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Experimental study of a basin type solar still with internal and external reflectors in winter

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ABSTRACT

A basin type solar still with internal and external reflectors was constructed and then examined in outdoor experiments in winter in Kurume, Japan. The external reflector was inclined slightly forward to make the reflected sunrays hit the basin liner of the still effectively. The daily productivity of a basin type still can be increased about 70% to 100% with a very simple modification using internal and external reflectors. The experimental results and the theoretical predictions are in fairly good agreement, especially on clear days.

1. Introduction

Internal and external reflectors can increase the distillate productivity of a basin type still, and many reports about the effect of internal reflectors [1–4] and external reflector [5,6] on the distillate productivity of basin type stills have been presented. However, a detailed and quantitative analysis of the effect of an external reflector on a basin type still had not been presented.

Therefore, we have added to this research by presenting a geometrical model to evaluate the effect of internal reflectors as well as a vertical external flat plate reflector on the distillate productivity of the basin type still [7]. We found that an internal reflector and a vertical external flat plate reflector can remarkably increase the distillate productivity of the still during the spring and autumn seasons. But during the summer and winter seasons, the effect of the vertical external reflector would be less than during spring and autumn, or would be even negligible. In summer, the vertical reflector would not effectively reflect the sunrays onto the basin liner around noon since the sunrays would be nearly vertical. In winter, the solar altitude angle would be so small that a considerable amount of the sunrays from the vertical reflector would escape to the ground without hitting the basin liner. Therefore, the arrangement of the external reflector has to be changed from vertical for these seasons.

During the winter season, inclining the external reflector slightly forward would enable the reflected sunrays to hit the basin liner even when the solar altitude angle is small. Therefore, we have presented an additional analysis to calculate the solar radiation reflected from an external reflector inclined forward and then absorbed onto the basin liner [8], and found that distillate productivity was predicted to be increased by inclining the external reflector.

Besides the use of reflector, many modifications have been done to increase the productivity of distillate of a basin type still (reviewed by Tiwari et al. [9]), such as reducing water depth, use of dye, reducing bottom loss coefficient and so on. However, in this study, we used a typical basin type still, which does not take into consideration of these modifications, since we focused the effect of the reflector. Therefore, the structure of a basin type still we constructed is basically the same with other basin type stills tested by many researchers such as Cooper [10], and so on [1,3,4].

In this paper, we present the results of outdoor experiments of a basin type still with internal reflectors and an external reflector inclined forward during the winter season in Kurume, Japan (33.2°N latitude and 130.2°E longitude). The purpose of the study is to investigate whether the basin liner of basin type still with internal and external reflectors can absorb solar radiation adequately as predicted by the geometrical models described in our previous papers [7,8], since such outdoor experiments on basin type still had not been reported.

2. Experimental apparatus and procedure

A schematic diagram and a snap shot of an outdoor experimental apparatus are shown in Figs. 1 and 2. The still consists of a basin liner, a 5-mm-thick glass cover, and an external reflector inclined forward. The angle of the glass cover was set at 20° from horizontal. The angle of the external reflector was set at 10°, which was predicted as an optimum reflector angle when glass cover angle is 20° [8]. The width

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Nomenclature

Symbols

G_{df}, G_{dr}	diffuse and direct solar radiations on a horizontal surface, (W m^{-2})
G_h	global solar radiation on a horizontal surface, (W m^{-2})
ΣG_h	daily global solar radiation on a horizontal surface during experimental period, (MJ m^{-2} day^{-1})
I_0	extra-terrestrial solar radiation, (W m^{-2})
l_s	length of still, (m)
mc_p	heat capacity, (J/K)
$m_{d,cal}$	calculated daily productivity during experimental period, (kg m^{-2} day^{-1})
$m_{d,exp}$	experimental result of daily productivity, (kg m^{-2} day^{-1})
Q_c	convective heat transfer rate, (W)
Q_d	conductive heat transfer rate, (W)
Q_e	heat transfer rate by mass transfer, (W)
Q_r	radiative heat transfer rate, (W)
$Q_{sun,b}$	solar radiation absorbed on basin liner, (W)
$Q_{sun,g}$	solar radiation absorbed on glass cover, (W)
$Q_{sun,df}$, $Q_{sun,dr}$	diffuse and direct solar radiations absorbed on basin liner, (W)
$Q_{sun,ext}$, $Q_{sun,int}$	solar radiation reflected by external and internal reflectors and absorbed on basin liner, (W)
T	temperature, (°C)
t	time, (s)
w	width of still, (m)
α	absorptance of basin liner
β	incident angle of sunrays to glass cover, (°)
ϕ	solar altitude angle, (°)
θ	angle of glass cover, (°)
τ_{atm}	transmittance of atmosphere
τ_g	transmittance of glass cover
$(\tau_g)_{df}$	transmittance of glass cover for diffuse radiation

