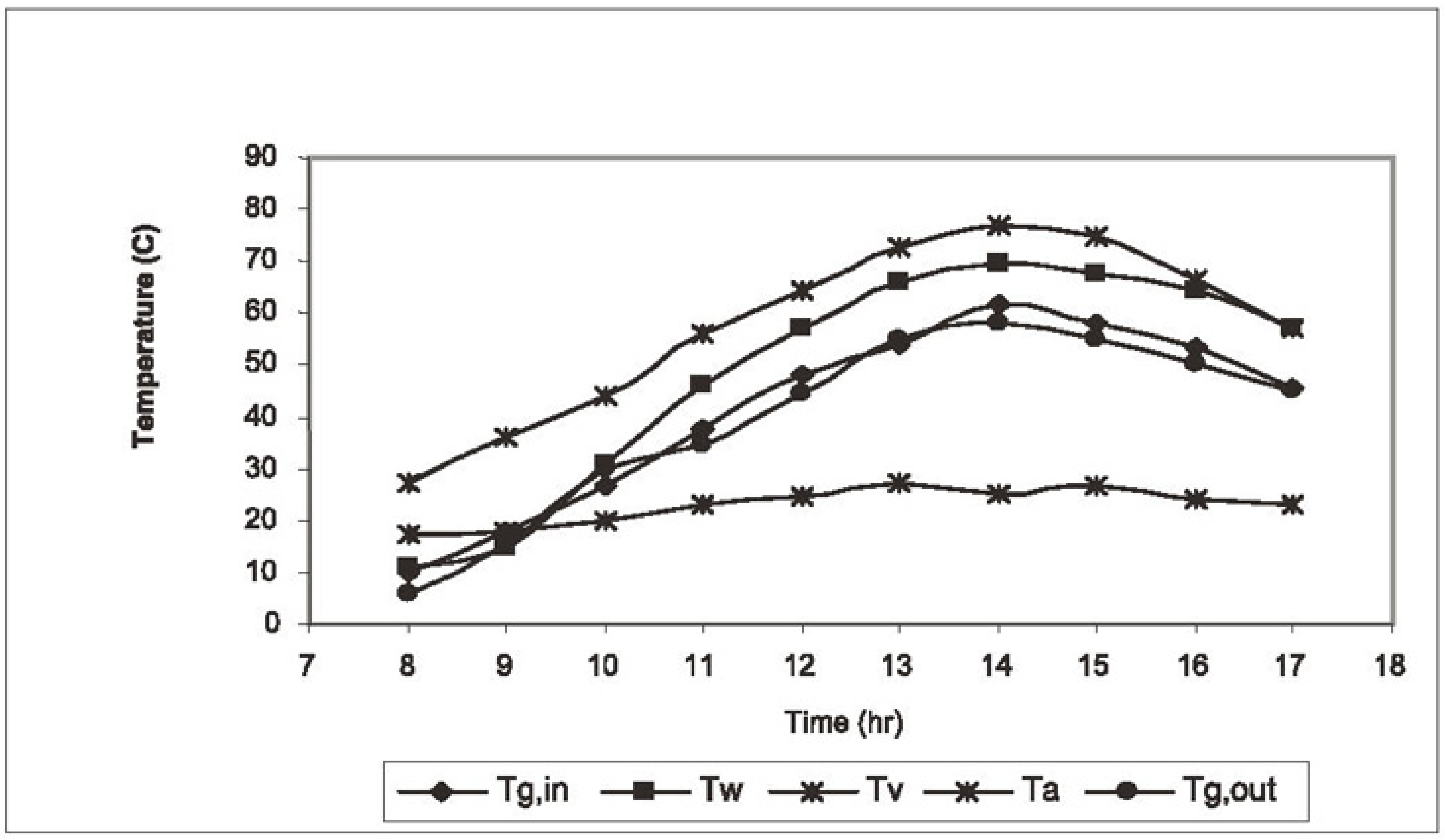


Figure 3. Temperature variations at different locations in the still.

