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Numerical optimization and convective thermal loss analysis of improved solar parabolic trough collector receiver system with one sided thermal insulation

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ABSTRACT

Two type of receiver systems currently employed in solar parabolic trough collector technology are evacuated annuli receivers and air filled annuli receivers. While former receiver finds its way into high-temperature grid-acquaintance solar parabolic trough collectors, latter are more inclined towards non-grid solar thermal applications like low-temperature process heat. Evacuated receivers utilize vacuum filled annuli to reduce down the convection losses; this makes them substantially expensive – while prizing them as benchmark among receivers. Contrary, air filled annuli based receivers are relatively less expensive but are sub-par in thermal performance relative to evacuated receivers. This work deals with the air filled receiver system and would try to abridge the economy and efficiency between both types of systems using computational fluid dynamics (CFD) based numerical simulation approach. A heat blocking thermal insulation was tailored and fitted in the sun facing receiver annulus which does not receive concentrated radiation of the Sun, and was simulated for the reduction in convective losses and for favourable circumferential temperature distribution (CTD) around the absorber. Consequently, its convective heat losses were investigated for varying wind speeds and mass flow rates of heat transfer fluid (HTF) and were compared with mainstream air filled annuli receivers. Simulation results are compared with experimentation in which wind velocity was in a range of 0.43–4.99 m/s. It has been found that glass envelope temperature decreases with increase in wind velocity which directly insinuates the decrease in convection losses around glass envelope. These comparative implications could be served as a point of reference to develop solar parabolic trough collector for small scale process heat applications in India.

1. Introduction

Linear concentration technology has made parabolic trough collector vanguard of concentrated solar power (CSP): there is no definitive focusing point, rather a line. Serious development and evolution of this technology, in fact, came into existence when researchers analyzed existing forefront point focusing technology and suddenly stumbled upon a general concept – why, point concentrate the heat when it will be redistributed in line circuitry of the heat transfer fluid. Parabolic trough based concentrated solar thermal power plants, for the most part, consists of parabolic trough solar fields, heat generation system or absorber/receiver system, power block powered with Rankine steam turbine and a temporary or optional power storage system. Good performance of solar fields or collectors is undeniably indispensable for parabolic trough technology. A decade long of research on parabolic trough technology has been summed up by Fletcher (2001) and Barlev et al. (2011) who clearly adduced the work of Steinmann et al. (2005); Arasu and Sornakumar, 2007; Dudley et al. (1994), Alguacil et al. (2014) and Zhang et al. (2015). This interesting and invaluable research includes – performance and analysis of heat transfer fluids and thermal storage, support structure and reflector development, receiver development, process development for direct steam generation and numerical optimization of thermo-physical factors. In addition, thermo - physical parameters such as solar irradiance, wind velocity, mass flow rate and inlet temperature of heat transfer fluid (HTF) are urgently critical, in order for parabolic trough collector (PTC) to perform efficiently. To illustrate, Fig. 1 describes a PTC receiver with vacuum filled annulus that is being used as a *'nouveau technology'* to put down

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Nomenclature

Symbols

A	area (m^2)
C_p	specific heat at constant pressure (kJ/kg K)
C_ε, $C_{3\varepsilon}$	RNG eq. constants, 1.420, 1.680
$C_{2\varepsilon}$	constant for turbulent kinetic energy
c, m	correlation parameters, 0.26, 0.6
D	diameter (m)
G_b	turbulent kinetic energy generation owing to buoyancy effect
G_k	turbulent kinetic energy generation owing to mean velocity gradient
g	gravitational constant (m/s^2)
h_a	convective heat transfer coefficient for annular space (kW/m^2 K)
h_g	convective heat transfer coefficient for glass envelope (kW/m^2 K)
k	thermal conductivity (kW/m K)
k_{in}	turbulent intensity (%)
k_T	turbulent conductivity (kW/m K)
k_1	turbulent energy production
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number
p	pressure (N/m^2)
Pr	Prandtle number
Q	rate of heat transfer per unit length (W/m)
q	heat flux (W/m^2)
Re	Reynolds number based on hydraulic diameter
T	temperature (K)
t	time (s)
u, v, w	velocities in x, y, z direction
V	velocity (m/s)
x, y, z	cartesian coordinates

Greek

δ	molecular diameter of air in annulus (cm)
ε	turbulent energy dissipation or emissivity
η	efficiency
ρ	density (kg/m^3)
μ	dynamic viscosity (Pa s)
μ_t	turbulent eddy viscosity (Pa s)
σ_k	turbulent Prandtle number for diffusion of k
σ_ε	turbulent Prandtle number for diffusion of ε
Δ	increment value
φ	circumferential angle
∞	condition pertaining to ambient

Subscripts

a	absorber interaction point
a - $cond$	conduction losses from absorber
a - $conv$	buoyancy induced convective heat transfer from absorber to trapped air in annulus
a,f- $conv$	heat transfer from absorber to fluid *via.* convection
a - rad	radiation losses from absorber
avg	average
D	hydraulic diameter
f	heat transfer fluid
g - $conv$	convection losses from glass to ambient
g	condition pertaining to glass envelope
g - rad	radiation losses from glass envelope
in	condition at inlet
i, j	pertaining to nodes i, j
o	condition at outlet
sol	solar incidence
sol-abs	solar radiation transmitted through glass envelop to absorber
w	wall

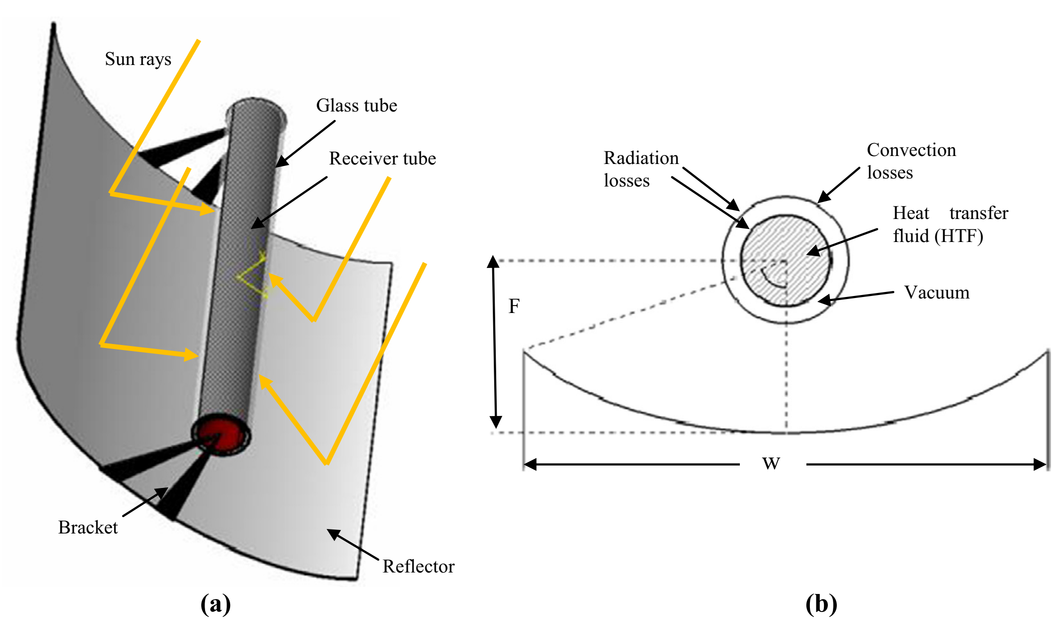

Fig. 1. (a) Schematic of vacuum annulus parabolic trough collector, and (b) prevailing heat losses in it.