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Tilted wick solar still with flat plate bottom reflector

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ABSTRACT

This paper presents a theoretical analysis of a tilted wick solar still with a flat plate bottom reflector extending from the lower edge of the still on four days (the spring and autumn equinox and summer and winter solstices) at 30°N latitude when the still's inclination is fixed at 30° and the reflector's length is the same as the still's length. We propose a geometrical model to calculate the solar radiation reflected by the bottom reflector and then absorbed on the evaporating wick. We also performed a numerical analysis of heat and mass transfer in the still. We found that the bottom reflector can reflect the sunrays to the evaporating wick and increase distillate productivity of the tilted wick still when the reflector's inclination is larger than about 15° on the spring and autumn equinox and winter solstice, and 25° on the summer solstice, and the average distillate value for four days is greatest when the reflector's inclination is about 35° and would be about 13% greater than that of a conventional tilted wick still.

1. Introduction

A tilted wick solar still has the simplest structure of the various types of solar stills. Many studies have been done to determine performance and increase distillate productivity of tilted wick stills [1–13]. Among the modifications, an external reflector can be a useful and inexpensive way to increase the distillate productivity of tilted wick stills. However, there have been few and limited reports about the effect of a reflector on tilted-wick stills [7,9]. Therefore, we have performed numerical analysis on a tilted wick still with a flat plate top reflector extending from the upper edge of the still [14–17].

In our former studies, we presented geometrical models to calculate the solar radiation reflected from a flat plate top reflector (vertical [14], and slightly inclined forwards [16] and backwards [17]) and then absorbed on the evaporating wick. We found that a top reflector can increase the solar radiation absorbed on the evaporating wick, and further, the amount of solar radiation reflected from the top reflector and absorbed on the evaporating wick can be increased by inclining the top reflector forwards in winter and backwards in summer. We also performed numerical analysis of heat and mass transfer in the still to predict the distillate productivity of the still, and determined the optimum inclination angle of the still as well as of the top reflector for each month at 30°N latitude [17]. As a result, we found that a tilted wick still with a flat plate top reflector can produce an average of about 21% more than a conventional tilted wick still throughout the year, when the height of the reflector is half of the still's length and both the reflector and the still is set to the optimum inclination for each month [17].

A flat plate bottom reflector extending from the lower edge of the still and inclined upwards from horizontal as shown in Fig. 1 would also be able to increase the solar radiation absorbed on the evaporating wick as well as the distillate productivity of a tilted wick solar still. However, to our knowledge, there have been no reports about the effect of a flat plate bottom reflector on tilted wick stills.

We have studied a vertical multiple-effect diffusion solar still coupled with a flat plate bottom reflector in detail [18–22]. We presented a geometrical model to calculate the solar radiation reflected by the bottom reflector and then absorbed on the vertical heated partition [18], and performed numerical analysis [18–20] and outdoor experiments [21,22] to determine the distillate productivity of the still. We found that the experimental results of the daily productivity of the still agree with the theoretical predictions with about a ±7% error margin [22], and this indicates that the solar radiation reflected by the bottom reflector and absorbed on the vertical heated partition of the still can be adequately calculated with the geometrical model we presented [18].

In a tilted wick solar still with a flat plate bottom reflector, the heated surface (an evaporating wick) is not vertical so the geometrical model for the vertical heated surface and the bottom reflector system [18] cannot be applied directly. Therefore, in this paper, we present a new geometrical model to calculate the solar radiation reflected by the flat plate bottom reflector and then absorbed on the evaporating wick, and determine the effect of the inclination angle of the reflector on the distillate productivity of the tilted wick still when the still's inclination angle is fixed at 30° from horizontal at 30°N latitude.

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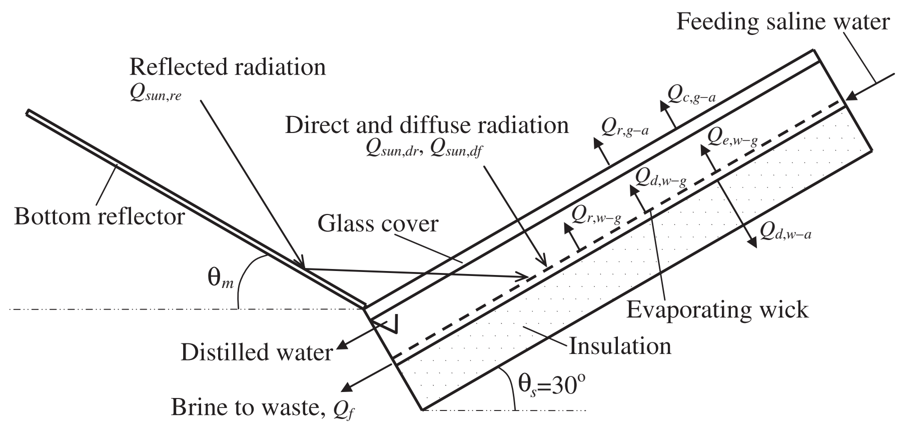

Fig. 1. Schematic diagram of a tilted wick solar still with a bottom reflector which can be inclined from horizontal, and heat and mass transfer in the still.

