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Influence of circumferential solar heat flux distribution on the heat transfer coefficients of linear Fresnel collector absorber tubes

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Abstract

The absorber tubes of solar thermal collectors have enormous influence on the performance of the solar collector systems. In this numerical study, the influence of circumferential uniform and non-uniform solar heat flux distributions on the internal and overall heat transfer coefficients of the absorber tubes of a linear Fresnel solar collector was investigated. A 3D steady-state numerical simulation was implemented based on ANSYS Fluent code version 14. The non-uniform solar heat flux distribution was modelled as a sinusoidal function of the concentrated solar heat flux incident on the circumference of the absorber tube. The k–ε model was employed to simulate the turbulent flow of the heat transfer fluid through the absorber tube. The tube-wall heat conduction and the convective and irradiative heat losses to the surroundings were also considered in the model. The average internal and overall heat transfer coefficients were determined for the sinusoidal circumferential non-uniform heat flux distribution span of 160°, 180°, 200° and 240°, and the 360° span of circumferential uniform heat flux for 10 m long absorber tubes of different inner diameters and wall thicknesses with thermal conductivity of 16.27 W/mK between the Reynolds number range of 4000 and 210,000 based on the inlet temperature. The results showed that the average internal heat transfer coefficients for the 360° span of circumferential uniform heat flux with different concentration ratios on absorber tubes of the same inner diameters, wall thicknesses and thermal conductivity were approximately the same, but the average overall heat transfer coefficient increased with the increase in the concentration ratios of the uniform heat flux incident on the tubes. Also, the average internal heat transfer coefficient for the absorber tube with a 360° span of uniform heat flux was approximately the same as that of the absorber tubes with the sinusoidal circumferential non-uniform heat flux span of 160°, 180°, 200° and 240° for the heat flux of the same concentration ratio, but the average overall heat transfer coefficient for the uniform heat flux case was higher than that of the non-uniform flux distributions. The average axial local internal heat transfer coefficient for the 360° span of uniform heat flux distribution on a 10 m long absorber tube was slightly higher than that of the 160°, 200° and 240° span of non-uniform flux distributions at the Reynolds number of 4 000. The average internal and overall heat transfer coefficients for four absorber tubes of different inner diameters and wall thicknesses and thermal conductivity of 16.27 W/mK with 200° span of circumferential non-uniform flux were found to increase with the decrease in the inner-wall diameter of the absorber tubes. The numerical results showed good agreement with the Nusselt number experimental correlations for fully developed turbulent flow available in the literature.

Keywords: Absorber tube; Solar heat flux; Numerical simulation; Heat transfer coefficients

1. Introduction

Solar thermal energy is currently one of the most important sources of clean and renewable energy, which has enormous potential in reducing overdependence of

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Nomenclature

A	surface or cross sectional area (m^2)
b_{hf}	heat flux parameters
C_R	concentration ratio of the reflector field
C_μ, C_1, C_2	empirical turbulence constants
c_p	specific heat of the fluid at constant pressure (J/kg K)
f	Darcy friction factor
G	kinetic energy transfer
g	acceleration due to gravity (m/s^2)
h, $\bar{h}$	heat transfer coefficient and average heat transfer coefficient (W/m^2 K)
I	turbulence intensity at inlets and outlets, or number of irradiated divisions
i	irradiated division number
k	thermal conductivity (W/mK)
L, L_{TOT}	axial dimension and total axial length of tube (m)
M	total number of the axial divisions
$\dot{m}$	mass flow rate (kg/s)
(m, n)	numerical surface location
N	total number of the circumferential divisions
Nu, $\overline{\text{Nu}}$	Nusselt number and average Nusselt number
P	pressure (Pa)
Pr	Prandtl number
q	heat transfer (W)
q''	heat flux (W/m^2)
R, $\bar{R}$	radius and average radius (m)
r	radial coordinate (m)
Re	Reynolds number
S	source term
T, $\bar{T}$	temperature and average temperature (K)
t	tube wall thickness (m)
U	overall heat transfer coefficient (W/m^2 K)
v, $\bar{v}$	velocity and average velocity (m/s)
x	axial coordinate (m)

Greek letters

α	angle span of the irradiated segment of the tube (rad)
α_{tu}	absorptivity of the absorber tube
ε	turbulent kinetic energy dissipation
ε_{tu}	emissivity of the absorber tube-wall surface
θ	non-uniform temperature factor
γ_{mi}	reflectivity of the concentrator mirrors
κ	turbulent kinetic energy generation
μ	viscosity (kg/ms)
ρ	density of the heat transfer fluid (kg/m^3)
σ_{SB}	Stefan-Boltzmann constant (W/m^2 K^4)
σ	empirical turbulence constants
φ	conservation variable in governing equations
ϕ	angle span of each circumferential division, °, or tangential dimension
Γ	diffusion coefficient

Subscripts

a	free stream air
b	bulk fluid property
conv	convection
DNI	direct normal irradiation
ed	turbulent eddy
ef	effective
f	fluid
i	inner surface
l	laminar
m	at position m
n	at position n
o	outer surface
r	in radial direction
rad	radiation
x	in axial direction
tu	tube
w	wall
ϕ	in tangential direction
∞	radiant surroundings

the global economy on fossil fuels and in mitigating greenhouse gas emissions. Two basic types of solar thermal collector systems have been developed over the years and they are the non-concentrating or stationary collectors and the concentrating collectors (Kalogirou, 2004). The non-concentrating collectors, which include flat-plate and evacuated tube collectors, are suitable for low to medium temperature applications. The single-axis sun-tracking concentrating collectors, which include the linear Fresnel collector, parabolic trough collector and cylindrical trough collector types, and the two-axis tracking collectors, such as the parabolic dish reflector and heliostat field collectors, are suitable for medium to high temperature applications as required in the industrial process heat applications and electric power generations.

The parabolic trough solar collector has been the most popular concentrator among other solar concentrating collectors due to the success of the solar electric generating plants in the Mojave Desert of southern California in the late 1980s. The plant size ranges from 30 MW to 80 MW and a total installed capacity of 354 MW$_e$, which feeds about 800 million kW h per year into the grid and displaces