Applied Thermal Engineering 130 (2018) 395–407

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Thermal performance of a nanofluid-based flat plate solar collector: A transient numerical study

Alper Mete Genc [a], Mehmet Akif Ezan [b], Alpaslan Turgut [b,*]

[a] Dokuz Eylul University, The Graduate School of Natural and Applied Sciences, Mechanical Engineering Department, Tinaztepe Campus, Buca, 35397 Izmir, Turkey
[b] Dokuz Eylul University, Engineering Faculty, Mechanical Engineering Department, Tinaztepe Campus, Buca, 35397 Izmir, Turkey

HIGHLIGHTS

- Transient behavior of nanofluid based flat plate solar collector was studied.
- Nanofluid increased the outlet temperature by 7.20% compared with water.
- Efficiency of the FPSC increases with increasing mass flow rate.
- Nanofluid is more effective on the collector efficiency at below 0.016 kg/s.
- Transient analyses provide the determination of thermal inertia of FPSC components.

ARTICLE INFO

Article history:
Received 17 January 2017
Revised 20 October 2017
Accepted 31 October 2017
Available online 16 November 2017

Keywords:
Flat-plate
Solar collector
Transient analysis
Al_2O_3
Nanofluids

ABSTRACT

Flat plate solar collectors (FPSCs) are commonly used devices to convert solar radiation into useful heat for a variety of thermal applications. Due to the lower thermal efficiencies of these systems, recently, nanofluids are suggested to be used in FPSCs as the working fluid to enhance their energy harvesting potential. This study introduces a transient heat transfer approach for determining the thermal inertia of each component such as glass, trapped air, absorber and working fluid for nanofluid based flat plate solar collectors. The analyses were carried out with water and three different volumetric concentrations of Al_2O_3 nanoparticles as 1%, 2% and 3%. Mass flow rate of the heat transfer fluid is varied in a wide range, between 0.004 and 0.06 kg/s, to demonstrate the effect of thermophysical properties at different flow Reynolds numbers. The results indicate that the maximum increase of the outlet temperature is obtained by 7.20% at 0.004 kg/s and 3% (vol.) mass flow rate and volumetric concentration, respectively, in July. On the other hand, the highest thermal efficiency is obtained as 83.90% at 0.06 kg/s mass flow rate for 1% (vol.) in October. It is worthy of note that nanofluids can increase the thermal efficiency of the FPSCs at lower flow rates and beyond a critical flow rate the base fluid becomes effective working fluid. For the current study, the critical flow rate is determined to be 0.016 kg/s.

1. Introduction

Energy is an essential factor for the development and economic growth of the countries. In order to consider the increasing energy demand of the world, various energy agencies such as: International Energy Agency [1], International Energy Outlook [2] and The Institute of Energy Economics-Japan [3] have been presenting long-term energy projections. These projections provide what may happen given certain assumptions under different scenarios. According to the main scenario of International Energy Agency [1], it is expected that global energy demand will grow 30% by 2040. Today, almost 86% of the primary energy consumption is met by fossil fuels [4]. However, fossil fuels are limited sources and also have negative effects on global warming. As released by European Commission [5] according to the Paris Climate Agreement, "Governments agreed on a long-term goal of keeping the increase in global average temperature to well below 2 °C above pre-industrial levels and to aim to limit the increase to 1.5 °C". The agreement has suggested shifting the resources away from polluting fossil fuels to clean energy and therefore, renewable energy has gained more important role since it is clean, safe and sustainable. As a promising renewable energy source, solar energy has attracted considerable attention in recent years. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW and about 30% of this reaches the earth. At every 20

* Corresponding author.
E-mail address: alpaslan.turgut@deu.edu.tr (A. Turgut).

https://doi.org/10.1016/j.applthermaleng.2017.10.166
1359-4311/

Nomenclature

A	area (m^2)
c	specific heat (J/kg K)
f	Darcy friction factor
g	gravitational acceleration (m/s^2)
Gr	Grashof number (= $g\beta\Delta T L_c^3/\vartheta^2$)
h	convective heat transfer coefficient (W/m^2 K)
I_{solar}	incident solar radiation (W/m^2)
i, j	node number in 2D space
k	thermal conductivity (W/m K)
L	length of the tube
L_c	characteristic length (m)
m	mass (kg)
t	mass flow rate (kg/s)
Nu	Nusselt number (= hL_c/k)
P	pressure (Pa)
Pr	Prandtl number (= $\mu c/k$)
Re	Reynolds number (=$\rho VD/\mu$)
q	rate of heat transfer (W)
t	time (s)
T	temperature (K or °C)
V	velocity (m/s)
v_{wind}	wind speed (m/s)
$\dot{W}$	pumping power (W)
x, y	position in Cartesian coordinates (m)

