Desalination and Water Treatment
www.deswater.com

27 (2011) 313–318
March

1944-3994/1944-3986
doi: 10/5004/dwt.2011.2088

Experimental study on the effect of internal and external reflectors on the performance of basin type solar stills at various seasons

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Received 12 June 2010; Accepted 2 August 2010

ABSTRACT

This paper presents an experimental investigation on the effect of internal and external reflectors on the output of simple-basin solar stills in summer, autumn and winter. A simple still that equipped with internal reflectors and an external reflector is investigated at a latitude angle of 33.3° N. It was found that the internal and the external reflectors increase the daily output throughout the different seasons except for summer where the reflector(s) effect was insignificant. The increase in the daily output averaged over the seven months test period by adding both internal and external reflectors was 35.5%, and that by adding the internal reflector only was 19.9% compared to a still with no reflectors. The percentage increase in output by adding the internal and/or external reflector(s) is higher in winter than in summer. The results of this study agree with the trend of the theoretical predictions and with the winter experimental results cited in the literature at 30° N and 32.2° N latitude angles, respectively.

Keywords: Solar still; Reflector; Validation; Productivity; Desalination

1. Introduction

The productivity of solar stills may be increased by several modifications, such as adding internal and/or external reflectors to increase the solar radiation incident on the basin liner. The simplest structure of a solar still, as shown in Fig. 1, is a basin having a certain quantity/depth of saline water and a cover transparent to solar radiation, yet blocks the long wavelengths radiation emitted by the interior surfaces of the still. A sloped cover, which provides a cool surface for condensation of water vapor, facilitates an easy flow of the water droplets into the condensate trough. The base of the still is usually blackened on the interior surface to maximize absorption of solar radiation, and insulated on the exterior surface to minimize heat losses.

Several experimental and theoretical studies may be found in the literature that examine the effect of using reflectors to enhance the yield of simple solar stills. Al-Hayek and Badran [1] found that a single-slope still with an internal reflector is 20% more productive than a double-slope one without a reflector. El-Swify and Metias [2] compared a single-slope still having a back wall of glass plate with one whose inner sidewalls and outer surface of the back glass wall were covered by highly reflecting materials. They found that the productivity was increased by 83% and 22% in winter and summer, respectively. A geometrical method to predict the increase in solar radiation absorbed by the basin liner due to the use of internal reflectors was also presented. El-Bahi and Inan [3] studied a basin type still with an external condenser and an external reflector that was used to increase solar radiation incident on the glass cover and to make a shadow for the condenser. Abdallah et al. [4] installed reflecting mirrors on all the interior sides of a solar still to improve the system thermal performance by up to 30%. Badran and Al-Tahaineh [5] investigated experimentally the effect of coupling a flat plate collector on the productivity of a single-slope solar

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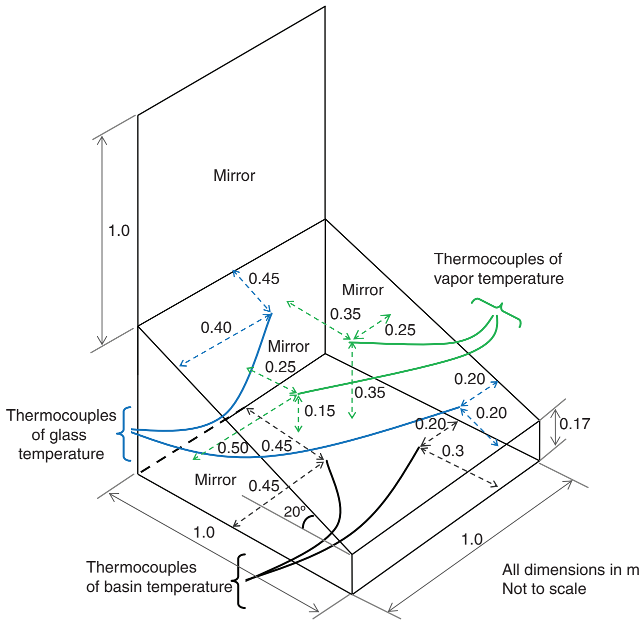

