TYPE 536: LINEAR PARABOLIC CONCENTRATING SOLAR COLLECTOR

General Description

Type536 models a type of solar collector called a linear parabolic concentrator that is commonly used in high temperature applications. In the simplest form of a linear parabolic concentrator, fluid passes through a long evacuated tube that runs along an east-west axis and is horizontal to the plane of the ground or which runs on a north-south axis and is in a plane tilted with respect to the ground. The Type536 parabolic concentrator is modeled based on theoretical equations developed in Solar Engineering of Thermal Processes [1].

Nomenclature

$\dot{Q}u$	[kJ/hr]	The useful energy gain of the LPC collector.
A_c	[m^2]	The collector area.
$F_R(\tau\alpha)_n$	[ ]	The efficiency with which solar radiation is absorbed by the plate and removed by fluid flowing through the collector.
I_t	[kJ/hr.m^2]	The amount of solar radiation incident on the plane of the collector surface.
$F_R U_L$	[ ]	The collector loss rate.
ΔT	[ºC]	A temperature difference.
R_{test}	[ ]	
g_{test}	[kg/hr]	The mass flow rate of fluid flowing through the collector under test conditions.
Cp_{fluid}	[kJ/kg.K]	The specific heat of the collector fluid.
$F'U_L$	[ ]	
R_1	[ ]	
N_{series}	[-]	The number of collectors in series.
$\dot{m}_{fluid}$	[kg/hr]	The mass flow rate of fluid flowing through the collector at any given time.
$A_{aperture}$	[m^2]	The area formed by the mouth of the parabolic reflector and the length of a single collector tube.
R_2	[ ]	
$N_{parallel}$	[-]	The number of series collector strings in parallel.
IAM	[0..1]	The Incidence Angle Modifier; a dimensionless parameter that accounts for the collector's change in the transmittance absorptance product when the sun is not normal to the plane of the collector.
I_{beam}	[kJ/hr.m^2]	The amount of beam solar radiation incident on the plane of the collector surface.
$ConcRat$	[kg/hr]	
T_{in}	[ºC]	The temperature of fluid entering the collector array.
T_{amb}	[ºC]	The ambient dry bulb temperature of the collector's surroundings.
T_{out}	[ºC]	The temperature of fluid exiting the collector array.
$T_{\max}$	[ºC]	The maximum (user defined) temperature at which fluid may exit the collector array.
$\dot{Q}_{dump}$	[kJ/hr]	The amount of energy that had to be dumped from the outlet fluid stream in order to limit the collector outlet temperature to T_{max}

Detailed Description

The evacuated tube in a parabolic concentrating solar collector is located at the focus of a parabola made of some highly reflective material. As such, parabolic concentrating collectors do not receive a significant amount of diffuse radiation; their useful energy output is dictated by beam radiation as all the beam radiation incident on the aperture area (the area formed by the "mouth" of the parabola) is reflected onto the absorber contained in the evacuated tube. Thermal losses from parabolic concentrating collectors occur only from the absorbing surface which, while high in temperature, have comparatively small area. Because beam radiation is of such importance to the performance of a linear parabolic concentrating solar collector, the reflector is often tracked so that beam radiation remains within its acceptance angle. Figure 1 shows some schematic views of a linear parabolic concentrating collector.

