# Performance Analysis of Evacuated Tube Heat Pipe Solar Water Heating System using Nanofluid coupled with parabolic Trough Concentrator

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*Abstract*— Utilization of solar energy is the major hurdle in the application of thermal energy. Solar energy is one of the cleaner forms of renewable energy resources which achieve the need of people in the field of thermal energy. The study shows the utilization solar energy with the help experimental setup involve of parabolic through collector concentrating solar energy on evacuated tube heat pipe which transforming radiation energy into useful heat. Currently use of nanofluids in solar thermal technology for heat transfer enhancement is focus of interest. Experimental setup consist four heat pipes out of that two as a single unit and other two as another unit. The working fluid for each unit of heat pipe is water and Al2O3 respectively. Parabolic trough collectors concentrate solar radiation on heat pipe through evacuated tube. The experiment conducted for 12 days with different climatic condition. Temperatures at the outlet measured for both the system. The heat absorption rate was more in the unit consisting Al2O3 as a working fluid inside the heat pipe. Thermal performance of nanofluid contains heat pipe evacuated tube solar collector coupled with PTC is improved than conventional heat pipe evacuated tube solar collector with PTC. The enhancement in instantaneous collector efficiency obtained is 19-21%. At the same time effect of inclination angle and mass flow rate on performance of heat pipe evacuated tube collector is also studied.

***Key words:*** Evacuated Tube, Nanofluid, Solar Collector, Thermosyphon, Parabolic Trough Concentrator

## I. INTRODUCTION

To analysis the thermal performance and enhancement of heat transfer rate of wickless heat pipe evacuated tube solar collector with nanofluid and its comparison with conventional evacuated tube collector (ETC), it is essential to develop the integrate system in the same evacuated tube solar collector coupled with parabolic trough concentrator (containing four heat pipe with evacuated tubes), out of which two evacuated tubes containing the conventional fluid as water and remaining two tubes inclosing the nanofluids, with other accessories and measuring devices required for measuring necessary parameters to determine performance features of both these collectors. The arrangement can be made to different the inclination angle and different mass flow rate of water.

Objectives for this project are:

1) To study the thermal performance and enhancement of heat transfer rate of heat pipe evacuated tube solar collector using nanofluid with parabolic trough collector and its comparison with conventional ETC with parabolic trough collector.
2) Development of combined system in the similar evacuated tube solar collector (having four heat pipe with evacuated tubes), out of which two evacuated tube containing the conventional fluid as water and remaining two tubes containing the nanofluid.
3) The arrangement can be made to different the inclination angle and different the mass flow rate of water to measure the performance of solar collectors at various tilts angles.

Thermosyphons are two phase heat transfer devices with a very high effective thermal conductivity. Thermosyphon require very small area, simple the design, high rate of heat transfer, lighter in weight, cost effective and less maintenance are its biggest advantages. A typical two phase closed thermosyphon consists of metal pipe with fixed quantity of working fluid vacuum-packed inside. The hollow centre of the heat pipe is a vacuum so even at low temperature the fluid will vaporize. The vapour rises to the tip of the heat pipe then heat is transferred to the water flowing through manifold. Due to this heat transfer vapour will condense then flow back down the heat pipe so that this process will remain repeated again.

