Investigations of Nanofluid Based Direct Absorption type Flat Plate Solar collector

Ph.D. Thesis

by

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Dedicated to my parents inspired by wife Neha and daughter Tanzil

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DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

This is to certify that the thesis entitled "**Investigations of Nanofluid Based Direct Absorption type Flat Plate Solar Collector**" is being submitted by ***Mr. Hemant Kumar Gupta*** **(ID No.2010RME103)** to the Malaviya National Institute of Technology, Jaipur for the award of the degree of **Doctor of Philosophy** in Mechanical Engineering is a bonafide record of original research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirement for the submission of this thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.

Date: 30.11.2015

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ABSTRACT

The tube- in- plate type flat plate solar collectors utilize a black surface as the absorber, which then transfers heat to a fluid running in tubes embedded within or fused onto the surface. But these types of solar collectors exhibit several shortcomings such as low overall energy conversion efficiencies and higher heat losses (conduction and convection) at high temperature due to surface based solar energy absorption and indirect transfer of heat from hot absorber surface to working fluid flowing through tubes. In order to overcome the drawbacks of conventional surface based collector, the idea has been proposed to enhance the efficiency of the collector by directly absorbing the incident solar energy within the fluid volume flowing over the absorber plate (i.e. base plate) named as Direct Absorption Solar Collector (DASC), or alternatively also termed as Volumetric Absorption Collector (VAC).

Direct absorption system leads to the absorption of higher amount of solar radiation which results in higher collector efficiency and outlet temperature as compared to traditional flat plate collectors. Since, in DASC all of the solar energy is to be absorbed by the working fluid so the light absorption properties of the working fluid should be high enough to absorb incident solar radiation. In order to meet these requirements nanofluid is used as a fluid medium instead of conventional fluids in the new designed direct absorption solar collector to increase the absorption of solar energy, where nanoparticles in a liquid medium can absorb and scatter solar radiation leading to further enhance performance of solar collector .

In the thesis, three set ups of full scale direct absorption solar collector (one with glass and two with aluminum base plates) having gross area 1.4 m^2 working on volumetric absorption principle were designed, fabricated and developed to perform experimental study for evaluation of collector efficiency using two different types of nanofluids (Al_2O_3–water and TiO_2–water) of four different nanoparticle concentrations (0.001%, 0.003%, 0.005%, and 0.007 vol%) at three flow rates 1.5 lpm, 2 lpm and 2.5 lpm. ASHRAE standard 93-86 was followed for calculation of optical efficiency (zero loss efficiency) of direct absorption solar collector. Also the variation of outlet fluid temperature, single pass fluid temperature rise, base plate and glass plate temperatures

with different volume fraction and flow rate at different inlet temperatures were studied. Stable nanofluids were prepared by two step methods using procured powder of nano materials and mixing with distilled water for certain period in ultrasonic vibrator and the experiments were performed according to ASHRAE standard 93-86 under actual outdoor conditions.

Experimental results with glass base plate collector using Al_2O_3-water nanofluid of 0.001 vol% at 2 lpm flow rate, showed maximum efficiency improvement by 22.1 % as compared to water. Collector efficiency increased by 14.35% when nanoparticle concentration increased from 0.001 vol% to 0.005 vol% due to enhancement in energy absorbed parameter and then decreased for higher nanoparticle concentration.

Enhancement in optical efficiency with aluminum base plate collector using Al_2O_3-water nanofluid of 0.001% Al_2O_3 concentration was by 12%, 25% and 15% for flow rate of 1.5, 2 and 2.5 lpm respectively compared to pure water. The increase in nanoparticle concentration from 0.001% to 0.005% improved the collector efficiency by 26% (at 1.5 lpm), 10% (at 2.0 lpm) and 8% (at 2.5 lpm) and further increase in nanoparticle concentration from 0.005 % to 0.007% reduced the collector efficiency at all three flow rates.

Present study showed that TiO_2 and Al_2O_3 based nanofluid exhibited better and promising solar absorption characteristics than water and can be used as a good solar absorption fluid in solar collectors.

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NOMENCLATURE

English Symbols

Notation	Description	Unit
A_A	Absorber area of the collector	m^2
A_a	Aperture area of the collector	m^2
C	Specific heat	$Jkg^{-1} K^{-1}$
I_T	Global total solar irradiance	Wm^{-2}
k	Thermal conductivity	$Wm^{-1} K^{-1}$
$\dot{m}$	Mass flow rate of fluid	kgs^{-1}
Q_u	Useful heat gain	W
R^2	Uncertainty coefficient	unit less
t	Time	s
T_a	Surrounding air temperature	°C
T_{in}	Collector inlet fluid temperature	°C
T_o	Collector outlet fluid temperature	°C
ΔT	Temperature rise	°C
T_{bp1}	Base plate temperature at point 1	°C
T_{bp2}	Base plate temperature at point 2	°C
T_{gc}	Glass cover temperature	°C
u	Surrounding air speed	ms^{-1}
U_{Tout}	Uncertainty for outlet temperature	%
U_{Tin}	Uncertainty for inlet temperature	%
U_{IT}	Uncertainty for solar radiation	%
U_η	Uncertainty for efficiency	%
W	Weight	Kg-f

Greek Symbols

α	Absorptivity	Unit less
ε	Emittance	Unit less
τ	Transmisivity	Unit less
ρ	Density	kgm^{-3}
ϕ	Volume fraction	%

η	Collector efficiency	unit less
η_0	Zero loss efficiency	unit less
ν	Kinematic viscosity	m^2s^{-1}
μ	Dynamic viscosity	$kg\ m^{-1}s^{-1}$
Θ	Incidence angle of beam irradiance	°

LIST OF ABBREVIATIONS

DASC	Direct Absorption Solar Collector
FPC	Flat Plate Collector
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
SWH	Solar Water Heater
UC	Ultrasonic Cleaner
HTF	Heat Transfer Fluid
CPVC	Chlorinated Poly-Vinyl Chloride
BIS	Bureau of Indian Standards
nm	Nanometer
lpm	Liter per Minute
ppm	Parts per Million
MNRE	Ministry for New and Renewable Energy Source

Subscripts

eff	Effective
L	Loss
p	Particle
f	Fluid
R	Removal
U	Useful
i	Inlet
o	Outlet
a	Ambient
nf	Nanofluid
np	Nanoparticle