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A review of solar still performance with reflectors

Z.M. Omara[a,*], A.E. Kabeel[b], A.S. Abdullah[c]

[a] Faculty of Engineering, Kafrelsheikh University, Egypt
[b] Faculty of Engineering, Tanta University, Egypt
[c] Faculty of Engineering, Prince Sattam bin Abdulaziz University, Saudi Arabia

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ABSTRACT

In numerous respects, the solar still is a perfect wellspring of freshwater for both agriculture and drinking in remote areas or islands. There are numerous sorts of solar stills; the least difficult and most demonstrated is the basin solar still (conventional solar still). Investigations demonstrated that the conventional still has constrained productivity. Scientists have taken efforts to make diverse designs of solar stills to improve the productivity and deduced that solar stills integrated with reflectors are one of the most efficient and effective designs. The reflectors, either external or internal, are a good and cheap modification to increase the solar irradiation directed to the basin liner or the water as well as the distillate efficiency of the still. In this paper, a broad survey for diverse solar stills with reflectors has been conducted.

1. Introduction

People living in remote areas or islands, where freshwater supply by transport is expensive, face the problem of water shortage every day. Solar still presents specific advantages to be used in these areas due to its easier construction, minimum skills of operation and maintenance requirements, and friendliness to the environment. The clean free energy and friendly to the environment are two major advantages which strengthen the use of solar stills. The main disadvantage of solar stills is the low yield of freshwater in comparison with the other desalination systems. The production capacity for a simple type still is only between 2–5 l/m^2/day. This makes the solar stills uneconomical compared to the other conventional desalination systems [1].

Several researchers have reviewed, thoroughly, the recent work on solar stills such as classification of solar stills [2], design of solar stills [3], improvement techniques of solar stills [4], passive solar stills [5], active solar stills [6], inclined solar stills [7], stepped solar stills [8], wick type solar stills [9], and condensers with solar stills [10].

There is no specific accessible survey on solar stills with reflectors. Along these lines, this work is to make a documental survey on the solar stills combined with external and internal reflectors.

2. Working of conventional solar still with reflectors

Internal reflectors are useful tools to concentrate and redirect solar radiation. They are recommended when sunlight is weak or the local temperature is relatively low. External reflectors are preferred to be used to change the direction of solar beams to improve the flexibility of the absorber plate configuration such as vertical solar absorber plate which is helpful in recovering vapor latent heat of condensation. External and/or internal reflectors are recommended when sunlight is frail or the local temperature is moderately low, Fig. 1.

3. Classification of reflectors with solar stills

To get higher distillate yield, researchers introduced many efforts to make different designs of solar stills. They inferred that the solar still integrated with reflectors is effective and efficient. The reflectors with solar stills can be divided into three types; internal reflectors, external reflectors (top and bottom), and combination between internal and external reflectors. Utilizing external and/or internal reflectors can be an economical approach to expand the solar irradiation incident on the basin liner to make the productivity high as can as possible. A simple comparison of different solar stills with reflectors is illustrated in Table 1. They are compared based on location, daily yield, productivity improvement (%), efficiency, and observations in experiment.

3.1. Internal reflectors (IRs)

The reflectors (internal reflectors) inside the solar still affect significantly the output of distilled water, which is credited to the centralization of the reflected solar radiation incident on the water. Besides, reflectors decrease the waste heat energy from the solar still. Tamimi [11] studied experimentally the performance of a single-slope

* Corresponding author.
E-mail address: zm_omara@yahoo.com (Z.M. Omara).

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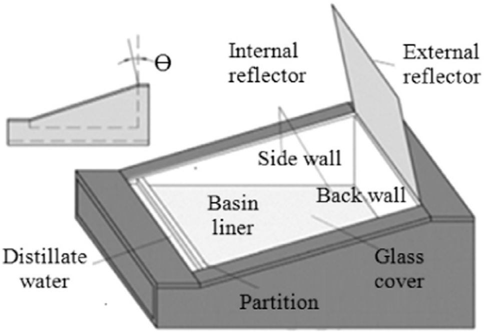

Fig. 1. A basin solar still with reflectors [41].

single-basin solar still with mirrors installed on the side walls of a still. He concluded that using mirrors increases the basin efficiency throughout the whole day. El-Swify and Metias [12] used mathematical modeling and conducted experiments to find out the effect of IRs on the back and side walls of a single slope still with its back wall acting as an additional condenser, Fig. 2. They mentioned that the distillate increase of 82.6% and 22% can be obtained by installing reflectors in the winter and summer, respectively.

A new design of solar still consisting of a metallic cylindrical parabolic reflector has been studied by Minasian et al. [13]. The reflector was designed to concentrate incident solar radiation on the black outside surface of a tray located on the focal line of the reflector. The tray was lined with blackened wick, representing the evaporative surface of the proposed still, as shown in Fig. 3. They showed that the productivity of the new still was 25–35% greater than that of a conventional basin type still.