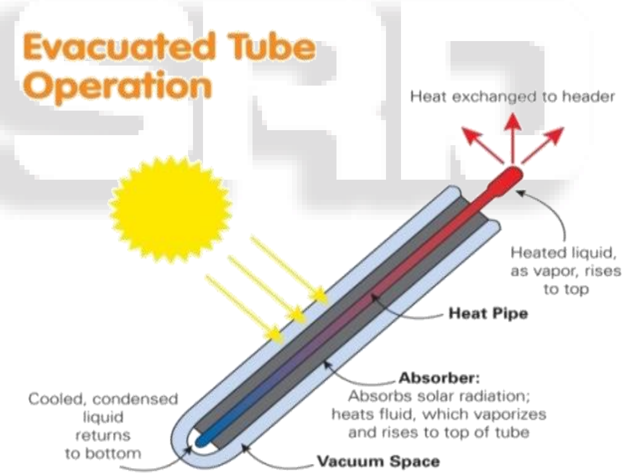


Fig. 1: Evacuated Tube Heat Pipe

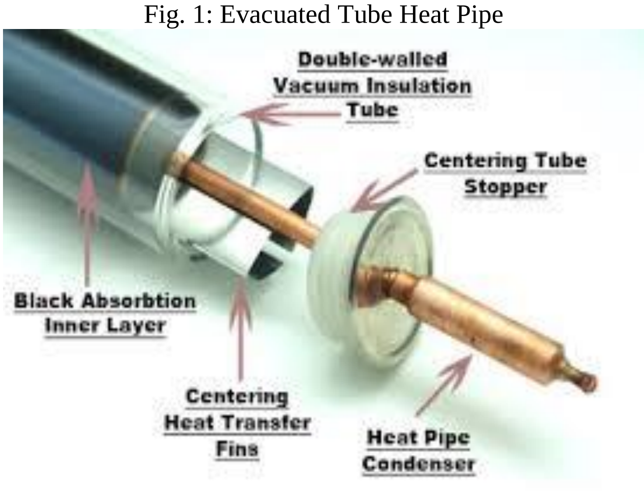


Fig. 2: Actual Evacuated Tube Heat Pipe

## II. LITERATURE REVIEW

Stephen U.S.Choi and Jeffrey A. [1] in this research they proposed an innovative new class of heat transfer fluids using suspending metallic nanoparticles in conventional heat transfer fluids. The resulting 'nanofluids' indicate the high thermal conductivity as compared to conventional heat transfer fluids. In this paper the results of theoretical study of thermal conductivity of nanofluids using copper nanoparticles is presented.

R shanthin and R. Velraj [2] exposed that latest innovative advancement in the use of nanofluids as the working fluid in the two phase gravity supported thermosyphon (TPGAT) extensively improved the heat transfer performance. In the present study, the performance enhancement of TPGAT by carbonaceous and metal based nanofluid as the working fluid is studied. The experimentations are conducted at several heat input in the evaporator and at different fill ratios. The results of the experiments revealed that the nanoparticles play a key role in enhancing the performance by attacking the formation of vapour bubbles in the evaporator section. It is similarly found that the fill ratio has varying role in the condenser and evaporator section at several heat input of the evaporator unit.

Lin Lu, Zhen-Hua Liu, Hong-Sheng Xiao [3] in this indoor experiment was out to study the thermal performance of the open thermosyphon using individually the deionized water and water based CuO nanofluids as the working liquid. Experimental results revealed that optimal filling ratio to the evaporator are 60%. CuO nanofluid significantly enhances the heat transfer as compared to deionized water.

Ahmet Samanci and Adnan Berber [4] in this study there is an experimental performance comparison between single–phase and two phase closed-thermosyphon solar water heater systems (SWHS).Two equal small-scale SWHS were constructed side by side. Tests were performed under similar environmental conditions. In the first system water was used as working fluid in the conventional SWHS named single-phase. In another single R-134a was used as working fluids in two phase SWHS. In both the systems temperature readings of collector inlet and outlet and water storage tank were taken. Efficiency values of single phase and two phase systems were determined with instantaneous solar radiation values available. After comparing results it is establish that as compared to single phase system two phase system is 42.8% more efficient.

H. JafariMosleh *et al.* [5] studied the different solar collectors commonly used in desalination systems and investigate the improvement in efficiency of a desalination system by the use of a linear parabolic trough collector. In this work, a combination of a heat pipe and twin-glass evacuated tube collector is used with a parabolic trough collector. Results show that, the rate of production and efficiency can reach to 0.27 kg/ (m2 h) and 22.1% when aluminium conducting foils are used in the space in the middle of the heat pipe and the twin-glass evacuated tube collector to transfer heat from the tube collector to the heat pipe. After oil is used as a medium for the transfer of heat, filling the space between heat pipe and twin-glass evacuated tube collector, the rate of production and efficiency can increase to 0.933 kg/(m2 h) and 65.2%, respectively.

