

# **Investigations of Nanofluid Based Direct Absorption type Flat Plate Solar collector**

**Ph.D. Thesis**

by

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**(ID No. 2010RME103)**



**DEPARTMENT OF MECHANICAL ENGINEERING  
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR  
November 2015**

*Dedicated to my parents inspired by wife  
Neha and daughter Tanzil*

# Investigations of Nanofluid Based Direct Absorption type Flat Plate Solar Collector

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Submitted in fulfillment of the requirements for the degree of  
**DOCTOR OF PHILOSOPHY**

to the



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**November 2015**

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**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.

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## ACKNOWLEDGEMENT

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Mere words never suffice in expressing my feeling of gratitude to my supervisors **Dr. G. D. Agrawal**, Associate Professor, Mechanical Engineering Department and **Prof. (Dr.) Ing.-Jyotirmay Mathur**, Head of Department, Professor, Centre for Energy & Environment for their valued guidance, their commitment in providing me with the guidance, advice, and support at each and every step in the completion of this work. Their scientific and analytic approaches to new problems, experience in academia and industry, wide knowledge and discerning remarks really have helped me at every stage of my work. Their encouragement and broad influences have given me so much confidence to pursue professional knowledge and develop my career. It was due to their immense keenness and continuous attention that this present work could take a final picture.

The financial help given by Department of Science and Technology (DST), India under the scheme of Solar Energy Research Initiatives (SERI) [sanction no. DST/TM/SERI/2k12/01/ (G)] is gratefully acknowledged.

I express my gratitude to Head of Department, Prof. Rakesh Jain and DRC Chairman of Mechanical Engineering Department, Prof. G.S. Dangayach for providing valuable suggestions and words of encouragement.

I am also thankful to all members of my doctoral guidance committee, **Prof. S. L. Soni**, **Prof. Dilip Sharma** and **Dr. Nirupam Rohatgi** who have provided valuable suggestions and keen support during the completion of my research work.

I am heartily thankful to all staff member of Mechanical Engineering Department, Malaviya National Institute of Technology, Jaipur for their help in making the experimental facility and conducting the research work.

My deepest gratitude and appreciation goes to my parents who have been impatiently waiting to see my academic achievements. I am grateful to my in-laws, brother, sisters and their family for their support, good wishes and blessings for my successful completion of research work.

I specially thank to my wife **Neha** for their hearty moral support, patience and the pains taken in looking after the entire family during accomplishing this work, which would not have been possible otherwise.

I am glad to express my sincere thanks to my little daughter TANZIL who has helped me to ease the pressure of the last crucial phase of work with his cheerful company all the times.

I am very much thankful to many of my friends, **Anuj Mathur, K. B. Rana, B.L.Gupta, Rahul Khatri, Rakesh, Mukesh,** and **Vikas** for helping me throughout my Ph.D. work.

Last but not the least; I am grateful to Almighty God, without whose blessings I could not have achieved so much.

Place: Jaipur

Date: 30.11.2015

**(Hemant Kumar Gupta)**

## ABSTRACT

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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  $1.4 \text{ m}^2$  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 ( $\text{Al}_2\text{O}_3$ -water and  $\text{TiO}_2$ -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  $\text{Al}_2\text{O}_3$ -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  $\text{Al}_2\text{O}_3$ -water nanofluid of 0.001%  $\text{Al}_2\text{O}_3$  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  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  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	$kg s^{-1}$
$Q_u$	Useful heat gain	$W$
$R^2$	Uncertainty coefficient	unit less
$t$	Time	$s$
$T_a$	Surrounding air temperature	$^{\circ}C$
$T_{in}$	Collector inlet fluid temperature	$^{\circ}C$
$T_o$	Collector outlet fluid temperature	$^{\circ}C$
$\Delta T$	Temperature rise	$^{\circ}C$
$T_{bp1}$	Base plate temperature at point 1	$^{\circ}C$
$T_{bp2}$	Base plate temperature at point 2	$^{\circ}C$
$T_{gc}$	Glass cover temperature	$^{\circ}C$
$u$	Surrounding air speed	$ms^{-1}$
$U_{T_{out}}$	Uncertainty for outlet temperature	%
$U_{T_{in}}$	Uncertainty for inlet temperature	%
$U_{I_T}$	Uncertainty for solar radiation	%
$U_{\eta}$	Uncertainty for efficiency	%
$W$	Weight	$Kg-f$

## Greek Symbols

$\alpha$	Absorptivity	Unit less
$\varepsilon$	Emittance	Unit less
$\tau$	Transmissivity	Unit less
$\rho$	Density	$kgm^{-3}$
$\phi$	Volume fraction	%

$\eta$	Collector efficiency	unit less
$\eta_0$	Zero loss efficiency	unit less
$\nu$	Kinematic viscosity	$\text{m}^2\text{s}^{-1}$
$\mu$	Dynamic viscosity	$\text{kg m}^{-1}\text{s}^{-1}$
$\Theta$	Incidence angle of beam irradiance	$^\circ$

## 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