2. Tilted wick solar still with a flat plate bottom reflector

The proposed still is shown in Fig. 1. The still consists of a glass cover, an evaporating wick, bottom insulation and a flat plate bottom reflector of highly reflective materials such as a mirror-finished metal plate, which extends from the lower edge of the still. The still is assumed to be fixed at $\theta_s = 30°$ in this calculation, while the bottom reflector can be inclined from horizontal with inclination θ_m. Saline water is fed to the wick constantly. The direct and diffuse solar radiation and also the reflected solar radiation from the bottom reflector is transmitted through the glass cover and absorbed on the wick. The evaporation and condensation processes occur between the wick and the glass cover. The distilled water is gathered by a channel placed under the surface of the glass cover, and excess of concentrated saline water flows out from the still. The still is assumed to be facing due south.

3. Theoretical analysis

3.1. Absorption of reflected radiation on the wick

To simplify the following calculations to determine the solar radiation absorbed on the wick, the walls of the still are neglected, since the height of the walls (10 mm) is negligible in relation to the still's length (1 m) and width (1 m).

Fig. 2 shows a schematic diagram of shadows and reflected projection of the proposed still on a horizontal surface caused by direct solar radiation. l_s or l_m is the length of the still (shown as ABCD) or the bottom reflector (shown as ABEF), and θ_s or θ_m is the inclination of the still or the reflector from horizontal, respectively. w is the width of both the still and the reflector. φ and ϕ are the azimuth and altitude angle of the sun, respectively. The shadow of the evaporating wick (as well as the glass cover) and the bottom reflector, and the reflected projection from the reflector on a horizontal surface caused by direct solar radiation are shown as ABC′D′, ABE′F′, and ABE″F″, respectively. Here, the shadows of the evaporating wick and the glass cover would be exactly the same since the walls are neglected as mentioned above.

All of the reflected radiation from the bottom reflector cannot be absorbed on the wick, and part of or all of the reflected radiation would escape to the ground or the sky without hitting the wick. To calculate the solar radiation reflected by the bottom reflector and absorbed on the wick, a mirror-symmetric plane of the wick to the bottom reflector is introduced as shown in Fig. 3. The incident point and incident angle of the reflected radiation on the wick and those of the direct radiation which goes through the bottom reflector and incidents on the mirror-symmetric plane of wick are exactly the same.

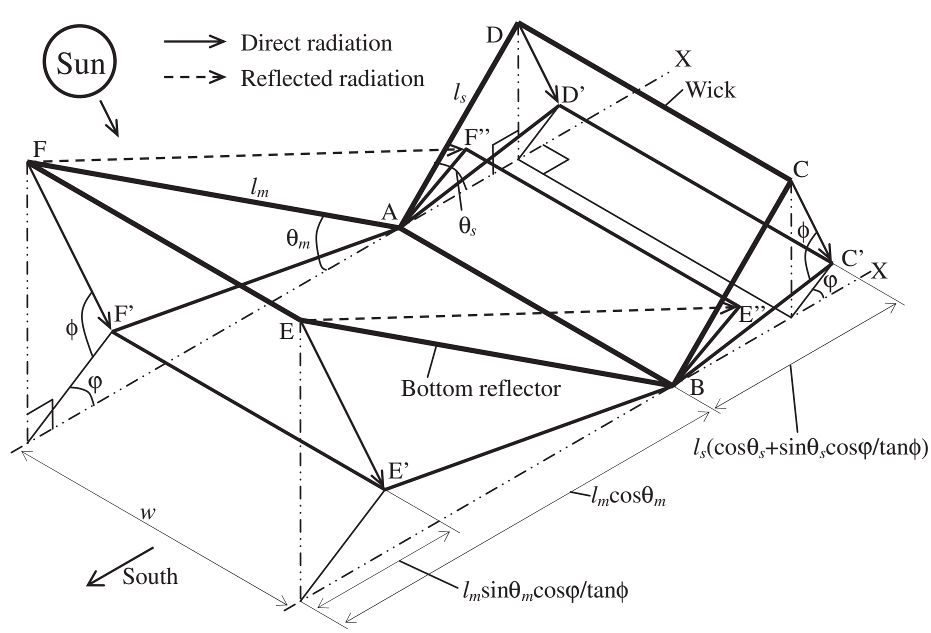

Fig. 2. Shadows of the still and bottom reflector and reflected projection of the reflector on a horizontal surface.