ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Desalination 209 (2007) 136–143

DESALINATION

www.elsevier.com/locate/desal

Experimental study of the enhancement parameters on a single slope solar still productivity

O.O. Badran

Al-Balqa Applied University, Faculty of Engineering Technology,
Mechanical Engineering Department, P.O. Box 331006, Amman 11134, Jordan
Tel./Fax +962-6-5679773; email: o_badran@yahoo.com

Abstract

The performance of a single slope solar still using different operational parameters was studied experimentally. The still productivity increased up to 51% when combined enhancers such as asphalt basin liner and sprinkler have been applied to the still. Also the ambient conditions were found to have direct effect on the productivity of the still. The night production in the absence of solar radiation contributed to 16% of the daily output due to the differences in temperature between the cover and water, and the decrease of heat capacity. The study also showed that the daily production of still can be increased by reducing the depth of the water in the basin.

Keywords: Solar still; Enhancers; Distillation; Operational parameters; Climatic parameters

---

1. Introduction

The availability of potable water is a main problem for the communities who will be lived in arid new regions or especially for people in remote region (i.e. deserts). 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, such as wind pumping systems. 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.

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 [1,2]. Solar distillation has been used to produce low yield, but safe and pure supplies of water in remote areas. For households without access to potable water,

The Ninth Arab International Conference on Solar Energy (AICSE-9), Kingdom of Bahrain

doi:10.1016/j.desal.2007.04.022

a simple solar still can easily produce the water needed for drinking and cooking. Also Distilled water can be used for industrial purposes (water jackets, batteries, chemical solutions).

There are 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 (2–4) liters per day per m^2 [2,3]. Different still designs [2–5] for solar distillation have been used in different regions globally where high-quality drinking water supplies are scares and the solar option is viable.

Many experimental and theoretical studies have been done on single slope solar stills [3–10]. Al-Karaghouli and Alnaser [7] investigated the performances of single and double basin. They performed two types of measurements; one with the still-sides insulated and the other without. They have noticed that the influence of side insulation is significant on the rate of water production, especially for the double-basin type. Also the daily average still production for the double-basin still is around 40% higher than the production of the single-basin still. El-Sebaii [4] studied the effect of wind speed on the daily productivity of some active and passive solar stills using computer simulation for different solar stills designs. He found that for the active and multi-effect passive stills the daily productivity increases with the increase of wind velocity up to a typical velocity, beyond after this the productivity becomes insignificant. For the single effect passive stills, he found that there is a critical basin water depth beyond which the productivity increases as the wind velocity increases until the typical velocity. He concluded that the typical velocity is independent on the still shape and the mode of operation (active or passive) with some seasonal dependence. Nijmeh et al. [11] studied the effect of using various absorbing materials on the productivity of a single-basin solar still. The materials used to enhance the absorptivity of water for solar radiation include dissolved salts, violet dye, and charcoal. The salts were potassium permanganate and potassium dichromate. They found that the addition of potassium permanganate resulted in 26% improvements in efficiency. The best result was obtained by using violet dye with an increase of about 29%. Other researchers investigated the effect of water depth on internal heat and mass transfer for active solar distillation [12]. They found that the convective heat transfer coefficient between water and inner condensing cover depends significantly on the water depth in the basin. They also observed that more yield is obtained during the off shine hours as compared to daytime for higher water depths in solar still due to storage effect. Abu-Hijleh and Rababa'h [13] showed that the daily production of solar stills can be greatly enhanced using sponge cubes.

Some researchers developed theoretical techniques to predict the daily productivity of a single sloped solar still [5]. They indicated that the solar radiation has a direct effect on the still productivity. Also they illustrated that when the brine depth increases, the solar still productivity decreases. Al-Hinai et al. [14] used a mathematical model to predict the productivity of a simple solar still under different climatic, design and operational parameters in Oman. They found that the shallow water basin, 23° cover tilt angle, 0.1 m insulation thickness and asphalt coating of the solar still are the optimum parameters for producing higher yields. Djebedjian and Abou Rayan [15] performed a theoretical investigation based on time-averaged Navier–Stokes equations; including the effect of the variable fluid properties, by using a mixture of air and vapour in the still. Aboul-Enein et al. [16] presented a simple transient mathematical model which based on analytical solution of the energy-balance equations for different parts of the still. While Abu-Hijleh and Mousa [6], investigated numerically, the effect of water film cooling of the glass cover on the efficiency of a single-basin still. They found that the use of the film cooling parameter has increased the still efficiency by up to 20%.

