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Experimental evaluation of flat plate solar collector using nanofluids

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ABSTRACT

The present analysis focuses on a wide variety of nanofluids for evaluating performance of flat plate solar collector in terms of various parameters as well as in respect of energy and exergy efficiency. Also, based on our experimental findings on varying mass flow rate, the present investigation has been conducted with optimum particle volume concentration. Experiments indicate that for ~0.75% particle volume concentration at a mass flow rate of 0.025 kg/s, exergy efficiency for Multi walled carbon nanotube/water nanofluid is enhanced by 29.32% followed by 21.46%, 16.67%, 10.86%, 6.97% and 5.74%, respectively for Graphene/water, Copper Oxide water, Aluminum Oxide/water, Titanium oxide/water, and Silicon Oxide/water respectively instead of water as the base fluid. Entropy generation, which is a drawback, is also minimum in Multiwalled carbon nanotube/water nanofluids. Under the same thermophysical parameters, the maximum drop in entropy generation can be observed in Multiwalled carbon nanotube/water, which is 65.55%, followed by 57.89%, 48.32%, 36.84%, 24.49% and 10.04%, respectively for graphene/water, copper oxide/water, Aluminum/water, Titanium Oxide /water, and Silicon oxide /water instead of water as the base fluid. Rise of Bejan number towards unity emphasizes improved system performance in terms of efficient conversion of the available energy into useful functions. The highest rise in energy efficiency of a collector has been recorded in Multiwalled carbon nanotube/water, which is 23.47%, followed by 16.97%, 12.64%, 8.28%, 5.09% and 4.08%, respectively for graphene/water, Copper oxide/water, Aluminum oxide/water, Titanium oxide /water, and Silicon oxide/water instead of water as the base fluid.

1. Introduction

The quest for efficient energy continues even today with scientists and engineers inventing new technologies and more efficient devices to harness energy. Nanofluids are such an invention that has, over the decades, revolutionized energy absorption, transportation and storage systems. A number of parameters, essential for enhanced thermal performance, get drastically modified when a material changes from macro to nano form. These parameters are thermal conductivity, heat transfer coefficient, optical extinction coefficient, electrical conductivity, viscosity and density. Solar collectors are a special kind of heat exchangers which capture incident solar irradiation and transform it partially to useful heat. The solar collector is an essential part of any solar system. In a conventional heat transform process, this device absorbs the incoming solar radiation, converts it into heat and transfers the heat to a fluid (air, oil, water). Flat plate collector along with Evacuated Tube Collector (ETC) are widely used solar energy absorbing system all over the world due to its simple design, compactness, low production and maintenance cost, and reliability established through long years of experience, research and development. However, efficiency of conventional solar collectors using conventional heat absorbing fluids is low. Muhammad et al. [1]reviewed applications of nanofluid in evacuated tube and flat plate solar collectors from efficiency, economic and environmental considerations and reaches to conclusion that nanofluids offers better alternative to conventional fluid. Sabiha et al. [2]experimentally investigated effect of Single Walled Carbon nanotubes/water (SWCNTs) as nanofluid on performance enhancement of Evacuated Tube Solar Collector (ETSC). Authors observed maximum efficiency enhancement 93.43% at 0.025 kg/s flow rate and 0.2% volume concentration. Tong et al. [3]experimentally investigated by filling the thermal resistance of air gap with MWCNTs as working fluid. Efficiency of Enclosed-type Evacuated U Tube solar collector (EEUTSC) enhanced by 4%. Its impact on annual reduction of CO_2 and SO_2 emissions reduction will be 1600 kg and 5.3 kg respectively when 50 solar collectors are employed.

Discovery of nanofluids, a new-age heat transfer fluid, has opened up many possibilities. Over the years, a number of researchers around the world have been working on various

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Nomenclature

Abbreviations

CNT	carbon nano tube
C P	centi poise
D.M	di mineralized
DASC	direct absorbing solar collector
ETSC	Evacuated Tube Solar Collector
FPSC	flat plate solar collector
H.I.M	human interaction machine
LPM	litre per minute
MWCNTs	multi walled carbon nanotubes
PEG	propylene ethylene glycol
P.L.C	programmable logic controller
TEM	transmission electron microscopy
XRD	X-ray diffraction

Subscripts

Ae	area of edge surface
C_P	specific heat (J/kg k)
$\dot{E}_X$	exergy rate (J/kg s)
F_R	heat removal factor
G_c	error component
G_s	absorbed solar energy per m^2
G_t	global solar radiation
h_a	heat transfer coefficient of air (J/kg m^2 K)
k_b	thermal conductivity of back insulation (J/K m)
k_θ	angle modifier
k_B	Boltzman constant (J/K)
P_{wr}	pressure loss ratio
R_e	Reynolds number

