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A theoretical analysis of basin type solar still with flat plate external bottom reflector

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ABSTRACT

A basin type solar still with a flat plate external bottom reflector extending from the front wall of the still in addition to the internal (two sides and back walls) reflector is presented and analyzed theoretically on three days (the spring equinox and summer and winter solstices) at 30°N latitude. We proposed a geometrical model to calculate the direct solar radiation reflected by the external bottom reflector and then absorbed onto the basin liner. We also performed a numerical analysis of heat and mass transfer in the still. We found that the external reflector can reflect the sunrays to the basin liner and increase distillate productivity. The daily amount of distillate of the still with internal and external bottom reflector is predicted to be 41%, 25% and 62% greater than that of a conventional basin type still on the spring equinox and summer and winter solstices, respectively, by setting the external reflector's inclination to the proper values according to the seasons when the glass cover's inclination angle is fixed at 20° from horizontal and the length of the external reflector is the same as the length of the basin liner.

1. Introduction

Basin type solar stills which basically consist of a basin liner and a glass cover have been widely studied because of the simplicity in structure of the various types of solar stills as reviewed by Tiwari et al. [1], Kaushal and Varun [2] and Velmurugan and Srithar [3]. Many attempts have also been made to increase the distillate productivity of a basin type still. Among these modifications, internal and/or external reflectors can be a simple and inexpensive way to increase the solar radiation incident on the basin liner as well as the distillate productivity of a basin type still.

Though many reports about the effect of reflectors (internal [4–9] and external [10–14]) on the distillate productivity of basin type stills have been presented, a detailed and quantitative analysis of the effect of an external reflector on a basin type still has not been presented. Therefore, we have performed numerical analysis [15–18] and outdoor experiments [19] on a basin type still with a flat plate external top reflector extending from the back wall of the still in addition to the internal (two sides and back walls) reflector. In our former studies, we presented geometrical models to calculate the solar radiation reflected from a flat plate external top reflector (vertical [15], and slightly inclined forwards [16] and backwards [17]) in addition to the internal reflector and then absorbed on the basin liner. We found that an external top reflector and an internal reflector can increase the solar radiation absorbed on the basin liner, and further, the amount of solar radiation reflected from the top reflector and then absorbed on the basin liner can be increased by inclining the top reflector forwards in winter and backwards in summer.

We have also calculated the distillate productivity of the still with the heat and mass transfer model for the still [15], and validated the theoretical predictions by performing outdoor experiments in winter using a basin type still with an internal reflector and an external top reflector which is inclined slightly forwards [19]. We found that the internal and external reflector can reflect the sunrays onto the basin liner effectively, and the experimental results and the theoretical predictions of the distillate productivity are in fairly good agreement. Khalifa and Ibrahim [20] also performed outdoor experiments using a basin type still with internal and external top reflectors over the 7 months from June to December. The external top reflector was inclined forwards throughout the experimental period. They reported that an increase in distillate productivity achieved by installing internal and external top reflectors in outdoor experiments is in reasonable agreement with the theoretical results in our previous paper [16], except for the months of June and July when the external top reflector should be inclined backwards.

A flat plate external bottom reflector extending from the front wall of the still and inclined upwards from horizontal as shown in Fig. 1 would also serve to increase the solar radiation absorbed on the basin liner as well as the distillate productivity of a basin type still. However, there have been no reports about the effect of a flat plate external bottom reflector on basin type stills. For the external bottom reflector, the geometrical models for the external top reflector [15–17] cannot be applied. Therefore, in this paper, we present a new geometrical model to calculate the solar radiation reflected by a flat plate external

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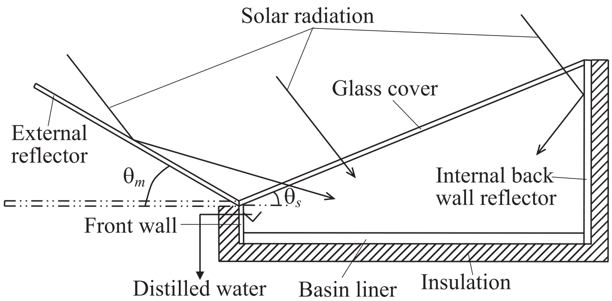

Fig. 1. Schematic diagram of basin type still with internal and flat plate external bottom reflectors.

bottom reflector and then absorbed on the basin liner, and determine the effect of the inclination angle of the external reflector on the distillate productivity of the basin type still at 30°N latitude when the glass cover's inclination angle is fixed at 20° from horizontal and the length of the external reflector is the same as the length of the basin liner.