Fig. 1. A schematic diagram of the basin type solar still.

still with mirrors fixed to its interior sides. Ayav and Atagündüz [6] studied theoretically and experimentally a solar still with an external reflector. Yadav et al. [7] and Yadav and Yadav [8] studied a solar still integrated with an inverted absorber asymmetric line-axis solar compound parabolic concentrator as an option for high-temperature solar distillation. Tripathi and Tiwari [9] performed numerical analysis by using AUTOCAD 2000 to determine the solar fraction of a basin type still. Tanaka and Nakatake [10] conducted a theoretical analysis of a basin type solar still with an internal reflector and an inclined external reflector on a winter solstice day at 30° N latitude. They found that the benefit of a vertical external reflector was insignificant for a still with a large value of the glass cover angle. Tanaka and Nakatake [11] proposed a solar still consisting of a vertical multiple-effect diffusion-type still and an external flat plate reflector.

An experimental investigation on the effect of internal and external reflectors inclined at angles 0° (vertical), 10°, 20° and 30° on the output of simple-basin solar stills in summer, autumn and winter was carried out by Khalifa and Ibrahim [12]. A simple still, which had a 20°cover tilt angle and equipped with internal and external reflectors was investigated at a latitude angle of 33.3° N. The average daily yield was found to increase by the use of reflectors except for summer when the effect of the reflectors was found to be negative. The increase in the productivity of the still with reflector(s) compared to one with no reflectors was averaged at 19.9% for still with internal reflector only and 34.5%, 34.4%, 34.8% and 24.7% for still with internal and an inclined external reflector tilted at 0°, 10°, 20°, and 30°, respectively. Later, Khalifa and Ibrahim [13] reported the results of an experimental investigation on the productivity of a basin type solar still with internal reflectors and an external reflector tilted at angles of 0° (vertical), 10°, 20° and 30° for still cover angles of 20°, 30° and 40°. The daily productivity was found to be greater for a still with a larger cover angle at any reflector angle. The benefit of the vertical external reflector in winter was found to decrease as the cover angle exceeds 40°. The most productive solar still in winter was a still with a cover angle of 20° and internal reflectors and an external reflector tilted at 20°. The results of [12,13] confirmed the trend of some of the theoretical predictions of [10] at 30° N latitude angle.

The cited literature tells that the use of reflectors do increase the productivity of basin type solar stills due to the increase in the solar radiation absorbed by the basin. However, the contribution and benefit of the reflector(s) for various months and seasons has not been experimentally examined in details. The theoretical study of Tanaka and Nakatake [14] predicted the effect of internal and external reflectors on the amount of solar radiation absorbed by the basin liner of a single-slope solar still for each month and on its distillate yield at 30° N latitude in Fukuoka/Japan. They concluded that the increase in the solar radiation absorbed by the basin liner and hence the daily output due to the use of the internal and the external reflectors was high in winter and low in summer. Furthermore, the increase in the daily output averaged over the entire year by adding the internal reflector was 22%, which was increased to 48% when both reflectors were used at a glass cover angle of 20°. Recently, Tanaka [16] reported the results of outdoor experiments in winter of a still with a glass cover angle of 20°, a water depth of 10 mm and internal and external reflectors at 33.2° N latitude. The experimental results of distillate production rate were reported to be 69–98% of the predictions reported in [14].

Some of these interesting findings have motivated the present investigation that aims at the experimental examination of the theoretical predictions of [14] at 30° N latitude and the experimental results of [16] obtained in winter at latitude 33.2° N. For this purpose, experiments on a single-slope solar still that cover the period from June to December at 33.3° N latitude are carried out in Baghdad/Iraq. The small differences in the latitudes of the examined regions are expected to have only trivial effect on the validation credibility.

