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ScienceDirect

Procedia Engineering 127 (2015) 63 – 70

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Computational Heat and Mass Transfer-2015

Numerical Analysis and Validation of Heat Transfer Mechanism of Flat Plate Collectors

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Abstract

Numerical and thermodynamic analysis has been carried out to understand the performance of solar flat plate collector (SFPC) so as to improve its performance. Though SFPCs' are been using as solar thermal collectors over the few decades, their thermal efficiency is considerably low. The thermal efficiency can be improved either by changing the geometric parameters or by changing its working fluid. The gap between absorber plate and glass, glazing glass thickness and number of glazing glasses plays a vital role in the performance of the SFPC. Since nanofluids possesses higher heat transfer coefficients, now-a-days they are been widely using in different engineering fields. Based on exergy analysis it has been shown that efficiency of SFPC has been improved considerably. Al_2O_3-water and CuO-water nanofluids are considered for the comparison. Heat transfer phenomenon inside the risers of SFPC is analyzed numerically by developing a 3D model in commercial CFD software ANSYS FLUENT 14. It is observed that that the proposed model is predicting the heat loss coefficients and fluid temperatures with good accuracy. The thermal efficiency obtained with this numerical model is validated against measured data. This paper also discusses about the heat transfer enhancement capabilities of nanofluid based SFPC.

Peer-review under responsibility of the organizing committee of ICCHMT – 2015

Keywords: nanofluid; numerical modelling; entropy generation

1. Introduction

Continuous evaluations in science and technology insists the energy demands dramatically, but, conventional

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Peer-review under responsibility of the organizing committee of ICCHMT – 2015
doi:10.1016/j.proeng.2015.11.331

primary energy sources like fossil fuels are already using at their critical rates, which also causes for environmental issues. This scenario demands the scientific community and worldwide researchers to choose other alternative energy conversion techniques to contribute future energy needs. Among many alternatives, solar energy is fundamentally an inexhaustible source and potentially capable of meeting the significant portion of the world's future energy desires. More intensive attention was focus on solar energy from the early of 1970's. Solar energy is an expected choice to resolve problems associated with energy and environment. It is the most promising unconventional energy sources particularly for contributing in low temperature applications. The solar energy collection has been the primary interests of many engineers and researchers due to its wide applications such as domestic water heating and in other commercial appliances.

Solar energy collectors are major components of solar systems; these are the special kind of heat exchangers that transform solar radiation energy into internal energy of the transport medium. Among many of the solar thermal collectors, flat plate collectors are special kind, though they produce lower temperatures, have the advantages of being simpler in design, no tracking mechanism, having lower maintenance and lower cost. Even solar collectors are existing in usage for decades, their thermal performance is considerably low due to the low convective heat transfer coefficients of working fluid. The conversion of low grade energy with improving effectiveness of these solar collectors has been carried out by many researchers. Selmi et. al. [1] carried out the experiments solar flat plate collectors with water as working fluid and compared its performance by changing different glazing materials. In current ages, some researchers' uses nanofluid as working medium in SFPCs to increase the overall heat transfer coefficient. In this context, Yousefi et al [2] consider the Al_2O_3-water nanofluid as working fluid and found that the efficiency is improved by 28.3%with 0.2wt% nano particles. Lu et al. [3] examined the thermal performance of water based CuO nanofluid and found the mass concentration of nanofluid had noted effects on heat transfer coefficient. Natarajan and Sathish [4] investigated the enhancement of thermal conductivity with carbon nano tube (CNT).

Nomenclature

A_c	Collector Area (m^2)
E	Exergy (J)
f	Friction factor
I_t	Total Solar radiation (W/m^2)
h_w	air heat transfer coefficient (W/m^2K)
k	Thermal conductivity (W/mk)
L	Length of the collector (m)
N_g	Number of glass covers
Q_u	Heat absorbed by the working fluid (W)
S	Entropy (W/K)
T	Temperature (K)
Nu	Nusselt Number
Pr	Prandtl Number
U_l	Overall heat loss coefficient (W/m^2K)
U_t	Top heat loss coefficient (W/m^2K)
U_b	Bottom heat loss coefficient (W/m^2K)
U_e	Edge heat loss coefficient (W/m^2K)

Greek letters

β	Collector tilt angle (deg)
ρ	Density (kg/m^3)
μ	Viscosity ($N.s/m^2$)
ε	Emissivity
τ	Transmissivity
σ	Stephen Boltzmann constant(W/m^2K^4)

Subscripts

a	Ambient
b	Bottom
e	Edge
g	Glass
i	Inlet
P	Plate
t	Top

Different thermodynamic and numerical modes are proposed in the past by other researchers to predict the performance of SFPC. Salma Parvin et al. [5] numerically investigated the direct absorption solar collectors with Cu-water and Ag-water nanofluids. It has been proposed that the heat transfer rates are increased by 31% and 11% respectively at 3% volume fraction. Pawan et al. [6] proposed that the entropy generation is increasing with nanofluid concentration. Damir et al [7] presented the numerical analysis of water based flat plate collector with tubes and channels as working fluid flow passages. Vasudeava Karanth [8] performed a CFD simulation of flat plate collector with water as working fluid at different mass flow rates and the simulation results shows that absorber plate temperature is decreases with increase in the working fluid mass flow rate. Mossad and Al-Khaffajy [9]