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Effect of number of supports on the bending of absorber tube of parabolic trough concentrator

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ABSTRACT

The circumferential non-uniformity in the temperature of absorber tube of parabolic trough leads to bending of the tube. The absorber tube is considered to be equidistantly supported at various points along the length. An analytical expression is presented in the current work for finding the bending and the results are compared with the experimental measurements. Further, the effect of number of supports and spacing between them on the shape of bent tube is analyzed using analytical equations. It is found that, keeping spacing between adjacent supports fixed, as number of supports and length of tube increase, the maximum bending does not vary beyond a certain length of tube. For the chosen system (keeping spacing between adjacent supports as 4 m), the results show that if lengths of tubes are larger than 16 m, the maximum bending remains same. The shape of bent tube is symmetric around the mid length. For one half of the tube, the bending is towards the vertex line of trough for the portion lying between 1st and 2nd support. It is away from the vertex line for the portion lying between 2nd and 3rd support and so on up to the mid length of the tube.

1. Introduction

The periphery of the receiver (of parabolic trough) facing the sun receives incident rays directly and the periphery facing the reflector receives concentrated rays. It results in non-uniform distribution of solar flux on the receiver. Many studies are available that analyzed the solar flux availability on the receiver of parabolic trough which are as follows.

1.1. Solar flux distribution

Evans [1] has analytically evaluated the solar flux distribution on the flat absorber for $\psi = 0^\circ$ (where, ψ is the angle of incidence of sun rays at trough's aperture). Nicolas and Duran [2] have extended the work of Evans [1] for all values of ψ. Rabl [3] and Guven and Bannerot [4] have analyzed the tubular receiver and analytically studied the effect of optical errors on the optical efficiency of parabolic trough. However, the solar flux distribution on the receiver has not been evaluated. In their studies, the spread of solar flux due to optical errors is considered to be normally distributed. Jeter [5] has analytically derived the circumferential distribution of solar flux on the tubular receiver. In the study, the sun-shape has been considered whereas optical errors have not been considered. The spread of solar flux due to sun-shape has been considered to be uniformly distributed within the angular width of sun. Jeter [6] has extended the previous work [5] by considering the optical errors. The spread of solar flux due to sun-shape and optical errors has been considered to be normally distributed. However, Hegazy et al. [7] have done deterministic analysis of the effects of optical errors (slope error in reflector surface and tracking errors) on the circumferential distribution of solar flux on tubular receiver.

Apart from analytical equations, ray tracing softwares are also used in some studies which are as follows. Thomas and Guven [8] have used ray tracing techniques to study the effect of optical errors on the circumferential distribution of solar flux on the tubular receiver. In the study, the spread of solar flux due to optical errors has been considered to be normally distributed. Yang et al. [9] have used MCRT (Monte Carlo Ray Tracing) method to compute the solar flux distribution on the tubular receiver. In the study, the spread of solar flux due to sun-shape has been considered to be uniformly distributed within the angular width of sun. The effects of tracking errors and rim angle on the solar flux distribution have also been

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Nomenclature

d	distance between adjacent supports to absorber tube (m)
$dq_A(\theta, \theta')$	the fraction of $q_{A,p}(\theta')$ absorbed by a differential surface located at angle θ (W/m^2)
E	modulus of elasticity of the material of absorber tube (Pa)
f	focal length of the trough (m)
h_f	convective heat transfer coefficient on inner surface of absorber tube (W/m^2-K)
I	moment of inertia of the cross section of absorber tube with respect to its centroidal axis (m^4)
I_{bn}	instantaneous beam normal radiation (W/m^2)
k	thermal conductivity of the material of absorber tube (W/m-K)
L	length of the parabolic trough and the continuous absorber tube (m)
M	bending moment (N-m)
M_T	moment induced in the absorber tube due to circumferential temperature gradient (N-m)
n	number of supports to absorber tube
q_A	solar flux absorbed on the surface of absorber tube per unit outer surface area of absorber tube (W/m^2)
$q_{A,p}(\theta')$	solar flux absorbed by a differential surface located at angle θ' considering the sun to be a point source and no optical errors (W/m^2)
r	radius (m)
R	reaction (N)
T	temperature of absorber tube (K)
T_a	ambient temperature (K)
T_f	fluid temperature (K)
U_L	over all heat loss coefficient of the receiver (W/m^2-K)
v_w	wind velocity (m/s)
w	width of the aperture of trough (m)