2. The experimental setup and procedure

A single-sloped basin type solar still, which has the dimensions and configuration shown in Fig. 1, is designed and constructed for the purpose of the investigation. The still, which has a 1 m^2 basin area, is made from 0.7 mm thick galvanized steel sheet and has a 4 mm thick glass cover. Calibrated copper-constantan thermocouples, covered with reflective shields where necessary, are fixed at the locations shown in Fig. 1 and connected to a microprocessor thermometer (range: –100 to 400 ºC and accuracy ± 1%) to measure the glass, basin and vapor temperatures. Distillate is collected every hour and measured with a flask and a precise balance. The still has a 60 mm polystyrene insulation on the base and sides of the still, 20 mm water depth and a cover tilt angle of 20º. Tap water, not brine, is used in the basin to keep the basin clean from deposits throughout all the tests.

Tests in only sunny days in each month from June to December are carried out. Glass mirrors, 4 mm thick, are fitted to the experimental still to act as internal and external reflectors. The internal mirror which covers all the inner sides (both side and back walls) has an area of 1.16 m^2, the external mirror which extends from the back wall of the wooden box which contains the solar still has an area of 1 m^2 as shown in Fig. 1. The specifications of the still are shown in Table 1. Three configurations are tested, namely a still without reflectors (NRS), a still with only an internal reflector (IS) and a still with internal and a vertical external reflectors (IES).

Table 1
The specifications of the solar still

Specifications	Details
Basin area	1 m^2
Glass cover	Thickness = 4 mm, transmissivity = 0.84, area = 1.06 m^2, Tilt angle = 20º
Polystyrene insulation	Thickness = 60 mm, density = 35 kg/m^3, thermal conductivity = 0.029 W/m ºC
Internal reflector (mirror)	Thickness = 4 mm, area = 1.17 m^2
External reflector (mirror)	Thickness = 4 mm, area = 1 m^2, inclination = 0º (vertical)

3. Results and discussion

Table 2 shows the daily productivity and the daily global solar insolation for sunny days for the three configurations tested, namely still with no reflector (NRS), still with only internal reflector (IS) and a still with both internal and vertical external reflector (IES) for each month. The global solar radiation values were calculated using a published correlation obtained for the test location.

Time variation of the hourly yield of the NRS, IS and IES stills for June (summer) is shown in Fig. 2. The global solar radiation for these tests was in the range 21.986 and 21.997 MJ/m^2 d. Small differences can be noticed between the hourly yields of the NRS (6.08 l/m^2 d), IS (6.26 l/m^2 d) and IES (6.08 l/m^2 d) stills. This trend confirms the conclusion of [14] who found a small or negligible benefit of the reflectors in summer. The negligible difference is attributed to the vertical position of the sun around noon which cause the reflected radiation to be zero or negligible from both reflectors, in addition to the shadows made by both reflectors when the Sun moves north.

The results for September (autumn), which should be comparable to that of spring, are shown in Fig. 3 for the three different configurations. Noticeable differences between the yields of the different configurations are evident. The global solar radiation for these tests was in the range 16.974 and 17.517 MJ/m^2 d. Daily yields of 4.39 l/m^2 d for NRS, 5.32 l/m^2 d for IS (an increase of 21% compared to NRS) and 6.39 l/m^2 d for IES (an increase of 46% compared to NRS) are obtained. Such trend agrees with the theoretical results of [14] who found an increase of 20% and 55% in the daily yields of IS and IES compared to NRS, respectively.

December (winter) results are shown in Fig. 4. The global solar radiation for these tests was in the range 9.135 and 9.158 MJ/m^2 d. The daily yield of the NRS still was 1.47 l/m^2 d compared to 1.96 l/m^2 d for IS (an improvement of 33%) and 2.29 l/m^2 d for IES (an improvement of 56%). Again, these experimental

Table 2
The daily productivity of the still (l/m^2 d) and the daily global solar insolation (MJ/m^2 d) for the different configurations tested

Configuration	NRS		IS		IES	
Month	Productivity	Solar insolation	Productivity	Solar insolation	Productivity	Solar insolation
June	6.08	21.986	6.26	21.997	6.08	21.989
July	5.74	21.513	5.97	21.443	6.45	21.334
August	4.96	19.956	5.74	19.596	6.70	19.502
September	4.39	17.517	5.32	17.111	6.39	16.974
October	2.62	14.047	3.29	13.390	4.42	13.781
November	1.87	10.381	2.62	9.779	2.98	10.062
December	1.47	9.153	1.96	9.145	2.29	9.158