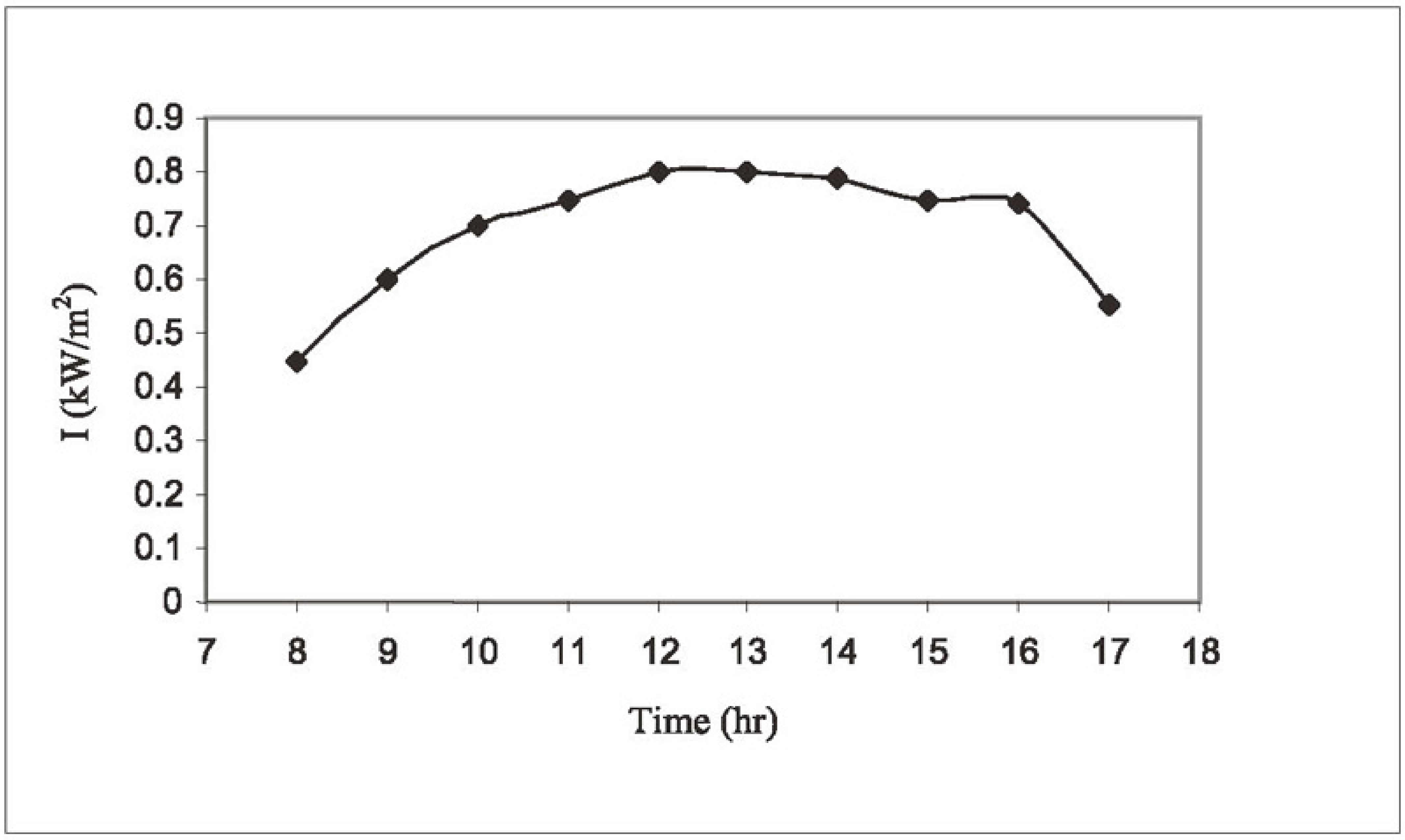


Fig. 4. Relation between the solar intensity and local time

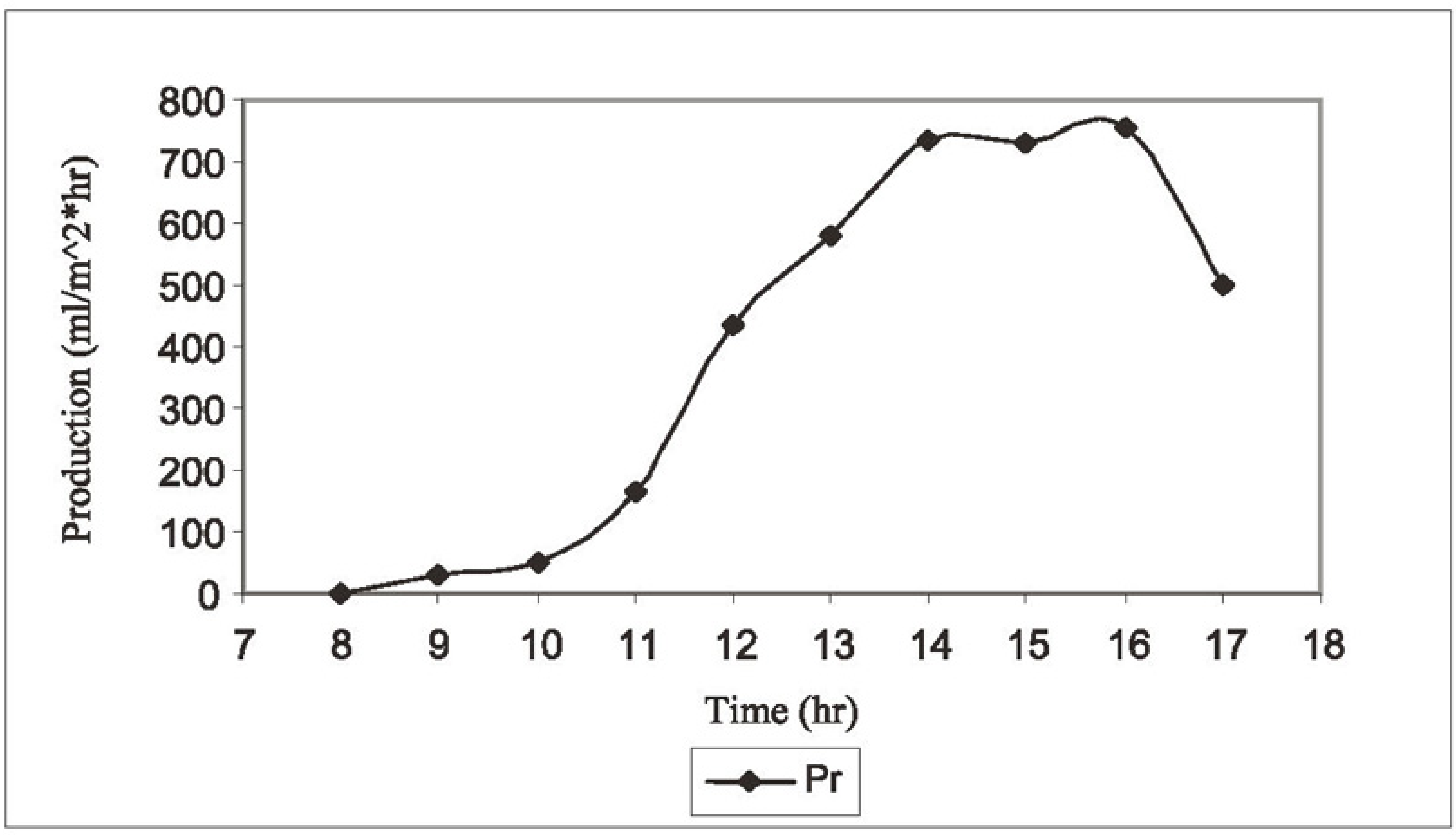


Fig. 5. Relation between the productivity and local time.

The effect of water depth in the still basin on the productivity is shown in Figure (6a). It is evident that as the water depth increases, the productivity will be decreased. This is due the increase of the heat capacity of the water in the basin (Figure (6b)), which results in lower temperature of water in the basin, and lower evaporation rate. The decrease of the water depth from 3.5 cm to 2 cm increased the productivity by 26% as shown in Figure (6a).