Tiwari et al. [17] have developed a computer model to predict the performance of the single slope solar still based on both the inner and outer glass temperatures. They concluded that there is a significant effect of operating temperature range on the internal heat transfer coefficients. Voropoulos et al. [9] evaluated experimentally and theoretically a simple and efficient method for the behavior of solar stills. Their method relates the main climatic data and operating conditions of the still with distilled water output in daily and night base with linear equations using characteristic coefficients.

Some researchers used single slope solar stills for many useful purposes. Hanson et al. [8] proved that their single basin stills were very successful in removing non-volatile contamination from the water. Their stills were also successful in removing bacteria. Potoglou et al. [18] employed a solar still for dewatering of olive mill wastewater over a series of consecutive days. Also Meukam et al. [19], showed in their experimental study the possibility of using solar energy for alcohol distillation.

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 techniques have been proposed to improve its productivity. All the results were compared together to reach to the best operating technique that can be used in future for solar still augmentation for production of drinking water to population of arid regions in the Jordanian desert.

2. 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.

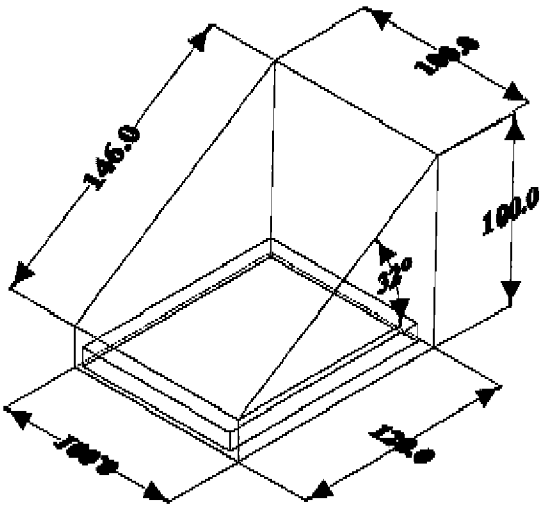

Fig. 1. Isometric view of the solar still.

A single slope solar still shown in Fig. 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.

2.1. Basin liner

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

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°

to solar radiation and resistance to accidental puncturing and in the case of damage (possibly by broken glass), it should be easily repaired. Two different basin liners were used to increase the absorptivity, such as asphalt and normal no glossy black paint. In this work the basin liner made of iron sheet (1.4 mm thickness) of 90 × 110 cm with maximum height of 5 cm.

2.2. Glass cover

In this work window glass of 4 mm thickness was used and its average transmissivity (τ) of 0.88, it was fixed at an angel 32° with the horizontal as shown in Fig. 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.

2.3. 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 in this work. The insulating material is a rock wool of 5 cm thickness and 0.045 W/m^2 °C thermal conductivity. Mirrors fixed inside the solar still on the inner sides' walls are very useful, because the mirrors can concentrate and reflect the scattered rays of the incident solar radiation in the solar still.

2.4. 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.

2.5. Measuring devices

2.5.1. 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 m/s.

2.5.2. 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] the accuracy of this device is in the range of 0.3°C for the temperature measurements between 1 and 99°C. Five thermocouples probe were used to measure the following temperatures: Basin, glass (in), vapor, water, and glass (out). An external thermometer is used to measure ambient temperature. Fig. 2 shows the locations of these thermocouples.

2.5.3. 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].

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 [2].

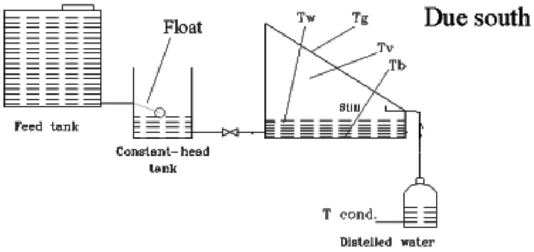

Fig. 2. Overall schematic diagram of the solar still.

3. Results and discussions

This section will present the influence of different conditions on the productivity of the solar still, such as ambient temperature, different water depths, different basin liner material (i.e. black paint, asphalt), sprinkler (cooling film) on glass and wind speed. Different variables were measured hourly such as inner glass temperature ($T_{g,in}$), outer glass temperature ($T_{g\text{'}out}$), ambient temperature (T_a), water temperature (T_w), basin temperature (T_b), vapor temperature (T_v), solar radiation (I), wind speed (V_w), and productivity (Pr). Fig. 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 effect of solar radiation on the productivity for the conducted experiments is shown in Figs. 4 and 5, the maximum yield will occur during the time period 13.5 pm and 14.5 pm corresponding to a higher solar radiation. Also Fig. 4 shows that the solar radiation is increases and reaches those maxima at mid day then decreases. These figures indicate that the effect of solar radiation intensity on still productivity is pronounced.