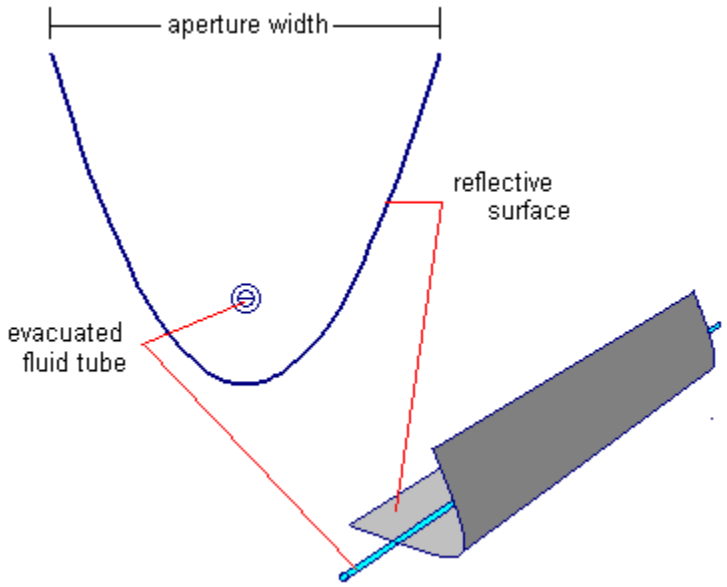


Figure 1: Linear Parabolic Concentrating Solar Collector Schematic

Incidence Angle Modifiers

Type536 relies upon an external data file to provide information on how the transmittance absorptance product of the evacuated tube changes with incidence angle. Because linear parabolic concentrators have an axis of symmetry and are often installed such that they track beam radiation throughout the day, only a one dimensional incidence angle modifier is necessary. For any given solar incidence angle, Type536 calls the TRNSYS Data Reading utility routine, which returns the corresponding value of the incidence angle modifier. Because Type536 uses the TRNSYS Data Reading utility, care must be taken in setting up the syntax of the external data file. That is to say that the first line of the data file must contain a at least one value of the solar incidence angle. The subsequent lines of the data file must each contain a single value of the incidence angle modifier that corresponds to a given incidence angle. An example file has been provided with this component and is reproduced at the end of this document for reference. One side effect of using the built in Data Reading utility is that while this subroutine is able to interpolate between provided values, it is unable to extrapolate beyond the data range given. If an incidence angle higher than the maximum value or lower than the minimum value present in the data file is sent to the Data Reading utility, the incidence angle modifier corresponding to the maximum or minimum value will be returned. For example, if the highest incidence angle present in the data file is 80

degrees and a solar incidence angle of 90 degrees is sent, the incidence angle modifier corresponding to an angle of 80 degrees will be returned and a warning will be printed in the simulation list and log files.

Collector Performance

The thermal performance of the Type536 linear parabolic concentrating collector is based upon theoretical equations described in Solar Engineering of Thermal Processes (SETP) [1]. SETP develops a modified loss coefficient called $F'U_L$. $F'U_L$ is based upon the standard collector loss coefficient F_RU_L provided by collector manufacturers and corrects the manufacturer specified loss coefficient for flow rates other than the rated flow rate.

$$F'U_L = \begin{cases} F_R U_L \quad if \quad \dfrac{F_R U_L}{g_{test}\ Cp_{fluid}\ ConcRat} \geq 1 \\ g_{test}\ Cp_{fluid}\ \left(1 - e^{\left(F_R U_L / \left(g_{test}\ Cp_{fluid}\ ConcRat\right)\right)}\right) \quad if \quad \dfrac{F_R U_L}{g_{test}\ Cp_{fluid}\ ConcRat} < 1 \end{cases} \qquad \text{(Eq. 536.1)}$$

The concentration ratio (ConcRat) in equation 536.1 above is defined as the ratio of the aperture area to the receiver area.

The standard collector performance equation is shown in equation 536.2.

$$\dot{Q}u = A_c\left[F_R\left(\tau\alpha\right)_n\ I_t - F_R U_L\ \Delta T\right] \qquad \text{(Eq. 536.2)}$$

Numerous temperature differences (ΔT in the equation above) can be used as the basis of the useful energy gain calculation. Some common standards are the collector inlet temperature minus the ambient temperature or the mean collector fluid temperature minus the ambient temperature. Type536 bases its calculation on the collector inlet temperature minus the ambient temperature. For parabolic concentrators, two modifiers (R_1 and R_2) are applied to equation 536.2 in order to correct for other flow rates than under test conditions and to account for more than one collector in a series string.