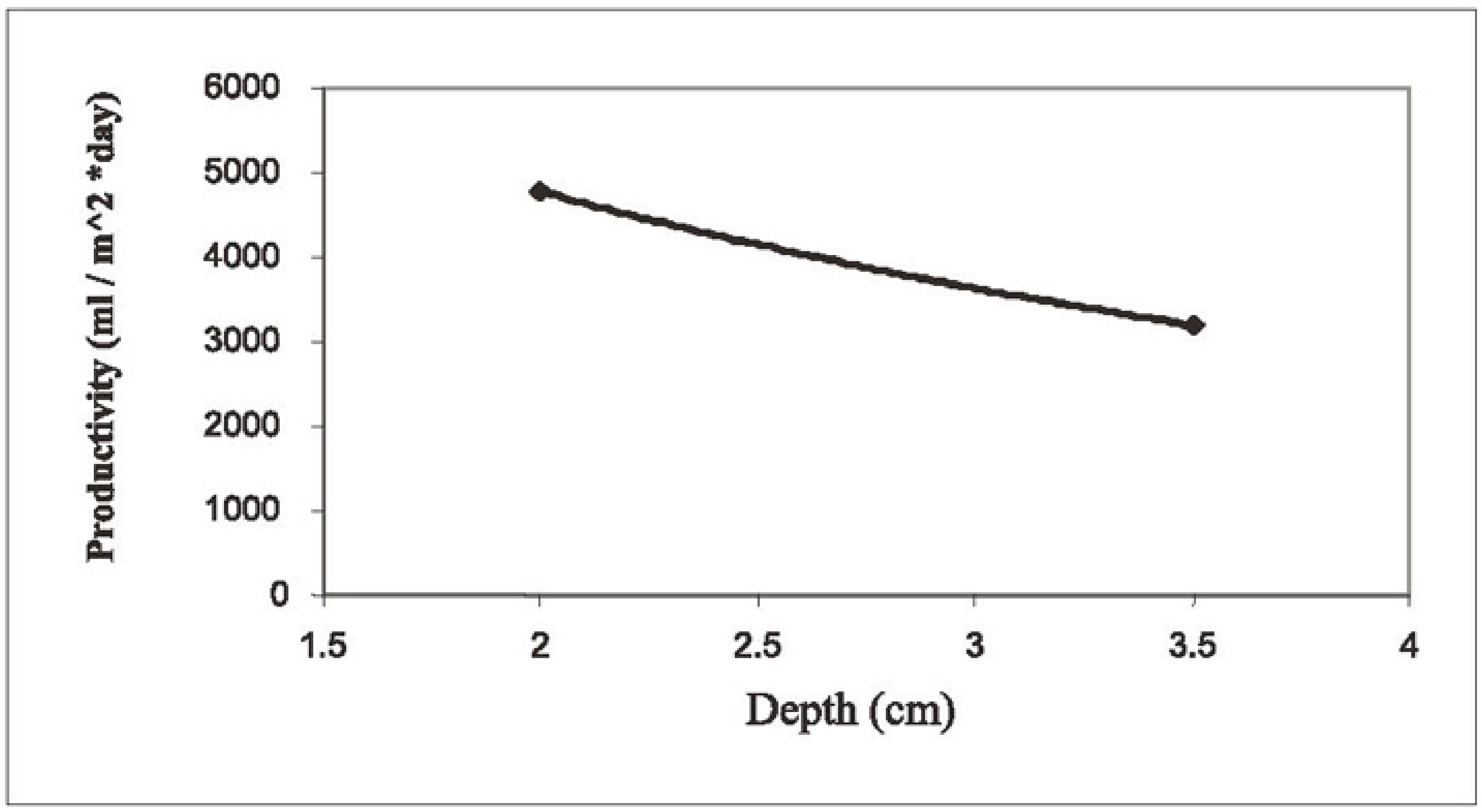


Figure 6a. Relation between water depth in the basin and the total productivity of still.