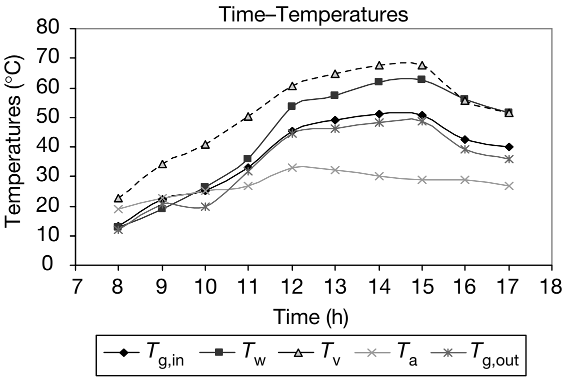

Fig. 3. Variations between the temperatures at different locations on the still.

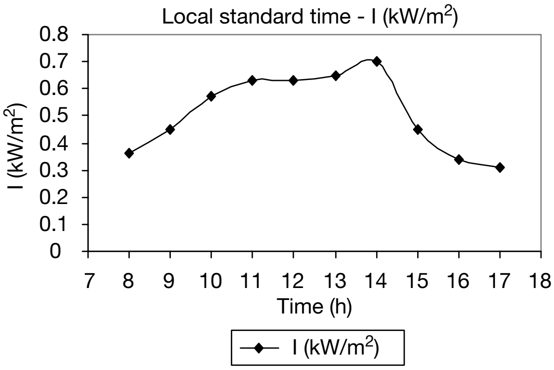

Fig. 4. Relation between the solar intensity and local standard time.

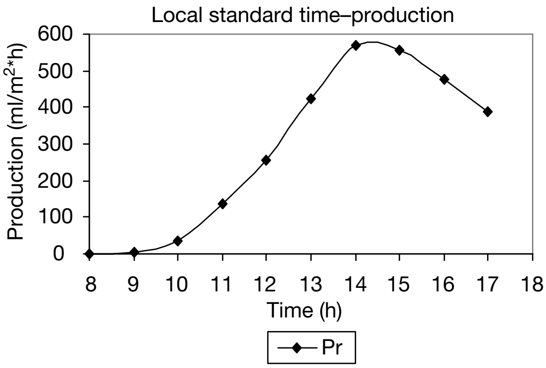

Fig. 5. Relation between the productivity and time.

From Fig. 6 it can be seen that the temperature difference is significantly higher at night than during the day. This explains the productivity at

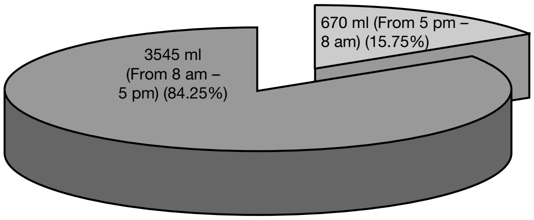

Fig. 6. The operating condition of still during the night and day.

night (during the period from noon until the early morning of the next day) where the temperature differences play the important rule on the productivity due to the increases of wind velocity and the absence of solar radiation. It was found that the productivity during the night contributed to around 16% of total day around productivity.

The effects of ambient temperature and the wind velocity are shown in Fig. 7a and b. It can be seen that as the ambient temperature and the wind velocity increases, the productivity will increase. These results are in agreement with those reported by El-Sebaii [4], Garg and Mann [20], Cooper [21] and Rajvanshi [22]. The productivity is found to be increased by 35% on increasing the wind velocity from 2.7 to 5 m/s, while an increase of 53% was noticed for the temperature increase from 28 to 32°C.

