Polarization Effects on Directional Transmittance of a Corrugated Cover

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Introduction

A model for directional transmittance of a corrugated cover employed to reduce convective and radiative losses in a solar collector was reported by Smith and Chaider [1]. The model accounts for effect of multiple reflection and transmission of incident solar energy. Reported results for directional transmittance illustrated that these effects may produce higher directional transmittances for the corrugated cover in comparison with those for a flat cover of the same material at large polar angles of incident solar energy. The model considers the corrugated cover to be optically smooth locally with local directional reflectance and transmittance specified by electromagnetic theory as expressed by the Fresnel relations [2]. Within the development of the model, it was assumed that polarization effects are negligible. The appropriateness of this assumption in view of multiple reflection and transmission effects and polarized components as stated by the Fresnel relations should be established. The purpose of this study, therefore, is to investigate polarization effects on directional transmittance of a corrugated cover.

The corrugated cover under consideration is similar to that examined previously [1]. The cover exhibits a uniform thickness δ_c, and its profile is described by a sinusoidal function with amplitude, A, and periodicity, L. The cover is taken to be locally smooth so that the Snell and Fresnel relations [2] can be applied. Incident solar energy is unpolarized. In view of the additional complexity of including polarization effects, directions of incident solar energy are limited to the plane of incidence that is perpendicular to the corrugations. Multiple reflection and transmission phenomena are contained within this plane since the cover is assumed to be locally smooth. Furthermore, the need to resolve the parallel and perpendicular polarized components [3] is eliminated, since they already exist in the local plane of incidence. As a result of multiple reflections and transmissions, polarization effects are expected to be more important for the considered orientation of the plane of incidence.

Analysis

In view of the intended application to evaluate the useful energy gained by a solar collector with a corrugated cover, the quantity of interest is the mixed component of directional transmittance for a corrugation period as given by

$$\bar{\tau} = \frac{\bar{\tau}_p + \bar{\tau}_s}{2} \tag{1}$$

where subscripts "p" and "s" denote, respectively, parallel and perpendicular polarized components of directional transmittance. These components can be evaluated in a manner similar to that described in reference [1] for the unpolarized directional transmittance, $\bar{\tau}_u$. For convenience, only expressions for the parallel component are presented with those for the perpendicular component obtained by interchanging subscripts s and p. The parallel component for directional transmittance is evaluated from [1]

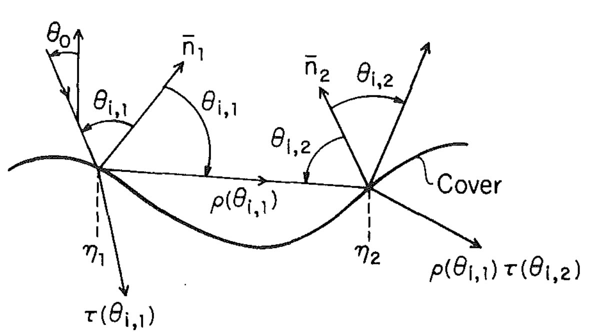

Fig. 1 Reflection and transmission pattern

$$\bar{\tau}_p = \sum_{j=1}^{N} \frac{[\tau_{0p}\cos\theta_{i,1}/\cos\phi_1\,\Delta\eta]_j}{2\pi\cos\theta_0} \tag{2}$$

where N denotes the number of elemental positions for a corrugation period. The local transmittance function τ_{0p} describes the fraction of solar energy directly incident at that location which is transmitted by the cover taking into account direct transmission as well as transmitted energy which may have experienced multiple reflections and transmissions. The local polar angle of incidence as measured from the local normal is $\theta_{i,1}$; ϕ_1 is the local surface slope angle as measured from a plane parallel to the mean plane of the corrugations. Subscript "1" applies to directly incident solar energy. $\Delta\eta$ is the increment size. The quantities contained within the brackets of equation (2) are evaluated at the particular location η_j on the corrugated cover and summed over one period of corrugation. θ_0 refers to the polar angle of directly incident solar energy as measured from the normal to the mean plane of the cover. The relation between $\theta_{i,1}$, θ_0, and ϕ_1 for the plane of incidence perpendicular to the corrugations is [1]

$$\cos\theta_{i,1} = \cos\theta_0\cos\phi_1 \tag{3}$$

The azimuthal angle of incident solar energy acquires a value of $\gamma_s = 90$ deg.