R_1 includes a term called R_{test} as shown in equation 536.3.

$$R_{test} = g_{test}\ Cp_{fluid}\ \left(1 - e^{\left(-F'U_L / \left(g_{test}\ Cp_{fluid}\right)\right)}\right) \qquad \text{(Eq. 536.3)}$$

R_1 is given by equation 536.4.

$$R_1 = \frac{N_{series}\ \dot{m}_{fluid}\ Cp_{fluid}}{A_{aperture}}\left(\frac{1 - e^{\left(\left(-F'U_L\ A_{aperture}\right) / \left(N_{series}\ \dot{m}\ Cp_{fluid}\right)\right)}}{R_{test}}\right) \qquad \text{(Eq. 536.4)}$$

R_2 is given by equation 536.5.

$$R_2 = \frac{1-\left(1-\frac{R_1\ A_{aperture}\ F_R U_L}{\dot{m}\ Cp_{fluid}\ N_{series}\ ConcRat}\right)^{N_{series}}}{N_{series}\left(\frac{R_1\ A_{aperture}\ F_R U_L}{\dot{m}\ Cp_{fluid}\ N_{series}\ ConcRat}\right)} \quad \text{(Eq. 536.5)}$$

The modified overall useful energy gain from the collector is based upon equation 536.2 as modified by the inclusion of incidence angle modifier effects, R_1, and R_2.

$$Qu = R_1\ R_2\ A_{aperture}\ N_{parallel}\left[F_R(\tau\alpha)_n\ IAM\ I_{beam} - \frac{F_R U_L}{ConcRat}(T_{in} - T_{amb})\right] \quad \text{(Eq. 536.6)}$$

Provided that there is flow, the temperature of fluid at the collector outlet is given by equation 536.7.

$$T_{out} = T_{in} + \frac{\dot{Q}u}{\dot{m}_{fluid}\ Cp_{fluid}} \quad \text{(Eq. 536.7)}$$

The flow rate in equation 536.7 is the mass flow rate of fluid in a single parallel branch of the collector array.

Under no flow conditions, the fluid outlet temperature is

$$T_{out} = T_{amb} + F_R(\tau\alpha)_n\ IAM\ I_{beam}\ \frac{ConcRat}{F_R U_L} \quad \text{(Eq. 536.8)}$$

Type536 is able to limit the outlet fluid temperature to a user specified maximum value. The theoretical outlet temperature calculated in either 536.7 or 536.8 is limited to the maximum allowable value specified by the user as an input to the model. The remaining energy is assumed to be dumped and is reported as an output to the model. The dumped energy for a single parallel branch of the collector array is given by equation 536.8.

$$\dot{Q}_{dump} = \dot{m}_{fluid}\ Cp_{fluid}\ (T_{out} - T_{\max}) \quad \text{(Eq. 536.8)}$$

Again, the mass flow rate in the above equation is the mass flow rate for one parallel branch of the collector.

Example Data File

An example of the incidence angle modifier data file syntax is shown below for ten incidence angle values. Because the same TRNSYS routine that reads an input file also reads data files, the same commenting rules apply to the data file. That is to say that any line containing an asterisk (*) character in the first column will be ignored, as will be any text appearing on a line following an exclamation point mark (!). Please note that the following data file is intended as a syntactical reference only and does not contain particularly realistic values of incidence angle modifiers.

```
0.0 10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0
1.0     !incidence angle modifier (IAM) corresponding to an incidence angle of 0.0 degrees.
0.9     !incidence angle modifier (IAM) corresponding to an incidence angle of 10.0 degrees.
0.8     !incidence angle modifier (IAM) corresponding to an incidence angle of 20.0 degrees.
0.7     !incidence angle modifier (IAM) corresponding to an incidence angle of 30.0 degrees.
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0.6     !incidence angle modifier (IAM) corresponding to an incidence angle of 40.0 degrees.
0.5     !incidence angle modifier (IAM) corresponding to an incidence angle of 50.0 degrees.
0.4     !incidence angle modifier (IAM) corresponding to an incidence angle of 60.0 degrees.
0.3     !incidence angle modifier (IAM) corresponding to an incidence angle of 70.0 degrees.
0.2     !incidence angle modifier (IAM) corresponding to an incidence angle of 80.0 degrees.
0.1     !incidence angle modifier (IAM) corresponding to an incidence angle of 90.0 degrees.
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References

[1] Duffie, J.A., and W.A. Beckman; Solar Engineering of Thermal Processes; J. Wiley and Sons, 1991