Solar Energy 167 (2018) 231–241

Contents lists available at ScienceDirect

Solar Energy

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

Performance analysis of hybrid nanofluids in flat plate solar collector as an advanced working fluid

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ARTICLE INFO

Keywords:
Hybrid
Nanofluid
Bejan number
Exergy
Efficiency

ABSTRACT

Nanofluids are innovative fluids. Hybrid fluids are engineered by mixing of different nanoparticles in suitable proportion with conventional fluid, in order to achieve desired thermo physical parameters. In present work, authors have investigated response of flat plate solar collector when conventional working fluid, water is replaced by nanofluids. The selected nanofluids are hybrid of CuO and MgO with MWCNTs with water base. Experimentation performed under varying concentration from 0.25% to 2.0% and varying flow rate (0.5 lpm to 2.0 lpm) for both nanofluids under given ambient condition. Quantitative and qualitative responses of flat plate collector have been observed by energetic and exergetic performance evaluation of the collector. Increase of Bejan number is an indication of system's quality credit. It enhances productive entropy due to transfer of heat caused by temperature difference and suppresses production of entropy, arises by systems irreversibilities. Findings strongly supports optimum operating conditions for flat plate solar collector are concentration of particles in range of 0.75–1.0% at mass flow rate 0.025–0.03 kg/s. Exergetic and energetic efficiency of collector for hybrid nanofluid are 71.54% and 70.55% for MgO hybrid nanofluid. Under similar parameters exergetic and energetic efficiency of collector for CuO hybrid is 70.63 and 69.11%. Percentage enhancement in exergetic and energetic efficiency of collector for MgO hybrid nanofluids are: 25.1% with respect to base fluid and 16.28% with respect to MgO/water fluid. As hybrid nanofluid MgO performs better than CuO hybrid and closer to MWCNTs/water fluid.

1. Introduction

Efficient energy utilization is an index of technological prowess and its application. The world has been witnessing progressive advancement in energy efficiency since beginning of industrial era. In contemporary world, to sustain industrial growth, huge amount of conventional energy resources are being used. Though conventional resources are easy to use, possess inherent limitations. Humanity is paying heavy price of environmental loss along with fruits of development. In order to meet ever growing energy needs and reduce its burden on unconventional resources and its impact on growing pollution and environmental degradation, dependence on nonconventional energy resources is an obvious choice (Hussein, 2015) emphasized in his review, importance of nanotechnology in optimum utilization of renewable energy resources. Among available nonconventional resources solar energy is the most popular and abundantly available. Technological knowhow and systemic support is highly mature to harness solar energy. Solar collectors and photovoltaic systems are being used to absorb solar energy and convert it into other form according to requirement. Among solar collectors, FPSC is more convenient, robust and easy to design and require less maintenance. Thermal efficiency of flat plate solar collector is comparatively lower compare to other type of collectors. Thermo physical property mainly thermal conductivity and viscosity have cardinal importance in thermal efficiency of solar collector. Nanofluids have shown viable alternative to replace conventional working fluid to achieve enhanced thermal efficiency. Experimental and theoretical observations have confirmed that nanofluids are highly promising and ready to be replaced by conventional fluid in order to enhance performance of solar collectors. Hybrid nanofluids are further advanced fluid prepared to achieve desired thermo-physical property.

In the light of above observation, discovery of nanofluids, has opened up new opportunities. The term 'Nanofluid' was coined by Choi (1995). Over the past decade, researchers all over the world vigorously working over wider aspects of energy transfers in forms of heat. Thermal performance is proportional to nanoparticles volume conc. of

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https://doi.org/10.1016/j.solener.2018.04.017
Received 18 September 2017; Received in revised form 25 January 2018; Accepted 9 April 2018
0038-092X/

Nomenclature

FPSC	Flat Plate Solar Collector
DASC	Direct Absorbing Solar Collector
LPM	Litre Per Minute
CNTs	Carbon Nano Tubes
MWCNTs	Multi Walled Carbon Nanotubes
PEG	Propylene Ethylene Glycol
TEM	Transmission Electron Microscopy
XRD	X-ray diffraction
C P	Centi Poise
H.I.M	Human Interaction Machine
P.L.C	Programmable Logic Controller
D.M	Di Mineralized
F_R	heat removal factor
U_L	overall heat transfer loss coefficient
U_t	upper loss coefficient
U_b	bottom loss coefficient
U_θ	edge Loss coefficient
P_{wr}	pressure loss ratio
T_a	ambient temperature (Kelvin)
T_P	plate temperature (Kelvin)
$G_{t:}$	global solar radiation
N	number of glazing
I	intensity of radiation (J/m^2)
h_a	heat transfer coefficient of air (J/m^2 K)
x_b	thickness of back insulation
k_b	thermal conductivity of back insulation
Ae	area of edge surface
W	width between risers
D	diameter of riser tube
C_P	specific heat (Joule/kgK)
k_θ	angle modifier
$\dot{E}_X$	exergy rate (Joule/s)
ψ_{in}	energy function at inlet (Joule)
ψ_{out}	energy function at outlet (Joule)
$T_{surr.}$	surrounding temperature in Kelvin
T_f	fluid temperature
$\dot{S}$	entropy rate (J/K s)
$\dot{S}_{gen}$	entropy generation rate (J/K s)
ρ	density of fluid (kg/m^3)
R_e	Reynolds number
G_c	error component
k_b	thermal conductivity of back insulation (J.m/K)
k_B	Boltzman constant (J/K)
R	gas constant for air (J/kg K)

