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Research Paper

Explicit expression for temperature distribution of receiver of parabolic trough concentrator considering bimetallic absorber tube

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HIGHLIGHTS

- Explicit expression is derived for temperature distribution of bimetallic tube.
- Design calculations consume significantly lesser time using the expression.
- Material with higher thermal-conductivity should be used as outer layer.
- Best rim angle is found out for a given aperture width of trough.

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ABSTRACT

The portion of the absorber tube facing the trough surface receives the concentrated sun-rays and the other side of the absorber tube receives the sun-rays directly. Consequently, the temperature of the absorber tube is non-uniform across the circumference which leads to differential expansion of the material of the tube. Thus, the tube experiences compression and tension in its different parts. This may lead to bending of the tube. In literature, the temperature of the absorber tube is computed using CFD software which take large computational time. Thus, in the previous work, an explicit analytical expression was derived for finding the distribution of absorber's temperature and it was found that the temperature gradient across the circumference of the absorber tube can lead to significant bending. Thus, in the current work, a bimetallic tube has been studied that can reduce the temperature gradient and an explicit analytical expression is derived for finding the temperature distribution of a bimetallic absorber tube. The study of the effects of thicknesses and material selection of the inner and outer layer of bimetallic tube on temperature distribution is a must for choosing right materials and dimensions. The appropriate thicknesses and materials of inner and outer layers can be found out from the current work. The issue of whether to use high conducting material on outside or inside has also been addressed in the current work and concluded that the material with higher thermal-conductivity should be used as outer layer of the bimetallic tube to minimize the non-uniformity across the circumference. It is also concluded that for Schott-2008-PTR70-receiver, 126°, 135° and 139° respectively are the appropriate rim-angles for trough's aperture-width = 3 m, 6 m and 9 m corresponding to minimum non-uniformity across the circumference. 72°, 100° and 112° respectively correspond to maximum solar-flux at the absorber tube.

1. Introduction

The electricity generation using solar parabolic trough concentrators is one of the economically feasible renewable technologies. The parabolic trough concentrates the sun-rays at its focal line, when tracked appropriately. A selectively coated tube with a concentric glass cover (used for reducing heat losses) is generally used as receiver which is placed such that its central axis is aligned with the focal line of the trough. The absorber tube receives the concentrated solar flux only on the portion facing the reflector. Consequently, the temperature of the absorber tube is non-uniform. Almanza et al. [1] have measured the circumferential difference in the temperature of the absorber tubes made up of steel and copper. Almanza et al. [2] have extended the previous work [1] to analyze the stratified fluid flow. Flores and Almanza [3] have analyzed

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Nomenclature

dF_{1-2}	view factor of differential surface 1 with respect to differential surface 2
f	focal length of the parabolic trough collector (m)
h_f	convective heat transfer coefficient on the inner surface of absorber tube (W/m^2 K)
I_{bn}	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 absorber tube (m)
q_A	solar flux absorbed by the absorber tube per unit outer surface area (W/m^2)
q_c	radiative heat loss from the inner surface of glass cover (W/m^2)
q_L	rate of heat loss from the outer surface of absorber tube (W/m^2)
r	radius (m)
T	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 parabolic trough (m)

Greek symbols

α	absorptivity of the absorber tube
ΔT_f	rise in fluid temperature per unit length of receiver (averaged over the whole length) (K/m)
Δz	length of each segment of the receiver (m)
ϵ	emissivity for long wavelength radiation
θ_{rim}	rim angle of the parabolic 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 surface of parabolic trough
$\rho\tau\alpha(\psi)$	effective product of reflectivity, transmissivity and absorptivity for concentrated rays at ψ angle of incidence
σ	Stefan–Boltzmann constant (W/m^2 K^4)
$\sigma_{sun,\psi=0°}$	equivalent rms angular width of sun, at $\psi = 0°$, in line focus geometry (rad)
$\sigma_{optical}$	equivalent rms angular spread caused by all optical errors (rad)
σ_{tot}	equivalent rms angular spread caused by sun-shape and optical errors (rad)
τ	transmissivity of the glass cover
$\tau\alpha(\psi)$	effective product of transmissivity and absorptivity for direct incident rays at ψ angle of incidence
ψ	angle of incidence of sun-rays at trough's aperture, i.e. the angle between the incident sun-ray and the normal to aperture plane (rad)

Abbreviation

CFD	Computational Fluid Dynamics
MCRT	Monte Carlo Ray-Trace

Subscripts

a	ambient
c	glass cover
ci	inner surface of glass cover
co	outer surface of glass cover
f	fluid
fr	flow restriction device
i	inner layer of bimetallic absorber tube
inlet	inlet of receiver
int	interface of inner and outer layers of bimetallic absorber tube
j	jth segment of absorber tube and glass cover
o	outer layer of bimetallic absorber tube
sky	sky
t	absorber tube
ti	inner surface of absorber tube
to	outer surface of absorber tube

the bimetallic receiver made up of steel and copper. Flores and Almanza [4] have analyzed the case when the concentrated solar radiation falling on one side of the absorber tube instead of the lower periphery. Apart from the experimental measurements, numerical studies are also available in which the distribution of solar flux is computed using Monte Carlo Ray Tracing (MCRT) software and the distribution of absorber's temperature is computed using Computational Fluid Dynamics (CFD) software. In these studies, different types of receivers have been analyzed which are as follows.

Reddy and Satyanarayana [5] have considered the porous fins (square, triangular, trapezoidal and circular) inside the absorber tube. Cheng et al. [6] have considered a flow restriction device (a concentric tube) inside the absorber tube. Wang et al. [7] have analyzed an eccentric absorber tube. Munoz and Abanades [8,9] have carried out the calculations considering the helical fins inside the absorber tube. Cheng et al. [10] have considered the residual gases in the space between the absorber tube and the glass cover. Cheng et al. [11] have studied the effect of the longitudinal vortex generators inside the absorber tube. Wang et al. [12] have studied the selection of the material of the absorber tube. Wang et al. [13] have considered the metal foams inside the absorber tube. Roldan et al. [14] have compared the numerical calculations of the absorber's temperature with the experimental measurements. Yaghoubi et al. [15] have analyzed the receiver by considering vacuum in the space between the absorber tube and the glass cover and compared it with the case in which vacuum is not considered. Cheng et al. [16] have analyzed the effects of various parameters on the distribution of absorber's temperature. Wang et al. [17] have investigated the receiver with a secondary reflector. Song et al. [18] have considered a helical screw-tape inside the absorber tube. Wu et al. [19] have presented the distributions of the temperature of absorber tube and glass cover. Natarajan et al. [20] have carried out the calculations considering the inserts (triangular, inverted triangular and semi circular) inside the absorber tube. Patil et al. [21] have computed the distribution of absorber's temperature considering the sun to be a point source. Wang et al. [22] have analyzed the effect of the fluid's inlet temperature, the fluid's velocity and the solar radiation on the distribution of absorber's temperature.

Guiqiang et al. [23] have analyzed the distribution of the solar flux on the flat receiver of compound parabolic concentrator and found that the distribution for concentrator having lens-walls is more uniform in comparison to the one having mirror-walls. Guiqiang et al. [24] have extended the previous work [23] and found that the optical efficiency of the concentrator can be increased by using air gap between the lens-walls and the reflector. Guiqiang et al. [25] have extended the previous work [24] to analyze the concentrated photovoltaic/thermal system.

Thus, to summarize, the distribution of the temperature of absorber tube of parabolic trough has been reported using CFD software. However, using explicit expressions, the design