Evaluation of local transmittance function is aided by reference to the reflection and transmission pattern schematically illustrated in Fig. 1. A more complex pattern for larger polar angle of incidence is shown in [1]. For the pattern in Fig. 1, local transmittance function at η_1 is

$$\tau_{0p} = \tau_p(\theta_{i,1}) + \rho_p(\theta_{i,1})\tau_p(\theta_{i,2}) \tag{4}$$

where ρ_p and τ_p are total reflectance and transmittance of a plane surface at the considered contact points and account for multiple inter-reflections within the thickness of the cover. Total reflectance and transmittance are evaluated from [4]

$$\rho_p = \rho_{\parallel}\left[1 + \frac{\tau_a^2(1-\rho_{\parallel})^2}{1-\rho_{\parallel}{}^2\tau_a{}^2}\right] \tag{5}$$

$$\tau_p = \tau_a\left[\frac{(1-\rho_{\parallel})^2}{1-\rho_{\parallel}{}^2\tau_a{}^2}\right] \tag{6}$$

where $\rho_{\parallel}$ ($\rho_{\perp}$ for s component) is the parallel (perpendicular) reflectance component as given by the Fresnel relations [1] evaluated at the local polar angle of incidence. The Fresnel relations are expressed in terms of the refractive index of the cover material, n_c, for a dielectric material. The internal transmittance, τ_a, for an absorbing, nonscattering medium is related to optical path length $\delta_c/\cos\theta_f$ and absorption coefficient κ by

$$\tau_a = \exp(-\kappa\delta_c/\cos\theta_f) \tag{7}$$

where θ_f is the local polar angle of refraction as given by the Snell law [1].

The properties of the corrugated cover are discussed elsewhere [1].

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Contributed by the Solar Energy Division for publication in the JOURNAL OF SOLAR ENERGY ENGINEERING. Manuscript received by the Solar Energy Division, February 4, 1982.

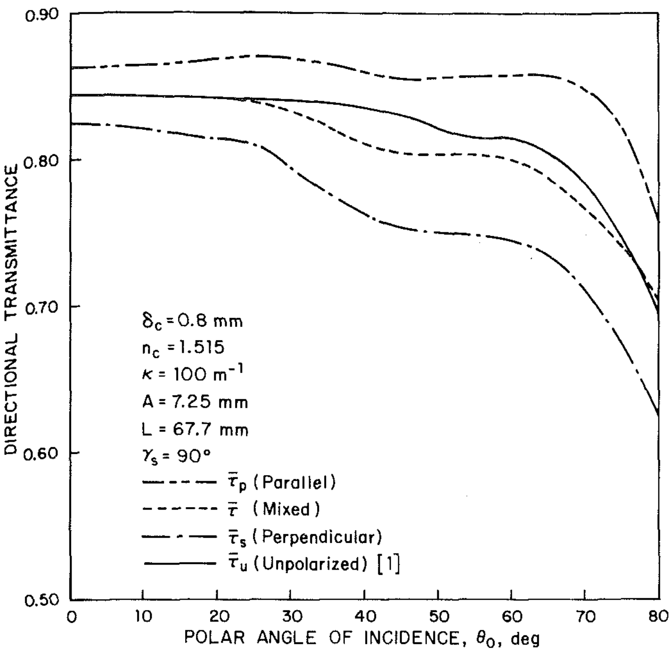

Fig. 2 Directional transmittances

Results and Discussion

Representative results for directional transmittances as a function of polar angle of incident solar energy are presented in Fig. 2. Dimension and property values for the corrugated cover are similar to those for the cover employed in a solar collector [5]. Results are shown for the parallel, mixed, and perpendicular components of directional transmittances as evaluated from the present analysis, which includes polarization effects. In addition, directional transmittances from the previous study [1] where polarization effects were not accounted for are shown. At normal incidence (θ_0 = 0 deg), the parallel and perpendicular directional transmittances are not identical as would be for a flat cover. This is attributed to the importance of non-normal local incidence of directly incident solar energy as created by the corrugation. For all polar angles of incidence, directional transmittances for the parallel component are greater than those for the perpendicular component. This finding is related to the behavior of the Fresnel relations [2].

Comparison of mixed and un-polarized directional transmittances shows good agreement between results of the present analysis and those previously reported [1]. Thus, for the corrugated cover under consideration, directional transmittances are adequately predicted by an analysis that neglects polarization effects.

References

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