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Solar thermal collector augmented by flat plate booster reflector: Optimum inclination of collector and reflector

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ABSTRACT

In this report we present a theoretical analysis of a solar thermal collector with a flat plate top reflector. The top reflector extends from the upper edge of the collector, and can be inclined forwards or backwards from vertical according to the seasons. We theoretically predicted the daily solar radiation absorbed on an absorbing plate of the collector throughout the year, which varies considerably with the inclination of both the collector and reflector, and is slightly affected by the ratio of the reflector and collector length. We found the optimum inclination of the collector and reflector for each month at 30°N latitude. An increase in the daily solar radiation absorbed on the absorbing plate over a conventional solar thermal collector would average about 19%, 26% and 33% throughout the year by using the flat plate reflector when the ratio of reflector and collector length is 0.5, 1.0 and 2.0 and both the collector and reflector are adjusted to the proper inclination.

1. Introduction

For a solar thermal collector, booster reflectors can be a useful and inexpensive modification to increase the solar radiation incident on the solar thermal collector. Many studies have been done to investigate the effect of booster reflectors on solar thermal collectors [1–13].

Chiam [3], Garg and Hrishikesan [6] and Kostic et al. [12,13] studied a solar thermal collector with top and bottom reflectors. The top reflector extends from the upper edge of the collector and is inclined slightly from vertical, while the bottom reflector extends from the lower edge of the collector and is inclined slightly from horizontal. Garg and Hrishikesan [6] reported the optimum inclination of both the top and bottom reflectors on March, June and December when the collector inclination is horizontal or equal to the latitude where the collector is located. Kostic et al. [12] reported the optimum inclination of both the top and bottom reflectors throughout the year when the collector inclination is fixed at 45°.

McDaniels and Lowndes [1], Rao et al. [7], Bollentin and Wilk [8] and Hussein et al. [9] studied the effect of the top reflector on the solar collector. McDaniels and Lowndes [1] reported the effect of the inclination of both the reflector and the collector on solar radiation absorbed onto the collector in winter. They also reported the effects of reflector size. Hussein et al. [9] reported the optimum inclination of the top reflector on 3 days (summer and winter solstice and spring equinox days) when the collector inclination is 30°. Bollentin and Wilk [8] reported that the solar radiation incident on the collector varied with the inclination of reflector and collector, respectively. Rao et al. [7] investigated the effect of reflector inclination when the collector is set at horizontal. Further, Taha and Eldighidy [2] studied an off-south oriented solar collector and reflector system.

The optimum inclination of a conventional solar thermal collector without booster reflector varies according to the seasons (or months), and can be easily determined. However, the optimum inclination for a solar thermal collector with a booster reflector may differ from that of a conventional solar collector. Further, the optimum inclination of the reflector would also vary with the seasons. So the optimum inclination of the collector as well as the optimum inclination of the booster reflector should be determined by considering the combination of these two inclinations to maximize solar radiation incident on the solar thermal collector. However, studies to determine these optimum inclinations have only been done in limited cases, and detailed analysis to determine the optimum inclination of both the collector and the reflector taking into account their combination has not been presented in spite of the fact that many studies have been done as mentioned above. Therefore, in this paper, the objective of the study is to theoretically determine the optimum inclination of the solar thermal collector as well as a flat plate booster reflector (top reflector only) throughout the year at 30°N latitude. We will also present a new graphical method to calculate solar radiation reflected by the flat plate top booster reflector and then absorbed onto the solar thermal collector.

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Nomenclatures

G_{df}, G_{dr}	diffuse and direct solar radiation on a horizontal surface, W/m^2	α_c	absorptance of absorbing plate
I_0	extra-terrestrial solar radiation, W/m^2	β	incident angle of sunrays to glass cover
I_{sc}	solar constant, W/m^2	ϕ, φ	altitude and azimuth angle of the sun
l_c, l_m	length of collector and reflector, m	ϕ', φ'	altitude and azimuth angle of reflected radiation
n_d	number of day	θ_c	angle of collector from horizontal
$Q_{sun,re}$	absorption of reflected solar radiation, W	θ_m	angle of reflector from vertical
$Q_{sun,df}$, $Q_{sun,dr}$	absorption of diffuse and direct solar radiation, W	ρ_m	reflectance of reflector
w	width of collector and reflector, m	τ_{atm}	transmittance of atmosphere
		τ_g	transmittance of glass cover

2. Theoretical analysis

2.1. Solar thermal collector with inclined flat plate top reflector

Recently, we have performed numerical analysis of a tilted wick solar still with a flat plate top reflector. The tilted wick solar still consists of a glass cover and black wick cloth. We presented a geometrical model to calculate solar radiation reflected by a flat plate reflector and then absorbed onto the wick [14–16]. The geometrical model can be applied to the solar collector and reflector system since the tilted wick solar still is also a flat plate system as is the solar thermal collector.