Greek symbols

α	absorptivity of absorber tube
α_{th}	thermal expansion coefficient of the material of absorber tube (/K)
δ	deflection in the central axis of absorber tube from the focal line of trough due to bending caused by non-uniform tube's temperature (m)
Δr	interval in which the value of integral is considered to be remained constant in radial direction (m)
ΔT_f	desired rise in fluid temperature per unit length of absorber tube (averaged over the whole length of absorber tube) (K/m)
Δz	length of each segment of absorber tube (m)
$\Delta\theta$, $\Delta\theta'$	interval in which the value of integral is considered to be remained constant in angular direction (rad)
ε	emissivity for long wavelength radiation
θ'	circumferential angle (rad)
θ_{rim}	rim angle of the trough (rad)
θ_{shd}	angle up to which the circumference of the absorber tube does not receive concentrated rays due to the shadow cast by absorber tube on trough (rad)
ρ	reflectivity of the trough surface
$\rho\tau\alpha(\psi)$	effective reflectance–transmittance–absorptance product for concentrated rays at ψ angle of incidence of sun rays
σ_{tot}	equivalent rms angular spread caused by optical errors and sun-shape (rad)
τ	transmissivity of glass cover
$\tau\alpha(\psi)$	effective transmittance–absorptance product for direct incident rays at ψ angle of incidence of sun rays
ψ	angle made by incident sun ray with the normal to aperture plane (rad)

Abbreviation

MCRT	Monte Carlo Ray-Trace

Subscripts

c	glass cover
ci	inner surface of glass cover
co	outer surface of glass cover
i	ith segment of absorber tube and glass cover
inlet	inlet of absorber tube
j	jth support
t	absorber tube
ti	inner surface of absorber tube
to	outer surface of absorber tube

studied. Cheng et al. [10] have developed a general MCRT method for finding the solar flux distribution on the receivers of parabolic trough, paraboloid dish and solar tower. Cheng et al. [11] have used MCRT method to compute the solar flux distribution on the absorber tube of parabolic trough. The maximum solar flux density on the circumference, average solar flux density and non-uniformity in the solar flux distribution have been found out for various values of geometrical parameters. Wang et al. [12] have analyzed the absorber tube of parabolic trough with secondary reflector. MCRT method is used to compute the solar flux distribution on the absorber tube. It has been concluded that the circumferential non-uniformity in the distribution of solar flux can be reduced significantly by using the secondary reflector. Wang et al. [13] have analyzed the elliptical glass cover for the absorber tube. It is concluded that the circumferential non-uniformity in the distribution of solar flux can be reduced significantly by using elliptical glass cover as compared to circular glass cover.

1.2. *Temperature distribution of absorber tube*

The non-uniformity in the distribution of solar flux and variation in fluid's temperature lead to non-uniform distribution of receiver's temperature. Most of the available studies have not considered the circumferential non-uniformity in receiver's temperature. However, few studies have computed the temperature distribution of absorber tube by using CFD softwares which are as follows. In these studies, different types of receivers have been analyzed.

Reddy and Satyanarayana [14] have analyzed the receiver having porous fins inside the absorber tube. Temperature distributions of the absorber tube have been computed for four different shapes (square, triangular, trapezoidal and circular) of fins. Cheng et al. [15] have computed the temperature distribution of the absorber tube having a concentric tube as a flow restriction device inserted inside the absorber tube. Wang et al. [16] have compared the temperature