2. Basin type solar still with internal and flat plate external bottom reflectors

The proposed still is shown in Fig. 1. The still consists of a basin liner (a black-painted steel plate), a glass cover (3 mm thickness), walls at the front, two sides and back, bottom insulation and a flat plate external bottom reflector extending from the front wall of the still. The two sides and back walls are assumed to be covered with reflective materials, so these walls serve as the internal reflector. The internal and external reflectors are assumed to be highly reflective materials such as a mirror-finished metal plate. Depth of basin water is assumed to be 10 mm. Direct and diffuse solar radiation and also the reflected radiation from the internal and external reflectors are transmitted through the glass cover and then absorbed onto the basin liner. The glass cover's inclination θ_s is assumed to be fixed at 20° in this calculation, while the bottom reflector can be inclined from horizontal with inclination θ_m. The still is assumed to be facing due south.

3. Theoretical analysis

3.1. Absorption of direct and diffuse radiation and reflected radiation from the internal back wall reflector on the basin liner

To simplify the following calculations, it is assumed that the same amount of solar radiation obstructed by one side wall hits the other inner side wall since both inner side walls are assumed to be covered with highly reflective materials. This assumption would be valid especially if the still's width w is sufficient in relation to the still's length l_s. The height of the front wall is assumed to be negligible.

Fig. 2 shows a schematic diagram of shadows and reflected projection of the proposed still on a horizontal surface caused by direct solar radiation. The basin type still is shown as ABCDEF and the external bottom reflector is shown as ABGH. l_s and l_m are the lengths of the basin liner (ABCD) and the external reflector. θ_s and θ_m are the inclinations of the glass cover (ABFE) and the external reflector from horizontal. w is the width of both the still and the external reflector. φ and ϕ are the azimuth and altitude angle of the sun. The shadows cast by the internal back wall reflector (CDEF) and the external reflector, and the reflected projection from the external reflector on a horizontal surface caused by direct radiation are shown as CDE′F′, ABG′H′ and ABG″H″, respectively.

The direct solar radiation absorbed on the basin liner, $Q_{sun,dr}$, can be normally determined as the product of the direct solar irradiance on a horizontal surface, G_{dr}, the area of the basin liner, wl_s, transmittance of the glass cover, $\tau_g(\beta)$, and absorptance of the basin liner, α_b, and this may be expressed as

$$Q_{sun,dr} = G_{dr}\tau_g(\beta)\alpha_b \times wl_s \tag{1}$$

where β is the incident angle of sunrays to the glass cover and expressed as [21]

$$\cos\beta = \sin\phi\cos\theta_s + \cos\phi\sin\theta_s\cos\varphi. \tag{2}$$

Diffuse solar radiation absorbed on the basin liner, $Q_{sun,df}$, can be determined assuming that diffuse radiation comes uniformly from all directions in the sky dome, and may be expressed as

$$Q_{sun,df} = G_{df}\left(\tau_g\right)_{df}\alpha_b \times wl_s \tag{3}$$

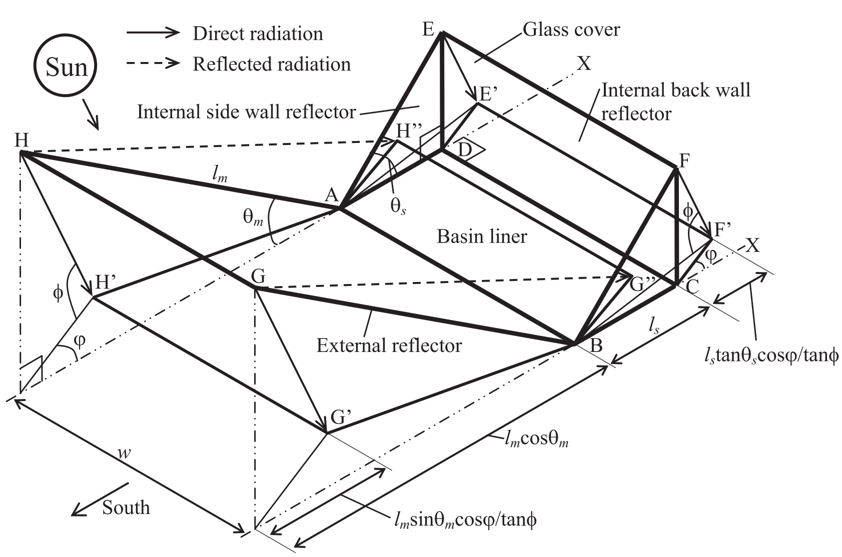

Fig. 2. Shadows of the glass cover and the external reflector and the reflected projection of the external reflector on a horizontal surface.