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Heat Transfer Enhancement in a Parabolic Trough Solar Receiver using Longitudinal Fins and Nanofluids

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In this paper, we present a three dimensional numerical investigation of heat transfer in a parabolic trough collector receiver with longitudinal fins using different kinds of nanofluid, with an operational temperature of 573 K and nanoparticle concentration of 1% in volume. The outer surface of the absorber receives a non-uniform heat flux, which is obtained by using the Monte Carlo ray tracing technique. The numerical results are contrasted with empirical results available in the open literature. A significant improvement of heat transfer is derived when the Reynolds number varies in the range 2.57×104 ≤ Re ≤ 2.57×105, the tube-side Nusselt number increases from 1.3 to 1.8 times, also the metallic nanoparticles improve heat transfer greatly than other nanoparticles, combining both mechanisms provides better heat transfer and higher thermo-hydraulic performance.

Keywords: numerical study, Monte Carlo ray trace, parabolic trough collector, heat transfer, longitudinal fins, nanofluid

Introduction

THE surge in fossil fuels prices during the petrol crisis launched the industrialized countries in the race for alternative and renewable energies such as solar energy. This source of energy is considered as the most economical and clean. At the same time, solar thermal power plants have been the subject of study among the technology of parabolic trough collectors, which are currently the most proven SOLAR CONCENTRATION TECHNIQUES [1]. Several studies have recently focused on the tube-side heat transfer enhancement of these devices, following both numerical and experimental methodologies. The descriptions of the convective heat transfer, the effect of the geometry and the use of different working fluids have been analyzed by these authors.

Aggrey et al. [2] presented a numerical investigation of thermal performance of receiver for a parabolic trough collector (PTC) with perforated plate inserts. Their results show that the use of inserts improve the thermodynamic performance of the receiver by minimizing the entropy generation rates, and described the dependence of the Nusselt number and friction factor on the spacing and size of the insert. Wang et al. [3] investigated numerically the heat transfer enhancement in the receiver tube of a direct steam generation system with parabolic trough by inserting metal foams; they reported the significant effect of the layout and dimensionless height of metal foams on the thermal performance greatly, whereas the porosity of the foam proved to have a slight influence on the heat transfer. Song et al. [4] analyzed the heat transfer enhancement of PTC receiver with non-uniform heat flux and helical screw-tape inserts; their results indicate that the maximum temperature on the outer surface

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Nomenclature			
A	area, m^2	ρ	Density, kg/m^3
C_p	Specific heat, J/ kg K	λ	thermal conductivity, W/m K
d	Diameter, m	μ	Viscosity, Pa s
DNI	Direct normal irradiance, W/m^2	η	thermo-hydraulic performance
f	Friction factor	**Subscripts**	
h	Heat transfer coefficient, W/m^2K	amb	Ambient
h_W	Glass cover outer heat transfer coefficient, W/m^2K	b	Bulk fluid state
L	Receiver length, m	bf	Base fluid
$\dot{m}$	Mass flow rate, kg/s	f	Fluid
Nu	Nusselt number	go	Outer glass cover wall
P	Pressure, Pa	in	Inlet
PEC	Performance evaluation criteria	nf	Nanofluid
Pr	Prandtl number	p	particle
$\overline{q''}$	Heat flux, W/m^2	ri	absorber tube inner wall
Re	Reynolds number	sky	sky temperature
T	Temperature, K	w	wall
v_w	Wind velocity, m/s	**Abbreviation**	
Greek letters		HTF	heat transfer fluid
φ	particle volume concentration	PTC	parabolic trough collector
ε	emissivity		

of the absorber tube increases along with inlet temperature and solar irradiation. Cheng et al. [5] carried out a numerical study of heat transfer enhancement by unilateral longitudinal vortex generators inside PTC receiver. They illustrated that the average Nusselt number and average friction factor increase with increasing each geometric parameter, whereas the thermal loss decreases with the increase of each geometric parameter.

Recently, a new class of fluids called nanofluid has been developed and tested, this term was proposed by Choi in 1995 [6] at Argonne National Laboratory; as a liquid mixture with a small concentration of nanometer-sized solid particles in suspension. Nanofluids have interesting thermo-physical properties such as high thermal conductivity.

The researches on the application of nanofluids have been popularized during the recent years; various authors have investigated the effects of using nanofluid on heat transfer enhancement inside PTC receiver. Sokhansefat et al. [7] studied the effect of using Al_2O_3/synthetic oil in a PTC tube, reporting that heat transfer augments for increasing nanoparticle volume fraction and operational temperature. Risi et al. [8] investigated the heat transfer enhancement for CuO+Ni/nitrogen gas in a PTC tube, demonstrating that above 0.3 %vol the drawback effect of pressure drop overwhelm the beneficial effects of thermal properties, additionally the optimization procedure found a maximum solar to thermal efficiency equal to 62.5%.

The present work prospects the use of a compound enhancement technique for parabolic trough collector, based on the use of nanofluids and the presence of two longitudinal fins in the tube side of the PTC. A three dimensional numerical model is implemented in ANSYS Fluent for the solution of the flow field and heat transfer in the enhanced geometry. The heat flux around the absorber tube was obtained applying MCRT (Monte Carlo ray tracing) method. The first part of this study analyzes the effect of using longitudinal fins inserts when the Reynolds number varies in the range $2.57\times10^4 \le Re \le 2.57\times10^5$ depending on the heat transfer fluid characteristics. In the last part we investigate a comparison between four different kinds of nanoparticles, with nanoparticle concentration of 1 % in volume. The aim of this paper is to develop the influence of heat transfer fluid properties and receiver geometries of a parabolic trough solar collector.

Physical model

In our investigation, we considered a simple model of receiver of the parabolic trough solar collector, in which all effects of the central rod and other supports are considered negligible.