P.Selvakumar et al. [6] studied an evacuated tube solar collector with therminol D-12 as heat transfer fluid coupled with parabolic trough. An experimental set-up was constructed to study the performance of evacuated tube collector with therminol D-12 as heat transfer fluid. The parabolic trough is coupled with evacuated tube collector for better performance. The efficiency of therminol based evacuated tube collector coupled with parabolic trough is 40% extra than that of water based evacuated tube collector coupled with parabolic trough. This study projects the potential of therminol based evacuated tube solar collector coupled with parabolic trough in the instant hot water generation.

Kapil Sharma et al. [7], studied the performance of solar collectors which is depends upon various factors like collector and receiver material, solar intensity, nature of working fluid etc. Here, an attempt has been made to improve the performance of a parabolic solar collector by using nanofluids instead of conventional fluid like water as working fluid. The performance of a parabolic solar collector is studied experimentally by studying the effect of alumina (Al2O3) & copper oxide (CuO) nanoparticles in water, as working fluids. Three mass flow rates (20, 40 & 60) l/hr. and particles volume concentrations of 0.01% have been studied. The average size of nanoparticle is 20-30 nm. Comparison of water based alumina nanofluid is done with copper oxide nanofluid and it is saw that by using CuO nanofluid as a working fluid the rate for maximum instantaneous & thermal efficiency has been better. Therefore, from the results it can be concluded that the performance of solar collector is enhanced by using nanofluids as working fluid in the solar collector.

M.A. Sabiha et al. [8] investigated the energy efficiency of an evacuated tube solar collector containing water based single walled carbon nanotube nanofluids. The effect of various parameters such as volume concentration of nanofluid, inlet and outlet fluid temperature, solar radiation and temperature on the collector efficiency is calculated. According to the results, higher efficiency is reached for higher volume concentration of single walled carbon nanotube nanofluids. The energy efficiency similarly increased with increasing solar radiation value. The highest collector efficiencies are measured for 84.24% and 94.73% using 0.05 and 0.25 volume concentration single walled carbon nanotube nanofluids respectively at a mass flow rate of 1.5kg/min.

WisutChamsa-arda et al. [9], research is carried out on design, fabricate and test the thermal efficiency of the heat pipe evacuated tube with compound parabolic concentrating (CPC) solar collector. The advantage of this system is, produces hot water over a period of time without adjusting the direction of the CPC to track the sun. The testing of CPC according to ISO 9806 - 1 found that the thermal efficiency was equal to 78%. The heat loss coefficient of the solar collector $a^1$ and $a^2$ are equal to 3.55 and 0.06 $W/m^{20}C$ respectively. The mathematical model was developed to determine the energy production base on solar radiation and ambient temperature data of Phitsanulok province. It was found that the monthly average energy of the CPC produced throughout the year is equal to 286.16 kWh or equal to 3433.87 kWh.

M.S. Naghavi et al. [10], prepare a theoretical model of solar hot water system consisting of an array of ETHPSC (evacuated tube heat pipe solar collectors) connected to a common manifold filled with phase change material and acting as a LHTES (latent heat thermal energy storage) tank. Solar energy incident on the ETHPSC is collected and stored in the LHTES tank. The stored heat is then transferred to the domestic hot water supply via a finned heat exchanger pipe placed inside the tank. A combination of mathematical algorithms is used to model a complete process of the heat absorption, storage and release modes of the proposed system. The results show that for a large range of flow rates, the thermal performance of the ETHPSC-LHTES system is higher than that of a similar system without latent heat storage. Furthermore, the analysis shows that the efficiency of the introduced system is less sensitive to the draw off water flow rate than a conventional system. Analysis indicates that this system could be applicable as a complementary part to conventional ETHPSC systems to be able to produce hot water at night time or at times with weak radiation.

Avadhesh Yadav, [11] in this experimental setup, the reflected solar radiations was focused on absorber tube which was placed at focal length of the parabolic through. In this setup, air was used as working fluid which collects the heat from absorber tube. To enhance the performance of parabolic through, collector with different type of reflectors were used. It was observed for aluminium sheet maximum temperature is 52.3ºC, which 24.22% more than steel sheet as reflector and 8.5% more than Aluminium foil as reflector, also efficiency by using Aluminium sheet as reflector compared to steel sheet as reflector is 61.18% more. Efficiency by using Aluminium sheet as reflector compared to Aluminium foil as reflector is 18.98% more.