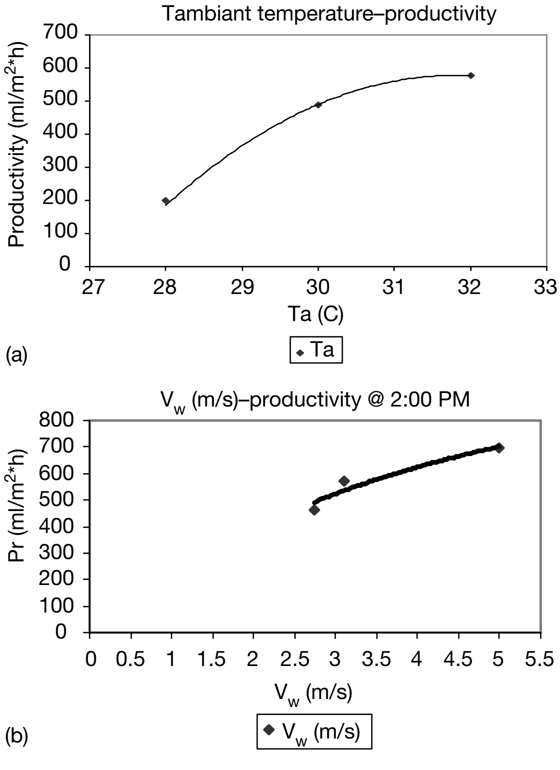

Fig. 7. The effect of wind velocity and ambient temperature on still yield.

The effect of water depth in the still basin on the productivity is shown in Fig. 8. It is evident that as the water depth increases, the productivity will be decreased. This is due to the increase of the heat capacity of the water in the basin, results in lower water temperature in the basin leading to lower evaporation rate. The decrease of the water depth from 3.5 to 2 cm increased the productivity by 26%. Tripathi and Tiwari [12] found similar behavior; they indicated that, the internal convective heat transfer coefficient decreases with water depth. Aboul-Enein et al. [16] concluded from his mathematical model that, the productivity of the still decreases with an increase of heat capacity of basin water during the daylight and reverse in case of overnight.

The solar still daily output using different basin surface absorbance layers were determined (Fig. 9). Fig. 9 shows the effect of the basin liner on the productivity of the solar still. It can be highlighted that when the asphalt basin liner was used the productivity increased by 29%, this may be due to the high absorbency of the asphalt compared to the black paint, and also the asphalt liner will act as an insulator in the same time. The same behavior was drawn by Al- Hinai et al. [14] and Voropoulos et al. [9]. Another enhancement in productivity of the still can be increased by introducing a sprinkler

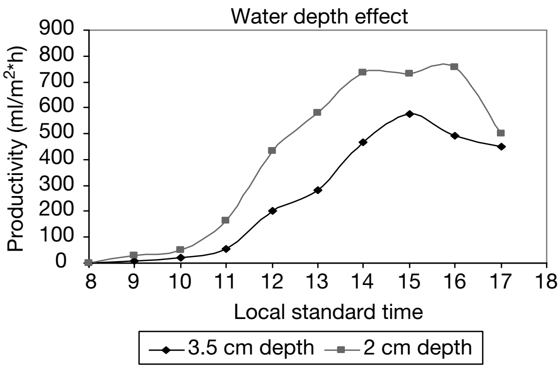

Fig. 8. The effect of water depth in the basin on the productivity.

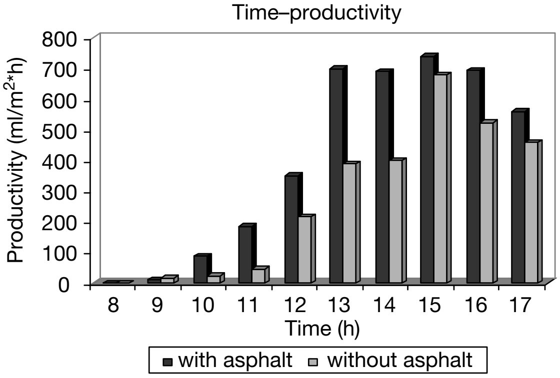

Fig. 9. Relation between the local standard time and productivity due to asphalt basin liner effect.

(cooling film) to the outer layer of the glass cover of the still; this will increase the productivity from the latter case by another 22%, as shown in Fig. 10. This increase in the still yield is due to the difference between the glass cover temperature and the water temperature which will increase the condensation process on the inner glass layer of the cover. This will be as a result of reduced convection and radiation energy losses to the ambient; also the cooling film will act as a continuous self cleaning of glass cover [6]. This finding is consistent with the numerical results reported by Bassam and Musa [6].

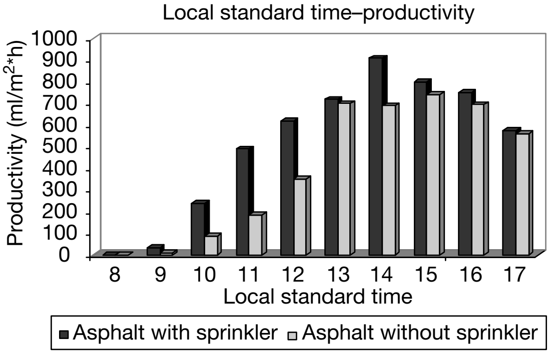

Fig. 10. Relation between the local standard time and productivity due to asphalt liner and sprinkler effect.

