TYPE 543: SINGLE COVER TOP LOSS MODEL

General Description

Type543 performs a combined radiation and convection energy balance on a plate of known temperature that is separated from an ambient temperature (for convection calculations) and an effective sky temperature (for radiation calculations) by a single sheet of cover material. The model iterates to balance energy and to converge upon a cover temperature. Wind effects on the outer cover surface are modeled. This model can be used to calculate a time dependent top loss coefficient for solar collector models that take top loss coefficients as an input (as is the case with the TESS Integral Collector Storage (ICS) models). The energy balance methodology of this component was developed at the National Renewable Energy Laboratory [1].

Nomenclature

h_{wind}	[kJ/hr.m2.K]	Convective heat transfer coefficient on the outside of the cover.
k_{air}		Thermal conductivity of air
Re		Reynolds number
Pr		Prandlt Number
$CharLength$	[m]	Collector plate characteristic length
$Length$	[m]	Collector plate length
$Width$	[m]	Collector plate width
$Q_{conv_PlateCover}$	[kJ/hr.m^2]	Convective energy transfer from the plate to the cover.
h_{pc}	[kJ/hr.m2.K]	Convective heat transfer coefficient between the plate and cover.
T_{Plate}	[ºC]	Plate temperature
T_{Cover}	[ºC]	Cover temperature
$Q_{conv_CoverSky}$	[kJ/hr.m^2]	Convective energy transfer from the cover to the sky.
$T_{Ambient}$	[ºC]	Ambient temperature
$Q_{rad_Sky2Cover}$	[kJ/hr.m^2]	Radiative energy transfer from the sky to the cover.
σ		Stefan Botzman constant.
T_{sky}	[ºC]	Effective sky temperature for radiation calculations.
$Q_{rad_Cover2Plate}$	[kJ/hr.m^2]	Radiative energy transfer from the cover to the plate.
τ_c	[0..1]	Cover transmittance.
ρ_c	[0..1]	Cover reflectivity.
ε_p	[0..1]	Plate emissivity
ε_c	[0..1]	Cover emissivity
ρ_p	[0..1]	Plate reflectivity
$Q_{rad_Plate2Cover}$	[kJ/hr.m^2]	Radiative energy transfer from the plate to the cover.
$Q_{imbalance}$	[kJ/hr.m^2]	The error in the plate / cover ambient energy balance.
Q_{loss}	[kJ/hr.m^2]	Unmodified amount of energy lost from the cover to the ambient.

U_{top}	[kJ/hr.m^2.K]	Unmodified top loss coefficient for the cover / plate system.
U'_{top}	[kJ/hr.m^2.K]	Top loss coefficient for the cover / plate system as modified by tuning factors
$X_{MultFactor}$	[-]	Multiplication tuning factor for U_{top}
$X_{AddFactor}$	[kJ/hr.m^2.K]	Addition tuning factor for U_{top}
Q'_{loss}	[kJ/hr.m^2]	Amount of energy lost from the cover to the ambient as modified by the tuning factors

Detailed Description

Type543 takes known values of plate temperature, effective sky temperature, and ambient temperature and calculates a cover temperature that balances convective and radiative energy exchange between the plate, cover and ambient. Figure 1 shows a schematic view of the plate / cover system modeled by Type543.

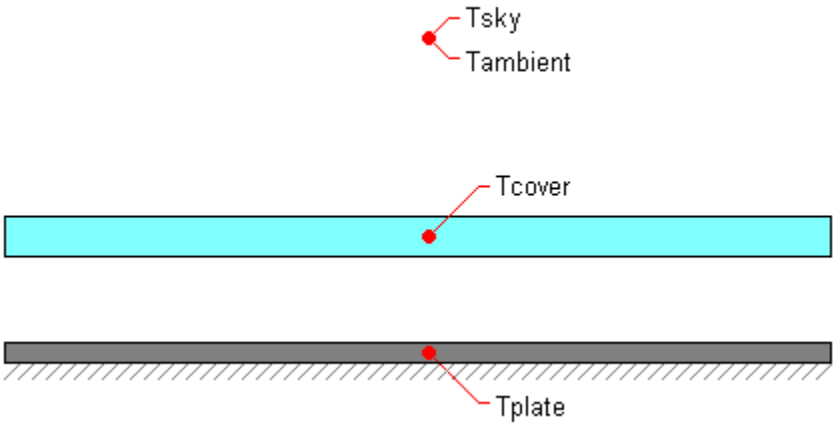


Figure 1: Plate / Cover System Schematic Diagram

External Convection

Type543 makes use of three utility subroutines that are provided with the TESS Component Libraries. One of these utilities calculates a forced convective heat transfer coefficient for a flat plate given the wind speed over the plate, the length and width of the plate, the ambient temperature and the ambient atmospheric pressure. These last are used by the external utility to estimate the density and thermal conductivity of the ambient air. The convection coefficient correlation is shown in equation 543.1.