## III. DESIGN AND DEVELOPMENT OF EXPERIMENTAL SET-UP

To investigate the performance of $Al_2O_3$-$H_2O$ nanofluid as working fluid in evacuated tube TPCT solar collector commercially existing evacuated tube TPCT solar collector can be chosen. The Collector modules consist of an array of evacuated tubes, isolated manifold header, maintain frame and regular frame package for single roof installation. Manifold headers have capacities of 4 tubes. The collector manifold casing and end cap are made of powder-coated aluminium profile. The link between the heat pipe and manifold is important to ensure optimal heat transfer. The heat pipe vacuum tube gathers heat from incoming emission. Later, the condenser of the heat pipe will transfer the heat to the manifold where the water is heated.

The arrangement will be made in a fashion that the single heat pipe collector containing four heat pipes will be divided in two parts. One part with two evacuated tube and heat pipe with conventional fluid as water. Whereas for remaining part the two heat pipes with working fluid as $Al_2O_3$-$H_2O$ nanofluid with 1% volume amount are inserted in the existing evacuated tubes available in the collector.

In this Experimental setup, for increasing efficiency of system, parabolic trough collector are used having an aperture area 0.32 $m^2$ and focal length 1.6 m, is used for solar air heating. The schematic diagram and experimental setup of parabolic trough collector are shown in Fig. 4.

The system consists of following parts:

### A. Reflector:

Reflector is one of the vital parts of the parabolic through collector as it decides the fraction of solar irradiance to be collected by the absorber tube. A parabolic reflector reflects and concentrates all the sun rays on the absorber tube. The reflector is a parabolic shaped galvanized with a reflectivity of 86% at clean surface.

### B. Absorber Tube:

The absorber tube is placed at the focal distance of the parabolic through collector. The outer diameter and inner diameter of absorber tube are 42 mm respectively along with a length of 1580mm. The solar radiations reflected by the parabolic trough collector are collected by the absorber tube. Water and nanofluid is used as working fluid in the absorber tube.

### C. Glazing:

The glazing is a concentric tubular glass shield which covers the absorber tube. The outer diameter and thickness of the glass tube are 57mm and 7mm respectively, having length equal to 1580mm.

### D. Preparation of Nanofluids:

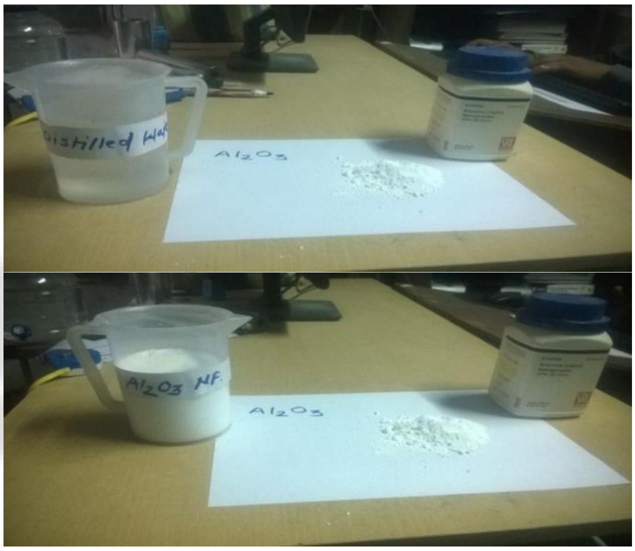

Fig. 3: Preparation of nanofluids

In this work nanofluid is prepared by two step process. Aluminum oxide is procured from SISCO research laboratory Mumbai. The average particle size (APS) of $Al_2O_3$ nanopowder is 30nm. This nanopowder is mixed with calculated quantity in distilled water. Mixture is stirred well for proper mixing of nanopowder. Later this nanofluid is set for accusing the heat pipes.