$\dot{S}_{gen}$	entropy generation rate (J/kg K s)
T_a	ambient temperature (K)
T_s	light source temperature (K)
T_{fin}	fluid inlet temperature
$T_{f\ out}$	fluid outlet temperature
T_P	plate temperature (K)
$T_{surr.}$	surrounding temperature in Kelvin
U_b	bottom loss coefficient (J/kg Km^2)
U_e	edge Loss coefficient (J/kg Km^2)
U_L	overall heat transfer loss coefficient (J/kg Km^2)
U_t	upper loss coefficient (J/kg Km^2)
x_b	thickness of back insulation
ψ_{in}	energy function at inlet (J/kg)
ψ_{out}	energy function at outlet (J/kg)

Symbols

D	diameter of riser tube
I	intensity of radiation (J/m^2)
V	wind velocity (m/s)
$\dot{S}$	entropy rate (J/kg K s)
W	width between risers

Greek symbols

φ	particle volume fraction (%)
tau	absorptance
alpha	transmittance
ρ	density of fluid (kg/m^3)

aspects of heat transfer. Pak and Cho [4] reported that convective heat transfer coefficient increased by 75% in Aluminum oxide (Al_2O_3) having 2.78% concentration of nanofluids. Natrajan and Sathish [5] investigated rise in thermal conductivity in base fluid with the use of carbon nanotubes (CNTs). Tyagi et al. [6] presented a theoretical study on a non-concentrating direct absorption solar collector (DASC) and compared its performance with flat-plate collector. Otanicar and Golden [7] examined the effect of nanofluids on environment and economy while using them to enhance efficiency of solar collector. Godson et al. [8] elucidates in his review article about unique features of nanofluids, which includes: enhancement of heat transfer, improvement in thermal conductivity, increase in surface to volume ratio, Brownian motion and thermophoresis. Wang et al. [9] in their review article emphasized that homogeneous suspension of nanoparticles in base fluid significantly changes the transport properties and heat transfer characteristics of the suspension. Kameya and Hanamura [10] reported a rise in solar radiation absorption by using a nanoparticle suspension. Yu et al. [11] through experiments discovered an increase in thermal conductivity of ethylene and propylene glycol nanofluids containing aluminum nitride nanoparticles at 0.2% volume concentration. Yousefi et al. [12] studied the effect of Al_2O_3/water nanofluid as a working medium. He reported a 28.3% increase in efficiency of flat-plate solar collector. In another study, Tiwari et al. [13] reported a 31.64% increase in efficiency of solar collectors with Al_2O_3 nanofluid at an optimum concentration of 1.5% as compared to water as a base fluid. Mwesigye et al. [14] studied the effect of Al_2O_3/synthetic oil following minimization of entropy. Kar [15] did an exergetic analysis of flat plate solar collector and found that exergetic analysis is important to design the optimum system as pressure drop plays an important role with the increasing flow rate. Said et al. [16] selected SWCNT/water to find out its effect on exergy and energy efficiency in flat plate solar collector. Results showed that the maximum enhancement in energy and exergy efficiency that could be attained was 95.12% and 26.25% as compared to water which has energy and exergy efficiency at 42.01% and 8.77%, respectively. Chen et al. [17] performed experimental and numerical analysis for nanoparticle fraction, collector height, and irradiation time on collector efficiency. Results shows that silver and gold nanofluids obtain high photo thermal conversion efficiency than titanium oxide nanofluid because of similarity of optical spectra with solar. Jeon et al. [18]performed experimental and simulation study for blended plasmonic gold nanoparticles prepared to widen absorption spectra within visible to near infra red for volumetric solar collector. Said et al. [19] experimentally evaluated effect of particle size, concentration and flow rate on performance of solar collector. Results show that performance with 13 nm particle size is significantly better than 20 nm at 0.1% concentration and 1.5 kg/min. flow rate. Pandey and Chaurasia [20] presented a comprehensive review about various ways to enhance performance of flat plate solar collector. Prominent contemporary methods discussed are application of advanced nanofluids and design modifications in absorbing plate. Sarsam et al. [21]in their review paper observed that solar collectors are the extensively used and well known types of solar collectors. however the effectiveness of the collectors absorber plate to absorb solar energy undermine the efficiency of this type. Leong et al. [22]in their review article have stressed the need for an efficient solar collector must be equipped with superior working fluid having advanced thermal and optical properties. Verma and Tiwari [23]in his review paper reinforces the working of nanofluids applied on solar systems. According to authors nanofluids have great potential to