4. Conclusions

An experimental work has been conducted to predict the productivity of a single slope solar still using different operational parameters. The use of asphalt in the basin resulted in a significant improvement in still production for an increase of 29%. The sprinkler combination with the asphalt was more effective than the use of asphalt alone by another 22%. It can be concluded also that the ambient conditions (i.e. wind and temperature) have a direct effect on the still productivity. Also it is evident from the result that as the depth of water decreases the daily still output is increased.

References

[1] J.A. Duffie and W.A. Beckman. Solar engineering of thermal processes 2nd ed. New York, Wiley, 1991.

[2] M.A.S. Malik, G.N. Tiwari, A. Kumar and M.S. Sodha, Solar distillation. Pergamon press Ltd Oxford, 1982, 20–150.

[3] I. Al-Hayek and O.O. Badran, The effect of using different designs of solar stills on water distillation, Desalination, 150 (2004) 230–250.

[4] A.A. El-Sebaii, Effect of wind speed on active and passive solar stills. Energy Convers. Mgmt., 45 (2004) 1187–1204.

[5] A.S. Nafey, M. Abdelkader, A. Abdelmotalip and A.A. Mabrouk, Parameters affecting solar still productivity, Energy Covers. Mgmt., 41 (2001) 1797–1809.

[6] B.A. Abu-Hijleh and H.A. Mousa, Water film cooling over the class cover of a solar still including evaporation effects, Energy, 22 (1997) 43–48.

[7] A.A. Al-Karaghouli and W.E. Alnaser, Performance of single and double basin solar-stills, J. Appl. Energy, 78 (2004) 347–354.

[8] A. Hanson, W. Zachritz, K. Stevens, L. Mimbela, R. Polka and L. Cisneros, Distillate water quality of a single-basin solar still: Laboratory and field studies, Sol. Energy, 76 (2004) 635–645.

[9] K. Voropoulos, E. Mathioulakis and V. Belessiotis, Analytical simulation of energy behavior of solar stills and experimental validation, Desalination, 153 (2002) 87–94.

[10] K. Voropoulos, E. Mathioulakis and V. Belessiotis, Experimental investigation of the behaviour of a solar still coupled with hot water storage tank, Desalination, 156 (2003) 315–322.

[11] S. Nijmeh, S. Odeh and B. Akash, Experimental and theoretical study of a single-basin solar still in Jordan, Int. comm. Heat Mass Transfer, 32 (2005) 565–572.

[12] R. Tripathi and G.N. Tiwari, Effect of water depth on internal heat and mass transfer for active solar distillation, Desalination, 173 (2005) 187–200.

[13] B.A. Abu-Hijleh and H. Rababa'h, Experimental study of a solar still with sponge cubes in basin, Energy Convers. Mgmt., 44 (2003) 1411–1418.

[14] H. Al-Hinai, M.S. Al-Nassri and B.A. Jubran, Effect of climatic, design and operational parameters on the yield of a simple solar still, Energy Convers. Mgmt., 43 (2002) 1639–1650.

[15] B. Djebedjian and M. Abou Rayan, Theoretical investigation on the performance prediction of solar still, Desalination, 128 (2000) 139–145.

[16] S. Aboul-Enein, A.A El-Sebaii and E. El- Bialy, Investigation of a single-basin solar still with deep basins, Renew. Energy, 14 (1998) 299–305.

[17] G.N. Tiwari, S.K. Shukla and I.P. Singh, Computer modelling of passive/active solar stills by using inner glass temperature, Desalination, 154 (2003) 171–185.

[18] D. Potoglou, A. Kouzeli-Katsiri and D. Haralambopoulos, Solar distillation of olive mill wastewater, Renew. Energy, 29 (2003) 569–579.

[19] P. Meukam, D. Njomo, A. Gbane and S. Toure, Experimental optimization of a solar still: application to alcohol distillation, Chem. Eng. Proc., 43 (2004) 1569–1577.

[20] H.P. Garg and H.S. Mann, Effect of climatic, operational and design parameters on the year-round performance of single-sloped and double-sloped solar stills under Indian arid zone conditions, Sol. Energy, 18 (1976) 159–164.

[21] P.I. Cooper, Digital simulation of transient solar still performance, Sol. Energy, 12 (1969) 313–331.

[22] A.K. Rajvanshi, Effect of various dyes on solar distillation, Sol. Energy, 27 (1981) 51–65.