### E. Intensity:

A solar power meter is used for measuring the flow of solar radiation. It uses the photovoltaic effect to measure the amount of solar radiation reaching a given surface. Solar power meter also called "silicon cell Pyranometer",


Fig. 4: Solar power meter (Model KM-SPM-11)

 

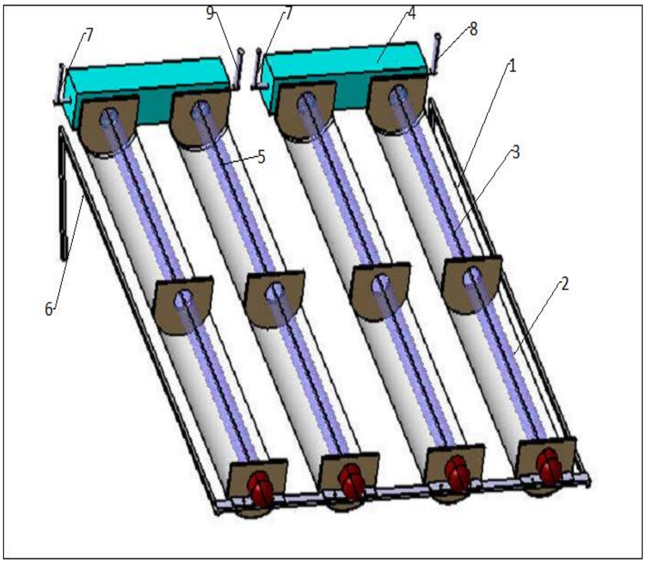


Fig. 5: Experimental set-up diagram.

1-Parabola trough collector 2-Evacuated heat pipe
3-Heat pipe contains nanofluid 4-Manifold
5- Heat pipe contains water, 6-Stand, 7-inlet, and 8-outlet for Nanofluid, 9-outlet for water

Evacuated tube Heat pipe collector dimensions:

Gross Dimensions:
- Length: 1.8 m
- Width: 0.8 m
- Depth: 0.12 m

Evacuated Glass tube Dimension:
- Tube length: 1.75 m
- Outside diameter of outer tube: 0.058 m
- Inside diameter of outer tube: 0.052 m
- Outside diameter of Inner tube: 0.049 m
- Inside diameter of Inner tube: 0.045 m
- Total No. of tubes 2 for each collector

TPCT Heat Pipe:
- Material: Copper
- Outer Diameter of Condenser section: 0.014 m
- Outer Diameter of Evaporator section: 0.008 m
- Length of condenser section: 0.057 m
- Length of Evaporator section: 1.62 m
- Total Length of Heat Pipe: 1.677 m
- Heat pipe thickness: 0.001 m

Volume of one heat pipe: $5.225*10^{-5}$ $m^3$
Collector effective area: 0.031 $m^3$
Working Fluid:
- Collector No.1: Distilled Water
- Collector No.1: $Al_2O_3$ Nanofluid


Fig. 6: Experimental set-upPhotograph

### *F. Test Methodology:*

Experimentation is carried out by placing collector facing towards south in May 2016. The effect of the tilt angle and mass flow rate on the collector efficiency will be calculated. The efficiency numerical values of nanofluid and conventional fluid water are to be compared. Four temperature sensors used to calculate the fluid temperature at the inlet and outlet of the solar collector for ETC containing four TPCT with functioning fluid as water and four TPCT with functioning fluid as nanofluid. The ambient temperature is to be measured by a thermometer. The total emissions are to be calculated with the help of emission Pyranometer.

The cold water to be frenzied will be kept in the tank. The water will be passed to the inlet of the manifold through the condenser unit of the evacuated tube solar collector. Set up will have mechanism to vary the tilt angle of the collectors. The performance will be carried out during the day from 11:00 a.m. to 5:00 p.m. Readings will be recorded at half hour break. The strength of solar emission will be measured by using Pyranometer. The inlet and outlet water temperature from each the collectors with ambient air temperature will be measured using RTDs.

During the analysis, each of the solar collectors were arranged in tilted position facing South and tested in outdoor conditions of pune, india (latitude 18.52°N and longitude 73.85°E). Analyses were carried out throughout the day from 10:00am to 4:00pm and numerical data of solar intensity ($I_s$) with different temperatures were recorded at each half hour interval. Different temperatures observed such as ambient air temperature ($T_a$), inlet water temperature ($T_i$), outlet water temperature for collector with water and nanofluid as working fluid ($T_o$, w and $T_o$, n resp.).It should be noted that each of these readings were found for a permanent mass flow rate. Experiments were carried out throughout the day for various tilt angles, namely 25°,30°, and 35°for a different mass flow rate 5lph, 10lph, 15lph,

 

### G. Formulae Used:

The thermal performance of the evacuated tube heat pipe solar collector coupled with parabolic through collector can be estimated by the solar collector efficiency factor η, which can be represented as the ratio of the net heat gain to the solar radiation energy based on diffuse reflection area of solar collector .