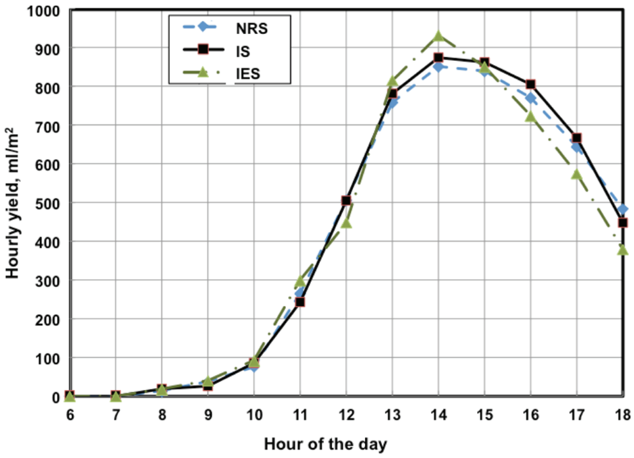

Fig. 2. Time variation of yield of NRS, IS and IES in June (summer).

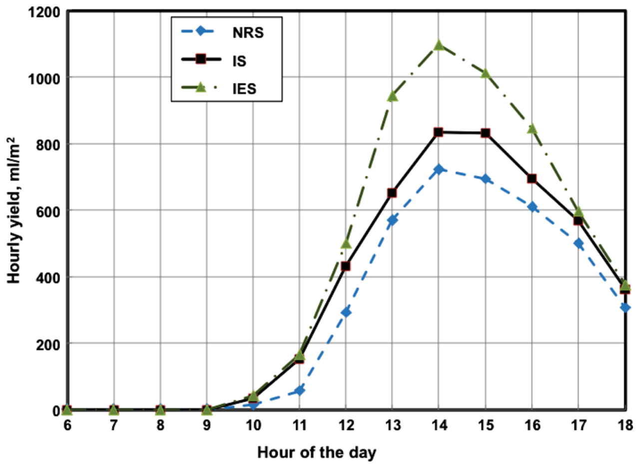

Fig. 3. Time variation of yield of NRS, IS and IES in September (autumn).

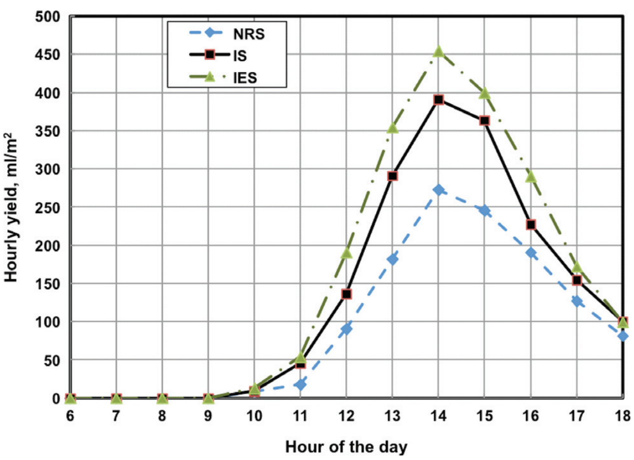

Fig. 4. Time variation of yield of NRS, IS and IES in December (winter).

results agree with the trend of the theoretical predictions of [14] who found an increase of 50% and 86% in the daily yield of IS and IES compared to NRS, respectively, but with values that are around 65% less.