Greek symbols

φ	particle volume fraction (%)
τ	absorptance
α	transmittance

basic fluid significantly. Lot of experimental work on synthesis, characterization, modeling, convective and boiling heat transfer have been done in past decade (Das et al., 2003) demonstrated that thermal conductivity of nanofluid increases with temperature. Investigative findings by many researchers establish that nanofluid enhances thermal conductivity, heat transfer coefficient, thermal efficiency, optical absorptivity, as shown by Bobbo et al. (2012), Das et al. (2003), Fedele et al. (2012), Murshed et al. (2005), Pak and Cho (1998), Said et al. (2014), Sajid et al. (2014), Vajjha et al. (2009). Many authors have presented their research on flat plate solar collectors using nanofluids. The findings establish that nanofluids are better than conventional fluids in terms of enhancement of thermal and exergetic efficiency. They unanimously supported, based on research outcome, that nanofluids pushes pressure drop and entropy losses but this is quite a meager compare to gain in heat transfer rate, thermal conductivity and heat transfer coefficient (Amin et al., 2015; Faizal et al., 2013; Malvandi et al., 2013; Nasrin et al., 2014; Rahman et al., 2014; Said et al., 2015a; Said et al., 2013; Sajid et al., 2014; Shojaeizadeh et al., 2014; Tiwari et al., 2013; Yousefi et al., 2012a,b). Exergetic analysis shows that with the use of nanofluids exergetic efficiency increases with small penalty of pressure drop. (Shojaeizadeh et al., 2015) reported 1% enhancement in exergy efficiency reported for Al_2O_3-Water nanofluid at reduced flow rate 68% and flow inlet temperature by2% respectively (Jafarkazemi and Ahmadifard, 2013) performed exergetic and energetic performance analysis of FPSC. They have found that exergetic analysis is better way to compare performance of solar collector and also provide necessary data to design collector for optimum efficiency (Said et al., 2015b) have used SWCNTs-Water and reported 95.12% enhancement in energy efficiency and 26.25% enhancement in exergy efficiency compare to water which exhibits 42.07% and 8.77% respectively (Gorji and Ranjbar, 2016) performed combined numerical and experimental investigation on performance of low flux (DASC) using, silver, magnetite and graphite nanofluids. Results show that nanofluid enhances thermal and exergy efficiency in the range of (33–57)% and (13–20)% respectively (Ojeda and Messina, 2017) performed mathematical model of dendritic geometry of pipes in disc shaped solar collector to study its performance using alumina/water nanofluid. Results established that thermal energy gain is proportional to nanoparticles volume fraction. Outlet temperature is higher for use of nanoparticles compare to base fluid (Rose et al., 2017) experimentally investigated optimum concentration Graphene oxide nanofluid which offer minimum reflectance and highest absorption at volume concentration 0.012% (Sint et al., 2017) performed mathematical simulation model study of FPSC using CuO/water. Results indicate that where size is not an influential parameter, collector efficiency increases up to 5% of particle volume concentration (Wang et al., 2017) performed experimental observation of solar steam generation by using plasmone Au nanoparticles. Investigation reveals that solar steam generation can be achieved up to 65% at 178 ppm Au nanoparticles at 10-sun illumination intensity (Parvin et al., 2014) performed modeling to see effect of Cu-Water nanofluid on entropy generation. Analytical observation confirms that both, mean Nusselt number and entropy production grows with solid volume fraction of Cu nanoparticles, Reynolds number or flow rate. Review articles presented on application of nanofluids for solar collector as an advanced and improved heat transfer fluid, strongly support nanofluids as an advanced working fluids. A nanofluid generally augments conductivity, surface conductance. It lessens specific heat and increases viscous effect (which decline with temperature) (Al-Shamani et al., 2014; Awad, 2015; Colangelo et al., 2016; Das and Choi, 2009; Devendiran and Amirtham, 2016; Javadi et al., 2013; Kasaeian et al., 2015; Khullar et al., 2014; Lomascolo et al., 2015; Mahian et al., 2013; Saidur et al., 2011; Sarsam et al., 2015; Suman et al., 2015; Sundar et al., 2013; Verma and Tiwari, 2015a,b). The major objective of synthesis of hybrid nanofluid is to obtain the synergetic association of properties of its constituting elements. No material may possess all desirable attributes for specific use; either it possesses better thermal property or rheological one. Many real applications demands for synergetic compatibility among various parameters, thus hybrid nanofluid appear into picture (Sarkar et al., 2015). Again, the hybrid nanofluid can bring enhanced thermal conductivity compared to individual nanofluid (Suresh et al., 2011) prepared Al_2O_3-Cu nanofluid by hydrogen reduction technique in ratio (90:10) from powder of Al_2O_3 and CuO. Measurement of thermal conductivity and viscosity shows that increase in viscosity is steeper than conductivity with