The rate of thermal energy input ($Q_{in}$), the rate of thermal energy gain ($Q_g$) and the instantaneous efficiency (η) of each collector is calculated as below:

$Q_{in} = I_t$.

Where, $Ac_{oll}$ is the area of each collector =0.632 $m^2$

Aperture area of the parabolic through collector is given by

$A_{coll} = L_P \times B_P$.

$L_P$ is the length of parabolic through collector (m)

$B_P$ is the breadth of parabolic through collector (m)

$Q_g = m\, C_p\, (T_o - T_i)$

Where m is mass flow rate and $C_p$ is specific heat of water

$\eta_{inst} = Q_g/Q_{in}$

Where $\eta_{inst}$ is the instantaneous efficiency.

## IV. Observation Table

Sample reading at flow rate 5 LPH on date 08/05/2016 to 10/05/2016

| Evacuated Tube Heat Pipe covered with PTC | | | |
|---|---|---|---|
| Time | Instantaneous collector Efficiency (%) | | |
| | Inclination Angle(°) | | |
| | 25 | 30 | 35 |
| 11.00 | 34.02 | 40.12 | 37.86 |
| 11.30 | 34.21 | 42.31 | 39.47 |
| 12.00 | 35.13 | 44.03 | 40.83 |
| 12.30 | 35.50 | 44.50 | 41.08 |
| 1.00 | 36.55 | 43.08 | 41.60 |
| 1.30 | 37.53 | 44.76 | 40.16 |
| 2.00 | 37.19 | 43.63 | 40.09 |
| 2.30 | 37.22 | 43.56 | 39.55 |
| 3.00 | 35.23 | 41.67 | 39.43 |
| 3.30 | 35.45 | 40.96 | 38.84 |
| 4.00 | 34.16 | 40.20 | 38.30 |
| 4.30 | 33.95 | 40.32 | 38.53 |
| 5.00 | 32.81 | 40.29 | 37.57 |

Table 1:

| Evacuated Tube Heat Pipe with Nanofluid covered with PTC | | | |
|---|---|---|---|
| Time | Instantaneous collector Efficiency() | | |
| | Inclination Angle(°) | | |
| | 25 | 30 | 35 |
| 11.00 | 40.78 | 49.50 | 43.85 |
| 11.30 | 40.52 | 49.26 | 46.95 |
| 12.00 | 42.16 | 52.64 | 48.58 |
| 12.30 | 42.03 | 52.11 | 49.07 |
| 1.00 | 42.48 | 52.56 | 49.40 |
| 1.30 | 43.00 | 52.76 | 48.84 |
| 2.00 | 42.17 | 51.66 | 48.28 |
| 2.30 | 42.05 | 51.65 | 46.29 |
| 3.00 | 42.02 | 50.36 | 45.96 |
| 3.30 | 41.08 | 50.27 | 43.89 |
| 4.00 | 41.12 | 49.76 | 43.84 |
| 4.30 | 40.27 | 49.45 | 43.82 |
| 5.00 | 40.53 | 49.07 | 43.17 |

Table 2:

## V. Results and Discussion

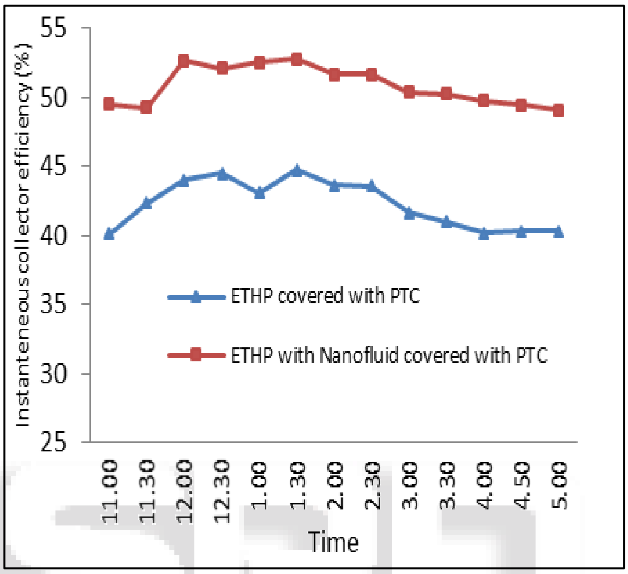


Fig. 7: Variation of instantaneous collector efficiency with time with $30^0$ inclination angle at 5 LPH