Later, Tanaka [16] reported experimental results for still with internal and external reflectors (IES) for winter (December to February) with the external reflector inclined forward by 10° from vertical. The results were 69% (for cloudy tests) to 98% (for clear days) of the theoretical yield predictions of [10]. The reported daily yields were 1.77 kg/m^2 d for a cloudy day in December, 1.19, 1.61 and 2.05 kg/m^2 d for cloudy days in January and 2.99, 3.31, 4.01 kg/m^2 d for clear days in February, compared to 2.29 kg/m^2 d for a clear day in December obtained in the present study. The main reasons that may lead to the difference in yield between the two experimental studies are the difference in the weather conditions (month and sky condition), the smaller water depth of 10 mm and the inclined external reflector used in [16] compared to a 20 mm water depth and a vertical external reflector used in this investigation. Reducing the water depth from 20 mm to 10 mm could increase the yield by about 5–14% [15,17] and tilting the external reflector by 10° from the vertical position would increase the yield by up to 33% in December [12]. Other minor causes of discrepancy include the difference in: (1) the type and thickness of insulation used in the still (60 mm thick polystyrene sheet compared to 50 mm thick urethane foam board in [16]); reducing the insulation thickness from 60 to 50 mm could reduce the yield by about 3% [18], (2) the thickness of the glass cover (4 mm compared to 5 mm in [16]) and (3) the difference in the material and thickness of the reflectors (4 mm thick mirror compared to 1.8 mm thick mirror-finished stainless steel plate in [16]).

The difference between IES and IS in the present investigation is smaller in winter (17%) and larger in autumn (20%). The curves that show the time variation of the hourly yield is not symmetrical around the hour 12:30 as suggested by Tanaka and Nakatake [14]. Instead, the yield is very small during the first few hours after sunrise, as can be seen in Figs. 2–4, since the received energy is utilized for heating the basin water during this period. Further, the still continues to produce distillate after sunset for several hours due to the thermal storage.

As more solar radiation is reflected on the still, its operating temperatures such as the basin, maximum and average vapor temperatures for IS and IES are increased compared to NRS for all months except for June as can be seen in Figs. 5–7 which justify the increase in output. The increase in temperatures was more noticeable for the IES still as might be expected.

The daily yield over the seven months is increased by the use of internal and/or external reflector as shown

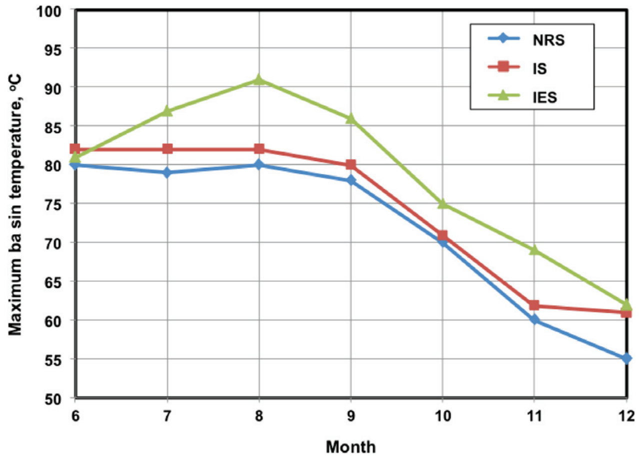

Fig. 5. Maximum basin temperature throughout the seven months.

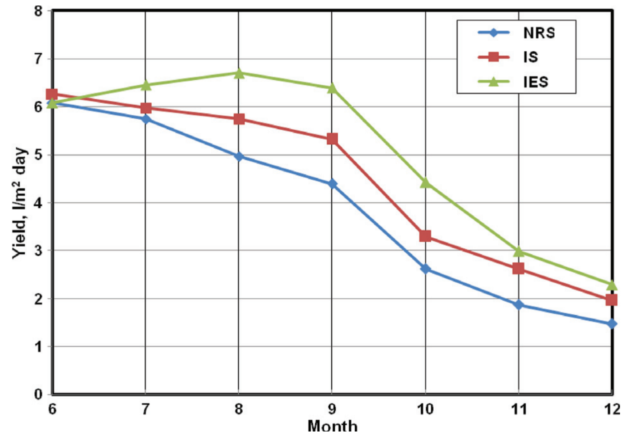

Fig. 8. Daily yield throughout the seven months.