Subscripts

a	surroundings
b	basin liner
g	glass cover

and length of the basin liner and external reflector are 355 mm × 343 mm and 355 mm × 348 mm, respectively, so both of the areas are almost the same. The basin liner and the walls of the still were made of plywood. The basin liner was coated with black silicone sealant, and the side and back walls were covered with the reflector. A 1.8-mm-thick mirror-finished stainless steel plate (reflectance is 0.7 [11]) was used for the internal and external reflectors. The bottom and all walls of the still were insulated using a 50-mm-thick urethane foam board. A partition was placed in front of the basin liner to make a channel for collecting the distilled water.

The direct and diffuse solar radiations as well as the reflected radiation are transmitted through the glass cover and absorbed on the basin liner. The absorbed solar energy heats up and evaporates the basin water, and the water vapor condenses on the glass cover. The distilled water flows down to the channel and is gathered through the collecting pipe placed at the bottom of the channel.

The experimental procedure is as follows: the still was oriented toward due south. Tap water was poured into the basin liner to form a water pool approximately 10-mm deep. Condensate was collected almost every hour and measured with a flask and a digital balance. Global solar radiation on a horizontal surface was measured on the roof of the neighboring building with an actinometer at a recording interval of 10 s. Since the place at which the experiments were performed was shaded by the neighboring buildings during early morning and late evening, the experiments were performed when solar radiation would not be obstructed and could be absorbed onto the basin liner each day.

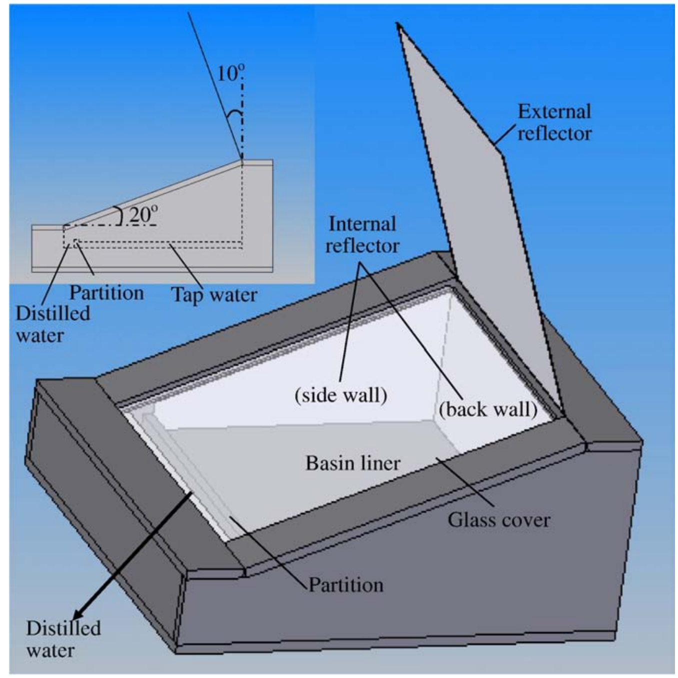

Fig. 1. Schematic diagram of experimental apparatus.

3. Theoretical analysis

Theoretical analysis of the proposed still was described in detail in our previous papers about the geometrical model to calculate the solar radiation absorbed on the basin liner [8] as well as heat and mass transfer in the still [7].

Fig. 2. Snap shot of experimental apparatus.