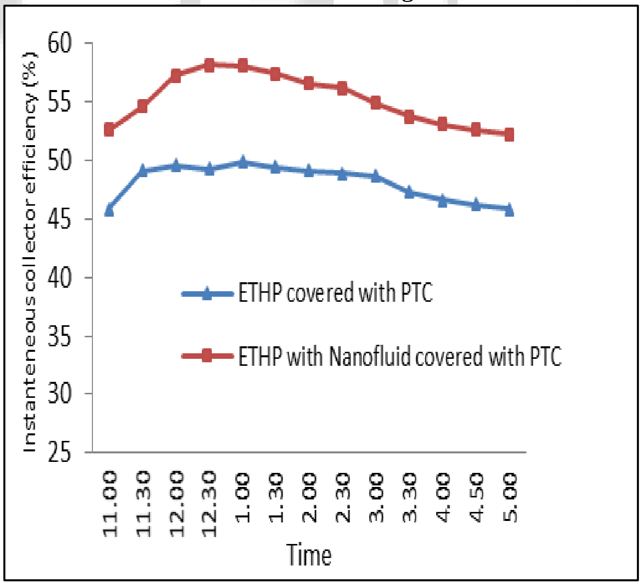


Fig. 8: Variation of instantaneous collector efficiency with time with $30^0$ inclination angle at 10 LPH

 

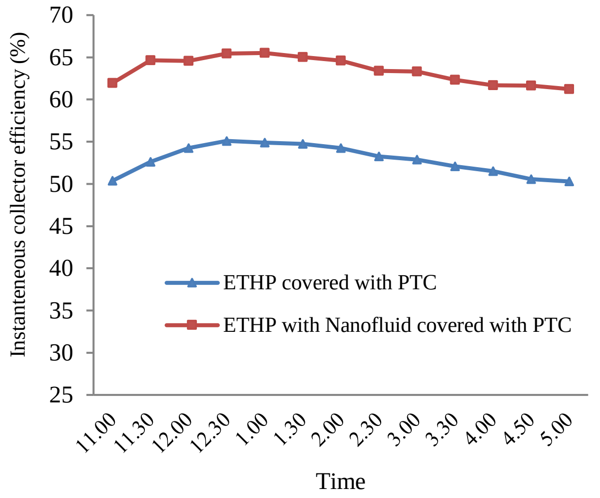


Fig. 9: Variation of instantaneous collector efficiency with time with $30^0$ inclination angle at 15 LPH

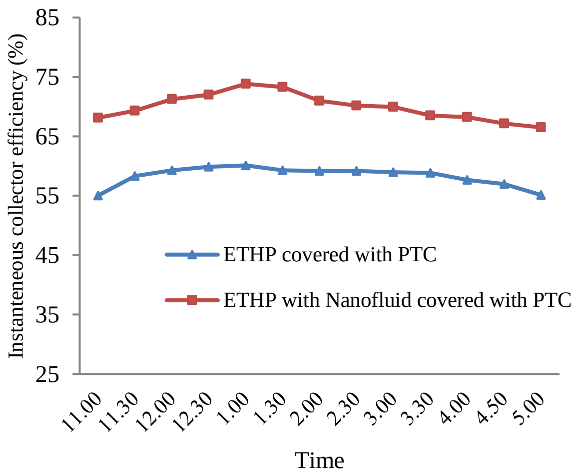


Fig. 10: Variation of instantaneous collector efficiency with time with $30^0$ inclination angle at 20 LPH

The above four graph shows that the variation in the instantaneous collector efficiency with time in case of evacuated tube heat pipe with and without nanofluid covered with parabolic trough collector. It shows that the instantaneous efficiency in case of ETHP with nanofluid covered with parabolic trough collector is 19-21 % more than the ETHP covered with parabolic trough collector