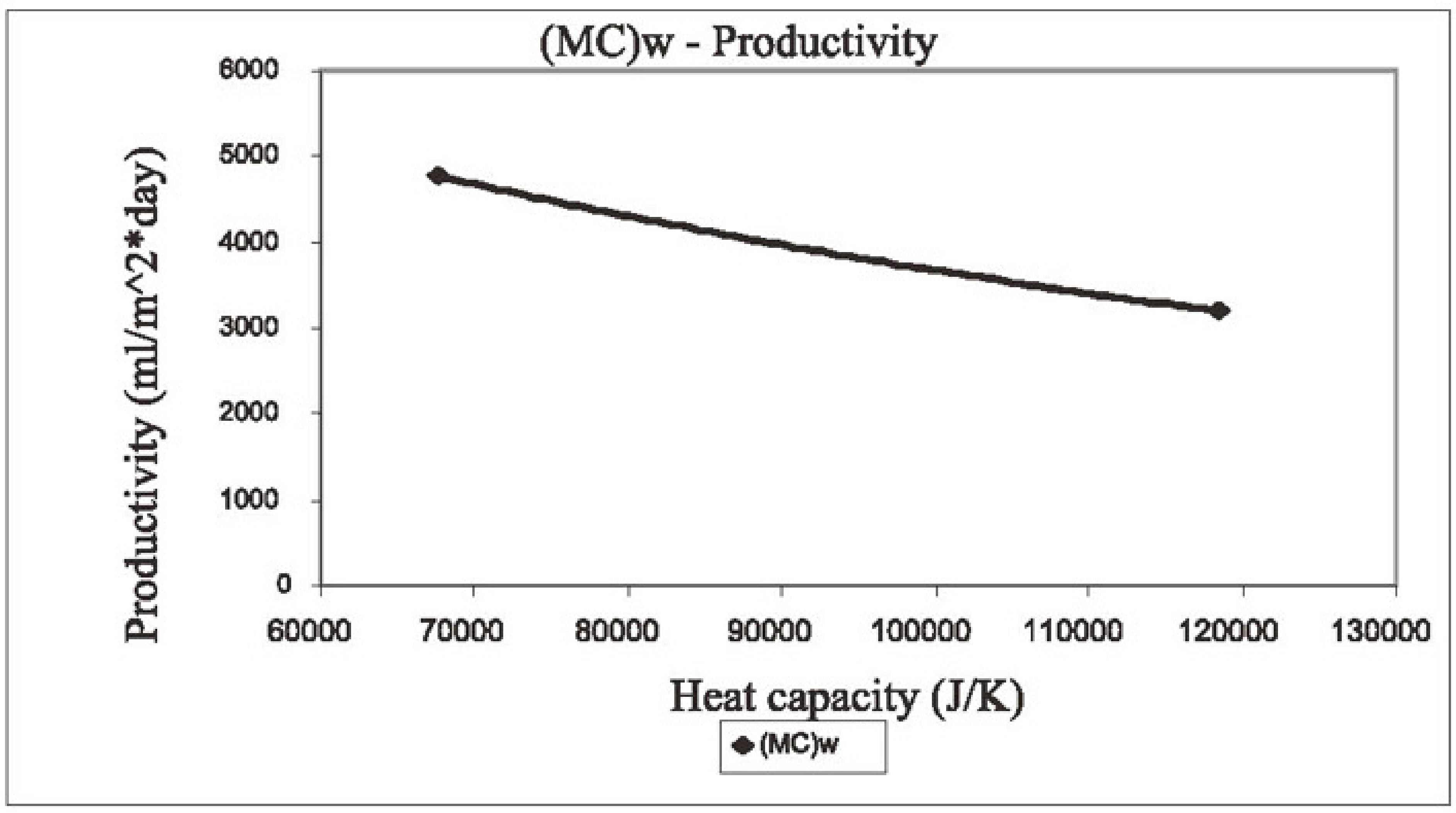
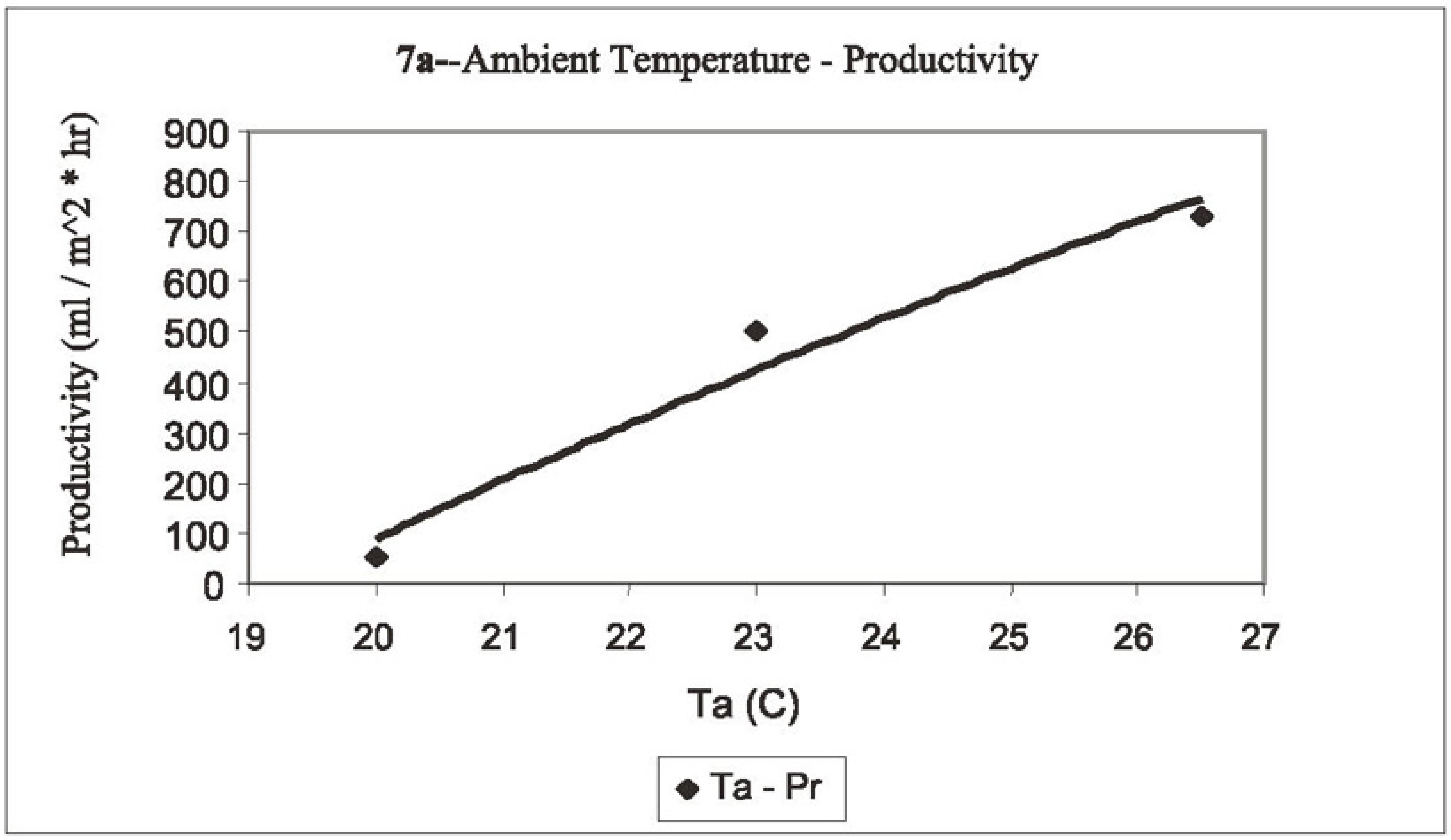


Figure 6b. Relation between heat capacity in the basin and the total productivity of still.

The effects of ambient temperature and the wind velocity are shown in Figure (7a) and (7b). It can be seen in Figure (7a) that as the ambient temperature increases, the productivity will increase.