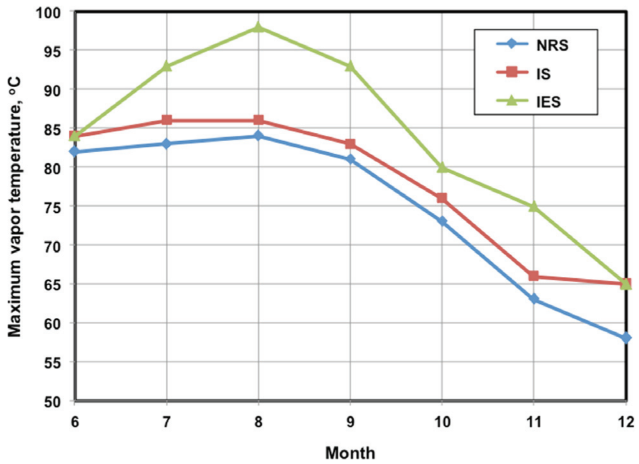

Fig. 6. Maximum vapor temperature throughout the seven months.

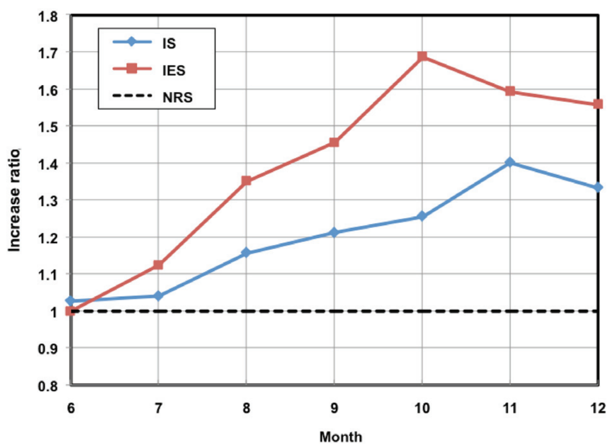

Fig. 9. Increase ratio of daily yield throughout the seven months.

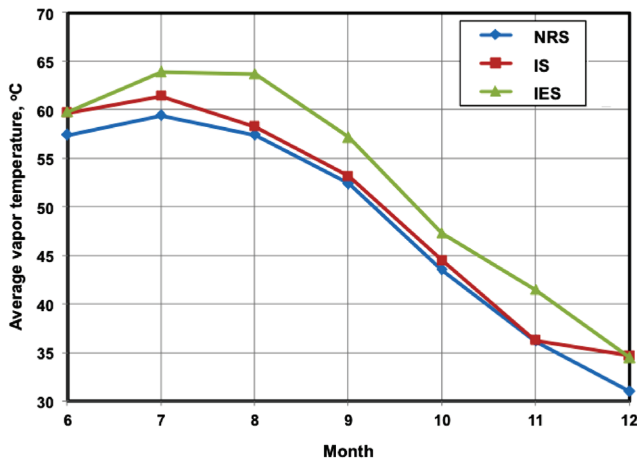

Fig. 7. Average vapor temperature throughout the seven months.

in Fig. 8 and Table 2. For June, however, the yields of the three configurations are close and the effect of the reflector(s) seems marginal. The yield of IES peaks in August and those of NRS and IS peak in June.

The increase ratio of the daily yield, which is defined as the ratio of the yield of IS or IES configuration to that of the NRS still, for the three configurations throughout the seven months is shown in Fig. 9. The increase ratio is larger for IES and IS except for June; it is higher in winter than in summer. More radiation is reflected by the internal and external reflectors to the basin of the still because of the smaller solar altitude angle in winter [14]. The increase ratio for the seven months is averaged at 19.9% and 35.5% for the IS and IES configurations, respectively, which is in reasonable agreement of the yearly averaged values of [14] of 22% and 48%, respectively.

4. Conclusions

The yield of a basin type solar still with internal and external reflectors at 33.3° N latitude is experimentally evaluated in summer, autumn and winter. The following conclusions may be drawn from this investigation:

1. The use of internal and the external reflectors with the simple basin solar still increase the daily yield throughout the various seasons of the year except for summer where their effect was insignificant.
2. The increase in the daily output averaged over seven months by adding both internal and external reflectors was 35.5%, and that by adding the internal reflector only was 19.9% compared to a still with no reflectors for an angle of glass cover of 20°.
3. The increase in distillate productivity by adding the internal and/or external reflector(s) was high in winter and small in summer.
4. The results of this study agree with the trend of some of the year-round theoretical results cited in the literature at 30º N latitude and with the experimental results for winter at 33.2º N latitude.

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