The proposed solar collector and reflector system is shown in Fig. 1. The solar collector consists of a glass cover and an absorbing plate, and a flat plate reflector is assumed to be made of highly reflective material. Direct and diffuse solar radiation and also the reflected solar radiation from the reflector are transmitted through the glass cover and then absorbed onto the absorbing plate. The reflector can be inclined forwards or backwards from vertical according to the seasons. In this paper, the inclination angle of the reflector was determined as positive when it was tilted forwards and negative when it was tilted backwards as shown in Fig. 1.

In winter, the altitude angle of the sun decreases so a considerable amount of the reflected radiation from the vertical reflector would escape to the ground without hitting the collector. Therefore, the reflector should be inclined slightly forwards to absorb the reflected sunlight on the collector effectively as shown in Fig. 2a. On the other hand, the altitude angle of the sun increases in summer and the vertical reflector cannot effectively reflect sunrays to the collector. Therefore, the reflector should be inclined slightly toward the back as shown in Fig. 2b.

Numerical models, such as vector analysis [2,4–6], graphical analysis [1,7–10] and two-dimensional analysis [12] have been proposed to calculate the solar radiation reflected by the inclined reflector and then absorbed onto the absorbing plate. In this paper, we introduce a new graphical analysis using geometrical models to calculate the absorption of solar radiation from an inclined reflector onto the absorbing plate. The geometrical models are similar to those for analyzing the tilted wick solar still with a flat plate reflector [14–16], and basically the same as the graphical analysis for solar collector reflector systems [1,7–10].

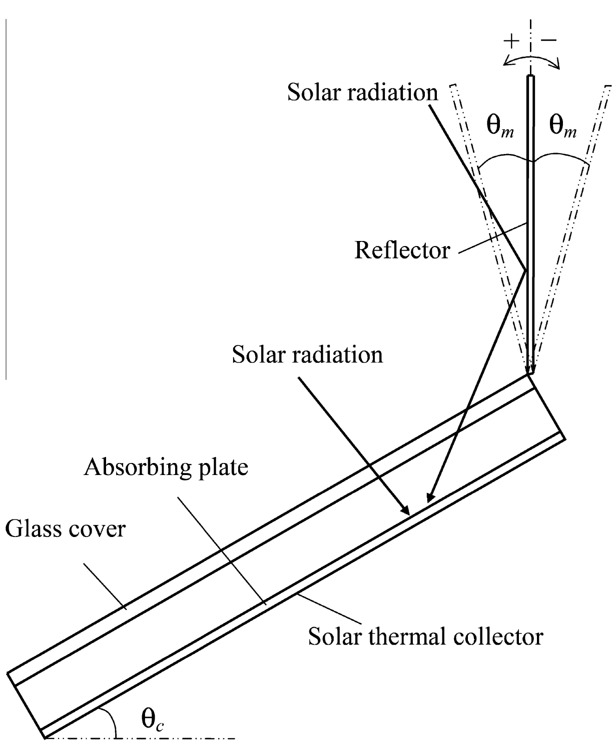

Fig. 1. Schematic diagram of a solar thermal collector and top reflector system that can be inclined backwards or forwards.

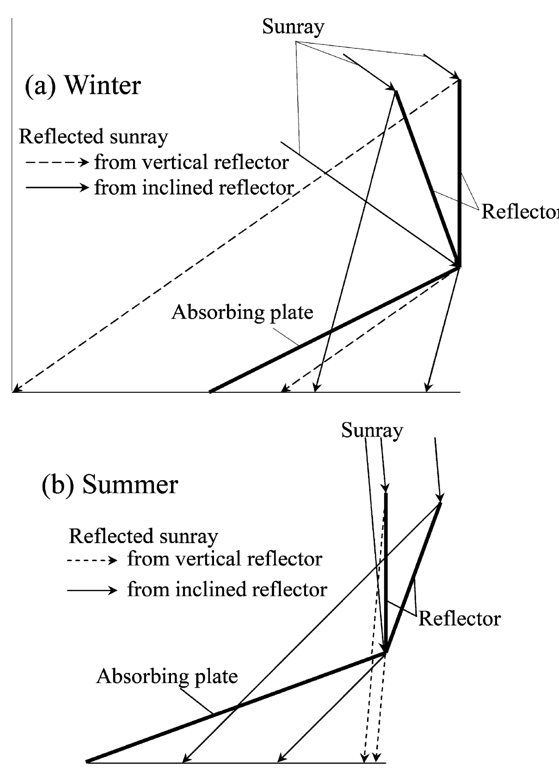

Fig. 2. Reflected sunlight from vertical and inclined reflectors on the absorbing plate in (a) winter and (b) summer.