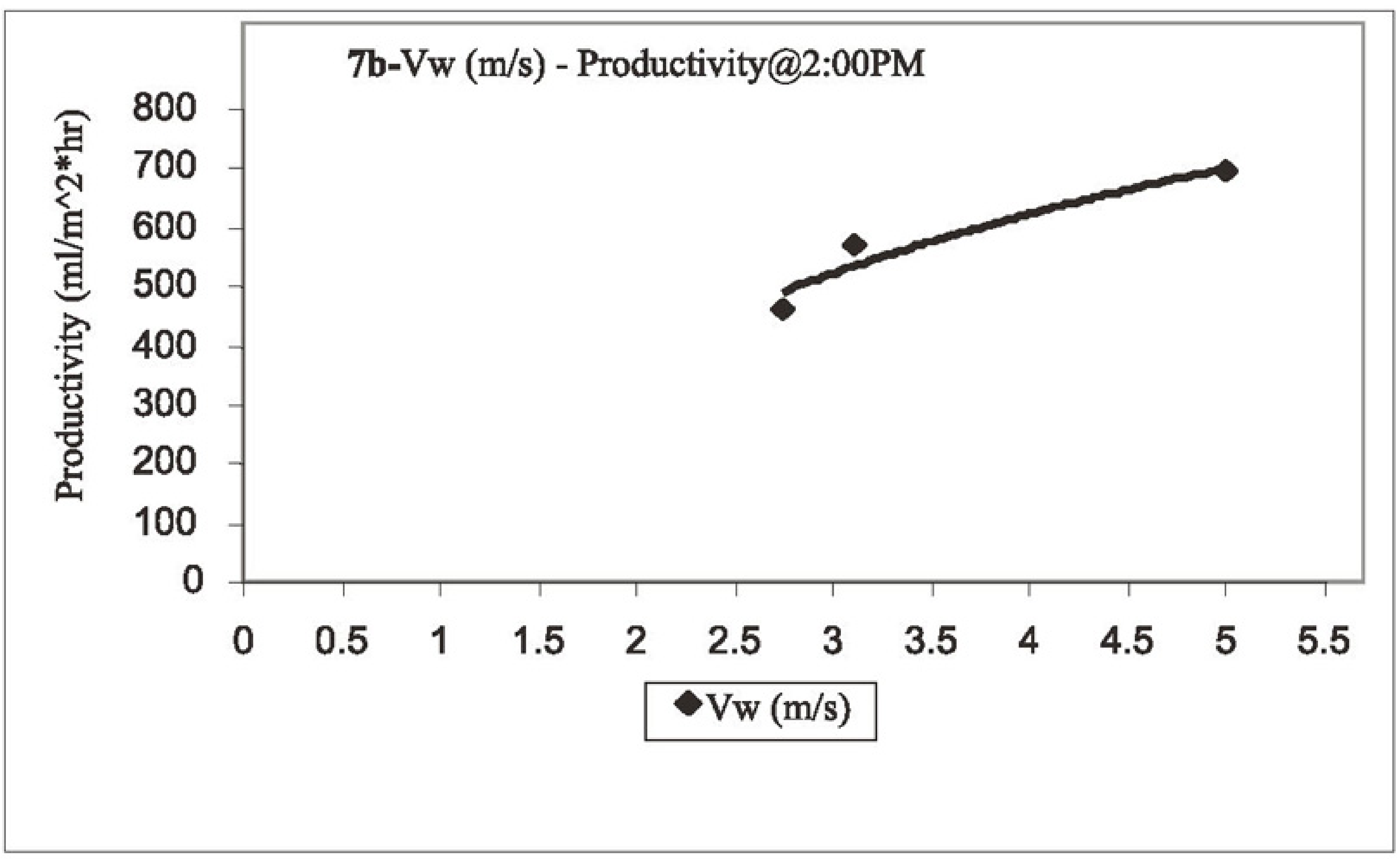


Figure 7:The effect of ambient temperature (top) and wind velocity(bottom) on productivity

Also the increase of the wind speed will increase the cooling process on outer glass, which will lead to the increase of temperature difference between the glass cover and the vapor, which will increase the condensation process on the inner glass layer of the cover and enhance the productivity by 33%.

Figure (8) shows effect of the salinity of water on the productivity of the solar still. It is noticed that when the salinity concentration increased by 4% the productivity decreased by 22%, this may be due to the high collection and storing of solar energy. When solar radiation (sunlight) is absorbed, the density gradient prevents heat in the lower layers from moving upwards by convection and leaving the basin. This will increase the temperature at the bottom of the basin while the temperature at the top of the basin will be cooler. The heat will be trapped in the salty bottom layer instead of uniformly distribution in the basin, which will reduce the evaporation process on the water surface in the still basin.

