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Optimization of geometrical dimensions of single-slope basin-type solar stills

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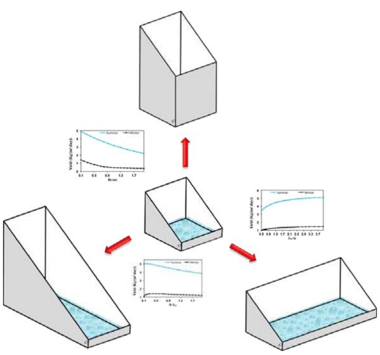
GRAPHICAL ABSTRACT



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ABSTRACT

In the present work, effects of height, length, and width of a single-slope basin-type solar still on its distillate production was investigated. For this purpose, a radiation model was developed which accounts for the influences of all walls on quantities of received solar radiation by the base and saline water of the still. Moreover, in this radiation model, the side walls of the still were considered as the trapezoid and the diffuse as well as beam components of solar irradiance were separately taken into account for the first time. Abilities of the present model were compared with earlier ones. Furthermore, the predictions of the current model were compared with the present experimental results, and it was observed that the predicted and measured values are in a close agreement. The results of this study show that by increasing the height of still's walls, its efficiency decreases. The model suggests that the height of the front wall should be less than about 0.10 m. Moreover, it is illustrated that by extending the still length, the side walls shadow reduces and consequently, the system efficiency increases. In addition, the optimal width to length ratio was found to be about 0.4.

1. Introduction

Basin-type solar stills are the most conventional, simple, and economically viable type of solar desalination devices [1]. In spite of many research on solar stills, this device suffers from insufficient water production rate [2]. As a result, many researchers tried to increase the

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Table 1
Comparison between earlier and the present radiation model in consideration of diffuse components.

	El-Swify & Metias [45]	Tripathi & Tiwari [44]	Tanaka & Nakatake [46]	Madhlopa & Johnstone [47]	Present model
Accounting for both beam and diffuse components	[a]	[b]	[c]	✓[d]	✓[e]
The shape of the side walls for calculating the shape factors	×	×	×	The side walls have been assumed to be rectangular in shape	The side walls have been considered as trapezoids.
Reflectivity of walls	Specular	Specular	Specular	Diffuse	Combination of specular and diffuse

[a] Total solar irradiance received by the basin liner and only beam irradiance received by the back and side walls.
[b] Total solar irradiance simultaneously received by the back wall and basin liner without separating its components.
[c] Only beam irradiance received by both back wall and basin liner and the whole diffuse irradiance received by the basin liner without striking the walls.
[d] Beam and diffuse components separately received by the back wall and the basin liner. Diffuse irradiance scattered in the system using shape factors.
[e] Beam and diffuse components separately received by all walls and the basin liner. Diffuse irradiance scattered in the system using shape factors.

efficiency of this device by innovative methods, such as recovering the energy of condensed vapors [3–12], utilizing additional condensers [13,14], employing energy storing materials [15–18], using reflectors to absorb more energy [19,20], coupling the still with solar thermal collectors [21–26], installing fins on the basin [27,28], taking advantage of wick to increase evaporation area [29], coupling to thermoelectric modules [30–33] and cooling condenser to increase the rate of vapors condensation [34].

Most of the above mentioned techniques require additional components which increase the capital and operating costs. By optimization of the dimensions of the still, one can improve the basic solar still's efficiency by enhancing the amount of received solar radiation, without any additional operating cost. Because of the shade of the still's walls, variation of its dimensions changes the received solar radiation to each part. On the other hand, the incident solar radiation to the still is the dominant environmental factor on its performance [35]. Therefore, for the investigation of the effect of dimensions of a still, accurate calculation of received radiation to each part of the still is vital.

In the past decades, many types of research have improved the still's performance by increasing the amount of incident solar irradiance to the basin or glass cover [36–43]. However, they have assumed that the walls of the still have no impact on the amount of accessible solar energy for the brackish water or basin. While in reality, the incident solar irradiance to the still can reach all walls as well as the liner. Therefore, the effect of walls should be accounted for a reliable prediction of the still's performance. To investigate this issue, few researchers have paid attention to the effect of walls in their modeling.

Tripathi and Tiwari [44] used total solar radiation in their analysis and did not separate the diffuse and direct components of solar irradiance. El-Swify and Metias [45] assumed that only the beam irradiance passed through the glass cover intercepted the inner walls (two side and back walls) of solar still, and the whole diffuse irradiance passed the glass cover reached the water surface. Tanaka and Nakatake [46] considered the beam and diffuse irradiance separately, but they assumed the beam irradiance reaches only the back wall and did not account for the diffuse irradiance coming to it. They assumed that the diffuse irradiance reached the basin liner is equal to the total diffuse irradiance reaches a horizontal surface multiple by the glass cover transmissivity without any attention to the obstacles that make barrier against solar irradiance. Madhlopa and Johnstone [47] separated the diffuse and beam components of solar irradiance for the solar radiation model. They utilized shape factors (view factors) for calculating the value of diffuse irradiance, which directly intercepted by the water surface and the back wall. In addition, they assumed the direct and diffuse irradiance reached the back wall reflect towards the basin liner according to shape factors. To compute the shape factors inside the still, side walls were assumed to be rectangular in shape [47,48].

By an appropriate radiation model for solar stills, the effects of the length (in the east-west direction), width (in the north-south direction) and height on the distillate productivity can be investigated. In this way, the role of the radiation model's ability in accounting for all walls and separating the diffuse and beam components of solar irradiance can be taken into account. To the knowledge of authors, a few researchers have dealt with investigating the influence of geometrical dimensions of a single-slope basin solar still on the distillate production. El-Swify and Metias [45] suggested the still aspect ratio (ratio of the length of the still to its width) should be in the order of 2 for a single-slope basin-type solar still with internal reflector. They believed this aspect ratio can maximize the amount of solar irradiance reached the basin liner. Tripathi and Tiwari [44] theoretically examined the effect of the length, width and height of a single-slope basin-type solar still on the production only for one day in March. As mentioned above, El-Swify and Metias' model [45] and Tripathi and Tiwari's model [44] are not perfect for exact investigation of geometrical dimensions of solar still because of not considering all walls and not separating the solar irradiance components.

To investigate the effect of dimensions of the solar still accurately, a new radiation model was developed in this work which considers the diffuse and beam components of solar irradiance separately. For this purpose, the diffuse solar irradiance to each part of the system is taken into consideration by using the concept of shape factors and also the beam solar irradiance was calculated using the developed relations in the authors' previous work [1]. The present radiation model accounts for the influence of all walls on the solar irradiance absorbed by the water. Also, the still's side walls are taken into account as the trapezoid. Moreover, the model considers the fact that at the beginning and end of day during warm months, the sun can radiate from the back of the still towards the brine [46]. The diffuse components of solar irradiance that were considered in the present radiation model are compared with the previous models in Table 1 to show the novelties of the current model.

In this work, the beam and diffuse components of solar irradiance are considered separately and also the diffuse solar irradiance to each part of the system is accurately taken into consideration. The developed model was validated by comparison of its predictions with the present experimental data, and effects of length, height, and width of the still on the distillate productivity were theoretically investigated using the proposed model.

2. Mathematical modeling

2.1. Thermal analysis

The proposed model is based on the energy balance written for three components of glass, brackish water and basin liner, respectively:

$$(mc_p)_g \frac{dT_g}{dt} = Q_{sun,g} + Q_{c,w-g} + Q_{e,w-g} + Q_{r,w-g} - Q_{c,g-a} - Q_{r,g-a} \tag{1}$$