Greek letters

α	absorptivity
β	thermal expansion coefficient (1/K)
ε	emissivity
η	efficiency
θ	angle of inclination
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
σ	Stefan-Boltzmann constant (= 5.67×10^{-8} W/m^2 K^4)
τ	transmissivity
ϑ	kinematic viscosity (m^2/s)
ϕ	particle volume fraction

Subscripts

abs	absorber
f	fluid
g	glass
htf	heat transfer fluid
in	inlet
c	cross section
out	outlet
p	particle
s	surface
x	exergy

Abbreviations

FPSC	flat plate solar collector
HTF	heat transfer fluid
ne-HTF	nano-enhanced heat transfer fluid
TES	thermal energy storage

min, the sun produces enough power to meet the requirements of the world for an entire year [6].

Among the several devices for harvesting solar energy, solar collectors are the most popular ones to convert solar radiation into useful heat. Although the most commonly used solar collectors are flat plate types, they have comparatively lower efficiencies and outlet temperatures [7]. Suman et al. [8] recently reviewed the advancements in solar technology by focusing on the methodologies of enhancing their thermal performance. A suggestion has been made to replace the heat transfer fluid (HTF) by new generation working fluids such as nanofluids. Nanofluids are composed of higher thermal conductive nanoparticles such as metal oxide, metal or carbon that are dispersed within conventional base fluids such as water, oil, ethylene glycol or brines. Therefore, nanofluids that are used in thermal applications to transfer thermal energy may be called as nano-enhanced heat transfer fluids (ne-HTFs). Although Masuda et al. [9] were the first who showed the great potential of improving the thermal conductivity of fluids by adding conductive nanoparticles, the nanofluid term was named by Choi [10]. Since then, many researchers have studied different properties and possible applications of nanofluids. One can find valuable information on the subject in the recent review papers. Ganvir et al. [11] presented a comprehensive review of heat transfer characteristics of nanofluids. They mentioned that the further application oriented research of nanofluid is the need of an hour. In addition, they concluded that nanofluid with enhanced thermal conductivity brings about enhanced heat transfer. Devenviran and Amirtham [12] described the heat transfer potential of different types of nanofluids. They mentioned that further research on various applications of nanofluids should be carried out. It was also mentioned that the requirement to improve the efficiency of thermal systems relies highly on the enhancement of thermal conductivity of the working fluid. Raja et al. [13] published a review paper on characteristics, heat transfer performances and applications of nanofluids. It is noted that convective heat transfer behavior of nanofluids is superior to conventional fluids.

Regarding the existing literature on nanofluid based solar energy systems, there are several review reports. Pandey and Chaurasiya [14] emphasized that using nanofluids on FPSCs bring about advantages such as cost effectiveness, being environmentally friendly and compact and lightweight. Verma and Tiwari [15] reviewed the nanofluids' effectiveness on the efficiency of solar energy systems, mainly: solar collectors, photovoltaic systems, solar thermoelectric and energy storage system. They concluded that nanofluids can be a better solution for use as heat transfer fluids in solar thermal systems. Sarsam et al. [16] reported a comprehensive review on nanofluid applications in flat plate solar collectors. They confirmed that nanofluids can be used effectively to enhance the performance of FPSCs.

Above mentioned reports present many experimental studies on nanofluid based FPSCs. In the most recent one, Verma et al. [17] investigated the effect of a wide variety of nanofluids on the performance of flat plate solar collector under steady state conditions. They concluded that the thermal efficiency was improved by 23.5% using MWCNTs/water at 0.75% (vol.). Verma et al. [18] experimentally investigated the effect of MgO/water nanofluid as working fluid on the flat plate solar collector. They found that the efficiency of solar collector was increased by using MgO/water nanofluid in comparison with water by 9.34% for 0.75% particle volume fraction and volume flow rate at 1.5 lpm. Vincely and Natarajan [19] investigated the influence of graphene oxide nanofluid on the performance of flat plate solar collector for steady state conditions. They reported that thermal efficiency was enhanced by 7.3% at 2% (wt.) and 0.01167 kg/s mass flow rate. Colangelo et al.