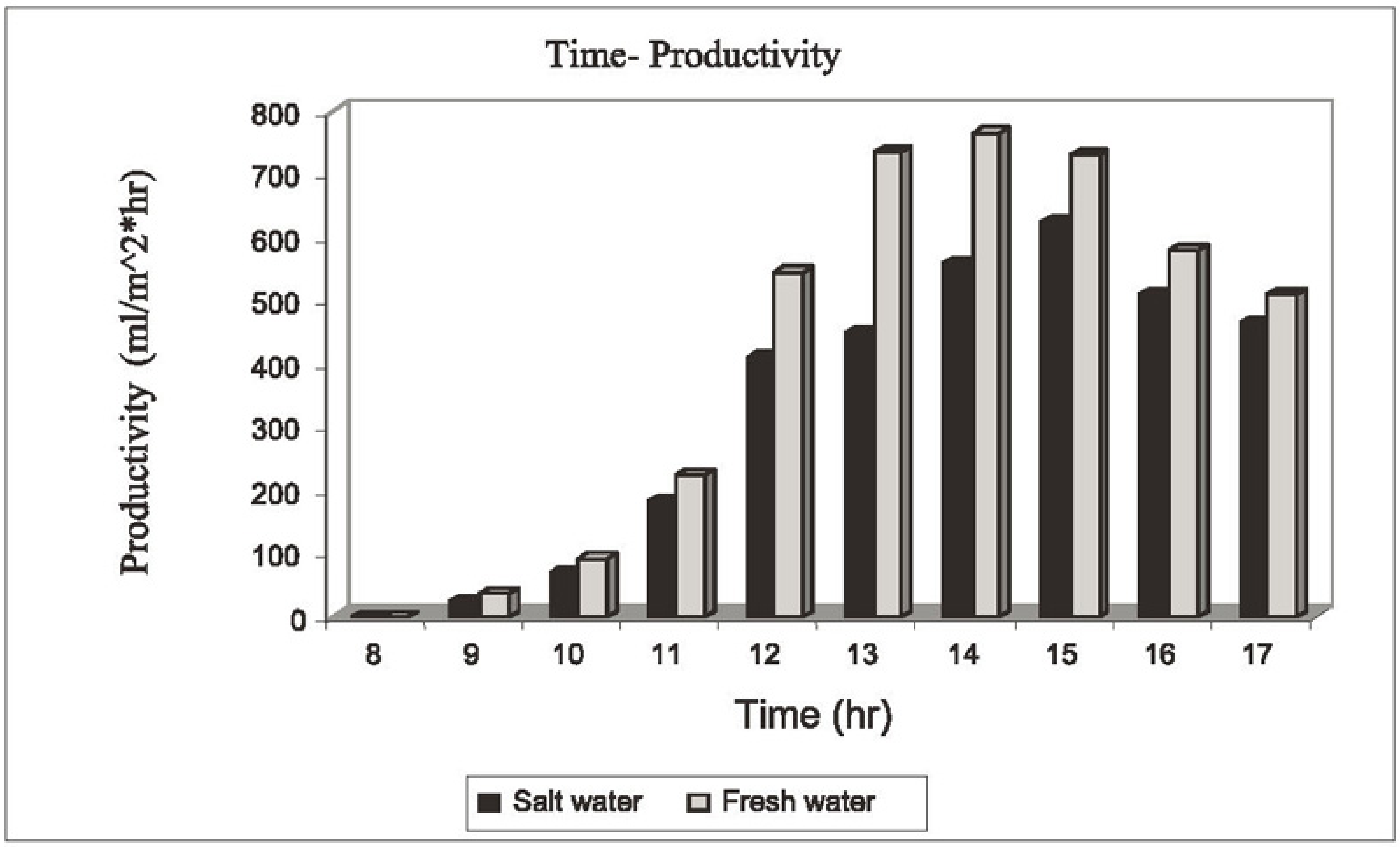


Figure 8. The differences between salt water and fresh water distillation.

This idea evolved in the present research, to investigate the effect of high salinity contained in water resources in some northeastern desert regions in Jordan on the productivity of solar stills.

CONCLUSION

An experimental work has been conducted to predict the productivity of a single slope solar still using different operational parameters. The use of high salinity in the basin resulted in a significant reduction of the still yield by 22%, while the increase of the wind speed enhanced the productivity by 33%.

It can be concluded also that the ambient conditions (i.e. wind and temperature) have a direct effect on the still productivity. It is evident from the result that as the depth of water decreases the daily still output is increased by 26%, due to the decrease of heat capacity of water.