Abdallah et al. [14] provided modified design of basin solar still. The design modification was fixing interior reflecting mirrors on the internal walls of the still to minimize the amount of energy lost, Fig. 4. The experimental results showed that the use of internal mirrors improved the system thermal performance up to 30%. The still design was modified from flat basin to stepwise basin and the efficiency increased by an average value of 180%.

AlHayek and Badran [15] compared the performances of a double-slope basin solar still and a single-slope basin solar still. The interior surfaces of whole walls were made of mirrors. They performed their experiments during August and concluded that using mirrors on the inside walls of the single slope basin solar still enhanced the production of distilled water by 20% higher than the double basin solar stills, Fig. 5.

The effect of an internal reflector (IR) on the productivity of a single-slope solar still (during the summer and winter) was investigated experimentally and theoretically by Karimi et al. [16], Fig. 6. They presented a mathematical model considering the effect of all walls (north, south, west and east) of the still on the amount of received solar radiation to brine. The model was validated with the experimental data. The model can calculate the yield of the still with and without IR on various walls. The results showed that the simultaneous use of IR on front and side walls enhances the still's efficiency by 18%. However, installation of an IR on the back wall can increase the annual efficiency by 22%. The installation of IRs on all walls in comparison to a still without IR can increase the distillate production at winter, summer, and the entire year by 65%, 22%, and 34%, respectively.

A modification of the stepped solar still through installing IRs on the vertical sides of steps (Fig. 7) was introduced by Omara et al. [17]. As expected, the productivity of the stepped still with IRs was higher than that without the IRs. The results also indicated that the productivity of the modified stepped solar still with and without IRs is higher than that of the conventional still by approximately 75% and 57%, respectively. Also, the efficiency of the stepped still with and without reflectors was 56% and 53% respectively, whereas, the efficiency of the conventional still was only 34%.

The performance parameters of the Corrugated Solar Still (CrSS) and Conventional Solar Still (CSS) were investigated experimentally by Omara et al. [18]. The authors' view concerns with using both double layer wick material and reflectors together inside the CrSS, Fig. 8. In addition, the influence of saline water depth (1, 2, and 3 cm) on CrSS performance was also investigated. During experimentations, the product of CrSS with wick and reflectors is about 145.5% higher than the CSS at a brine depth of 1 cm. Besides, the daily efficiencies of CrSS and CSS were approximately 59% and 33%, respectively. In another experimental research by Omara et al. [19], a hybrid solar distillation system comprising of corrugated and wick absorbers of solar stills was integrated with an external condenser and internal reflectors to examine their performance, Fig. 9. They illustrated that the productivity of corrugated wick still with reflectors and external condenser was improved by about 180% over CSS at a brine depth of 1 cm.

3.2. External reflectors (ERs)

The external reflectors (ERs) used in the solar still are made up of highly reflective materials such as mirror finished metal plate. The diffuse and direct beams transmitted through the glass cover are improved by using the ERs. Hiroshi Tanaka is the most scientist concerning to study the effects of reflectors on the distillate of stills.

3.2.1. External top reflectors

Tanaka et al. [20–22] conducted numerical investigation on a tilted wick solar still (TWSS) with a top mirror (vertical [20], forwards [21] and backwards [22]) extending from the upper edge of the still. They displayed geometrical models to compute the solar irradiation reflected from a top mirror and then absorbed on the evaporating wick. They concluded that the top mirror can increment the absorbed solar radiation by evaporating wick, and further, the amount of solar irradiation reflected from the top mirror and absorbed on the wick can be enhanced by inclining the top mirror to be backwards in summer and forwards in winter.

A theoretical analysis was used by Tanaka and Nakatake [20] to study the effect of a vertical flat plate ER on the productivity of a TWSS and showed an average increase of 9% a year, Fig. 10. Another theoretical analysis of a top ER with TWSS on a winter was investigated by Tanaka and Nakatake [21], Fig. 11. Their results indicated that the productivity of a still with an inclined reflector would be around 15% or 27% over that with a vertical reflector when the reflector's length is a half of or the same as the still's length.

In addition, a theoretical analysis was made on TWSS with external top reflector with the aim of determining optimum inclination for both reflector and solar still for different seasons by Hiroshi Tanaka [22], Fig. 12. Regarding to the results obtained, 30°N latitude was represented as the best inclination angle either for the still or the reflector monthly. In addition, he concluded that for any season the daily productivity of the solar still can be improved by adjusting the inclination of both the reflector and solar still, thus producing around 21% over the traditional TWSS throughout the year.

Tanaka and Nakatake [23] displayed another theoretical investigation of one-step azimuth tracking TWSS with a vertical flat plate reflector, Fig. 13. The TWSS is assumed to be rotated manually just once a day at southing of the sun. They performed numerical analyses of heat and mass transfer in the still to determine the daily productivity of the still on four typical days: the spring and autumn equinoxes and summer and winter solstice days at 30°N latitude. For four days, results indicated that the increase in the productivity of TWSS would be around 41%, and can be accomplished by the simple modification of utilizing a reflector.

E1-Bahi and Inan [24] examined a conventional still integrated with an outside condenser, Fig. 14. A reflector made of stainless steel was added to the glass cover to reflect the solar radiation into the still