$$h_{wind} = \frac{k_{air}\ 0.86\ \mathrm{Re}^{1/2}\ \mathrm{Pr}^{1/3}}{CharLength} \qquad \text{(Eq. 543.1)}$$

The characteristic length of the rectangular plate is taken as

$$CharLength = \frac{4\ Length * Width}{2(Length + Width)} \qquad \text{(Eq. 543.2)}$$

Convection Between Cover and Plate

Type543 makes use of a second utility routine to calculate the convection heat transfer coefficient between the plate and the cover. The interior convection coefficient is dependent upon the slope of the plate / cover system, the plate temperature, the cover temperature, the plate spacing and the ambient pressure. Because the cover temperature is recalculated as the model iterates toward an energy balance, the interior convection coefficient will be recalculated repeatedly during a given time step. For the purposes of the interior convection coefficient calculation, the plates are assumed to be semi infinite, which, given length, width and plate to cover spacings common in solar collectors is a reasonable assumption.

Energy Balance Calculation

The following six equations define the terms of the energy exchange between the plate, the cover and ambient conditions. The convective exchange between the cover and the plate is given by:

$$Q_{conv_PlateCover} = h_{pc}\left(T_{Plate} - T_{Cover}\right) \quad \text{(Eq. 543.3)}$$

The convective exchange between the cover and the sky is given by:

$$Q_{conv_CoverSky} = h_{wind}\left(T_{Cover} - T_{Ambient}\right) \quad \text{(Eq. 543.4)}$$

The radiative energy transfer from the sky to the cover is:

$$Q_{rad_Sky2Cover} = \sigma\, T_{sky}^{\ 4} \quad \text{(Eq. 543.5)}$$

The radiative energy transfer from the cover to the plate is:

$$Q_{rad_Cover2Plate} = \frac{\tau_c\ \sigma\, T_{sky}^{\ 4} + \rho_c\ \varepsilon_p\ \sigma\, T_{Plate}^{\ 4} + \varepsilon_c\ \sigma\, T_{Cover}^{\ 4}}{1 - \rho_c\ \rho_p} \quad \text{(Eq. 543.6)}$$

The radiative energy transfer from the plate back to the cover is:

$$Q_{rad_Plate2Cover} = \rho_p\ Q_{rad_CoverPlate} + \varepsilon_p\ \sigma\, T_{Plate}^{\ 4} \quad \text{(Eq. 543.7)}$$

The radiative energy transfer from the cover back to the sky is:

$$Q_{rad_Cover2Sky} = \tau_c\ Q_{rad_Plate2Cover}\ Q_{rad_Sky2Cover} + \varepsilon_c\ \sigma\, T_{Cover}^{\ 4} \quad \text{(Eq. 543.8)}$$

While the above terms could be written as individual energy balances on the cover and on the plate, the above formation can be solved sequentially as is necessary in a linear solving engine such as Fortran provides.

When iteration commences at a given time step, Type543 arbitrarily chooses a cover temperature guess of 0 K. It continues to iterate until it finds a cover temperature that causes the following energy imbalance to go to zero.

$$Q_{imbalance} = -\left(Q_{rad_Plate2Cover} + Q_{rad_Sky2Cover} - Q_{rad_Cover2Plate} - Q_{rad_Cover2Sky}\right) - Q_{conv_PlateCover} - Q_{conv_CoverSky} \quad \text{(Eq. 543.9)}$$

Once the converged cover temperature has been found, the total losses from the collector / plate system are calculated as

$$Q_{loss} = Q_{conv_PlateCover} + \left(Q_{rad_Plate2Cover} - Q_{rad_Cover2Plate}\right) \quad \text{(Eq. 543.10)}$$

From which the top loss coefficient is calculated

$$U_{top} = \frac{Q_{loss}}{T_{plate} - T_{ambient}} \quad \text{(Eq. 543.11)}$$

Type543 has often been used in projects in which it was necessary to match measured and simulation collector performance results. As a result of these projects, it became necessary to add tuning factors to the top loss model. Thus Utop is modified according to

$$U'_{top} = X_{MultFactor}\, U_{top} + X_{AddFactor} \quad \text{(Eq. 543.12)}$$

From which the total losses are then recalculated as

$$Q'_{loss} = U'_{top}\left(T_{plate} - T_{ambient}\right) \quad \text{(Eq. 543.13)}$$