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REFERENCES

1. Abu-Hijleh, B. and Rababa'h, H. (2003). "Experimental Study of a Solar Still with Sponge Cubes in Basin", *Energy Conversion and Mgmnt.* , Vol 44: pp1411-1418.
2. Akash, B. A., Mohsen, M. S. and Nayfeh, W. (2000). "Experimental Study of the Basin Type Solar Still Under Local Climate Conditions", *Energy Convers and Mgmnt;* Vol 41; 9: pp883-890.
3. Akash, B. A., Mohsen, M. S., Osta, O. and Elayan, Y. (1998). "Experimental Evaluation of a Single-Basin Solar Still Using Different Absorbing Materials", *Renewable Energy;* Vol 14; 1-4: pp307-310.
4. Al-Hayek, I. and Badran O. O. (2004). "The Effect of Using Different Designs of Solar Stills on Water Distillation", *Desalination* ;Vol 150: pp 230-250.
5. Al-Hinai H., Al-Nassri M. S., and Jubran B. A. (2002). "Effect of Climatic, Design and Operational Parameters on the Yield of a Simple Solar Still", *Energy Cons. Mgmt*; Vol43: pp1639-1650.
6. Badran, A. A. and Hamdan, M. A. (1995). "Inverted Trickle Solar Still", *Int J Solar Energy* ; Vol 17:pp51-60.
7. Badran, O. O. and Abu-Khader, M. M. (2006). "Evaluating Thermal Performance of a Single Slope Solar Still", Accepted in *J. of Heat Mass Transfer,* Springer-Verlag.
8. Badran, O. O. (2006). "Experimental Study of the Enhancement Parameters on a Single Slope Solar Still Productivity", *Desalination*; Vol 145: pp142-149.
9. Badran, O. O. and Al-Tahaineh, H. (2005). "The Effect of Coupling a Flat-Plate Collector on the Solar Still Productivity", *Desalination*; Vol 67; pp 137-142.
10. Duffie, J. A. and Beckman, W. A. (1991). "Solar Engineering of Thermal Processes", Madison, Wisconsin USA, Wiley 2nd ed.: pp 30-70.
11. El-Sebaii, A. A. (2000). "Effect of Wind Speed on Some Designs of Solar Stills", *Energy Convers Mgmt* ,Vol 41: pp523-538.
12. Jubran, B. A., Ahmed M. I., Ismail A. F., and Abakar Y. A. (2000). "Numerical Modeling of a Multi-Stage Solar Still", *Energy Convers Mgmt*, Vol 41: pp 1107-1121.
13. Kalogirou, S. A. (2004). "Solar Thermal Collectors and Application", *Progress in Energy and Combustion Science* ,Vol 30, Issue 3: pp231-295.
14. Kalogirou, S. A. (2005). "Seawater Desalination Using Renewable Energy Sources", *Progress in Energy and Combustion Science* ,Vol 31, 3: pp242-281.
15. Kamal, R., Maheshwari, K. P., and Sawhney (1992). "Solar Energy and Conservation, Wiley Eastern Limited, India.
16. Kumar S. and Tiwari G. N. (1999). "Optimization of Daily Yield from an Active Double Effect Distillation with Water Flow", *Energy Convers Mgmt.*,Vol 40: pp703-715.
17. Malik, M. A. S., Tiwari, G. N., kumar, A., and Sodha, M. S. (1982). "Solar Distillation", Pergamon Press Ltd. UK.
18. Malik, MAS, and Tran V. (1973). "A Simple Mathematical Model for Predicting the Nocturnal Output of a Solar Still", *Solar energy*; Vol 14: pp371-385.

19. Nafey, A. S., Abdelkader, M., Abdelmotalip, A., and Mabrouk, A. A. (2001). "Solar Still Productivity Enhancement", *Energy Convers and Mgmt*, Vol 42: pp1401-1408.
20. Nijmeh, S., Odeh, S., and Akash, B. (2005). "Experimental and Theoretical Study of a Single-Basin Solar Still in Jordan", *Int comm. Heat and Mass Transfer* ,Vol 32; pp565-572.
21. Samee, M. A., Mirza, U. K., Majeed, T., and Ahmad, N. (2007). "Design and Performance of a Simple Single Basin Solar Still", *Renewable and Sustainable Energy Reviews*; Vol 11: pp543-549.
22. Singh, H. N., and Tiwari, G. N. (2004). "Monthly Performance of Passive and Active Solar Stills for Different Indian Climatic Conditions", *Desalination*;Vol 168: pp145-150.
23. Tiwari, G. N., Kupfermann, A., and Agrawal, S. (1997). "A New Design of Double Condensing Chamber Solar Still", *Desalination*, Vol 114: pp 153-168.
24. Tiwari, G. N. And Suneja, S. (1998). "Performance Evaluation of an Inverted Absorber Solar Still", *Energy Convers Mgmt*, Vol 39 : pp 173-180.
25. Tripathi, R. and Tiwari, G. N. (2004). "Effect of Size and Material of a Semi-Cylindrical Condensing Cover on Heat and Mass Transfer for Distillation", *Desalination,* Vol 166:pp 231-241.
26. Voropoulos. K., and Mathioulakis. Belessiotis, V. (2001). "Experimental Investigation of a Solar Still Coupled with Solar Collectors", *Desalination* Vol 138: pp103-110.

دراسة عملية لمقطر شمسي ذو سطح مائل منفرد في الأردن

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الملخص

إن أداء المقطر الشمسي ذو السطح المائل المنفرد تمت دراسته عمليا تحت ظروف تشغيلية مختلفة. حيث وجد أن الزيادة في الإنتاجية لـ 33% يمكن الحصول عليها عندما تزداد سرعة الريح بزيادة 50%، وهذه نتيجة الزيادة في فروقات درجات الحرارة بين غطاء المقطر والماء. إن الظروف الجوية لها تأثير مباشر على إنتاجية المقطر، والدراسة أثبتت أن الإنتاجية اليومية للمقطر يمكن أن تزداد بتخفيض العمق والملوحة للماء في المقطر. وقد استنتج من هذه الدراسة أن الملوحة العالية سوف تسبب اختلافا حادا في الكثافة والتي ستقود إلى طبقه وسطية ذو تركيز ملحي مختلف تؤدي إلى عدم انتقال الطاقة وتمنع الانتقال الحملي وتخفض الإنتاجية إلى 22%. إن الماء المقطر بالمقطرات الشمسية يمكن أن يكون احد البدائل للتزود بالماء النقي (بعد معالجته) للمناطق النائية الصحراوية.