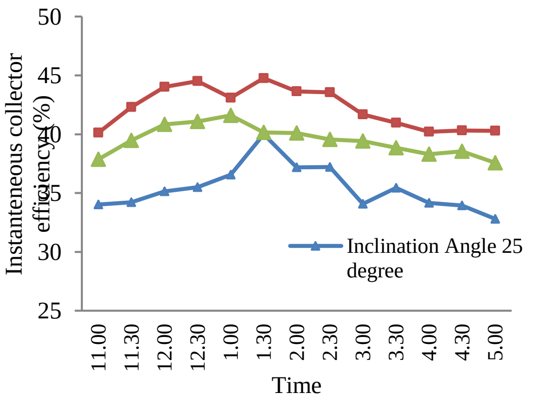


Fig. 11: Variation of instantaneous collector efficiency with time at 5 LPH with different inclination angle when Evacuated Tube Heat Pipe covered with PTC

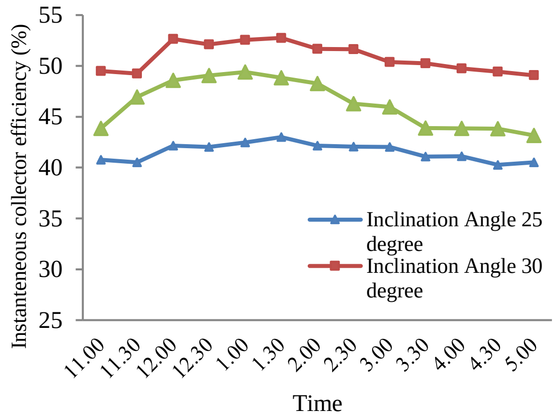


**Fig. 12:** Variation of instantaneous collector efficiency with time at 5 LPH with different inclination angle when Evacuated Tube Heat Pipe with Nanofluid covered with PTC

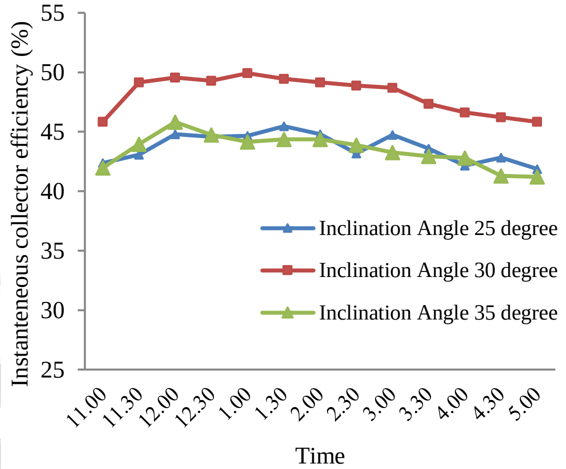


Fig. 13: Variation of instantaneous collector efficiency with time at 10 LPH with different inclination angle when Evacuated Tube Heat Pipe covered with PTC

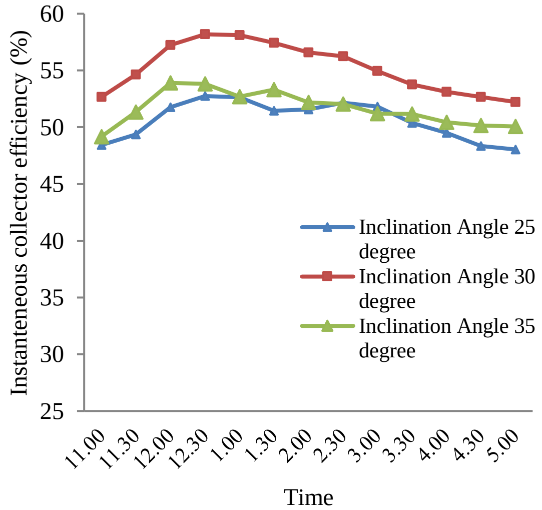


Fig. 14: Variation of instantaneous collector efficiency with time at 10 LPH with different inclination angle when Evacuated Tube Heat Pipe with Nanofluid covered with PTC

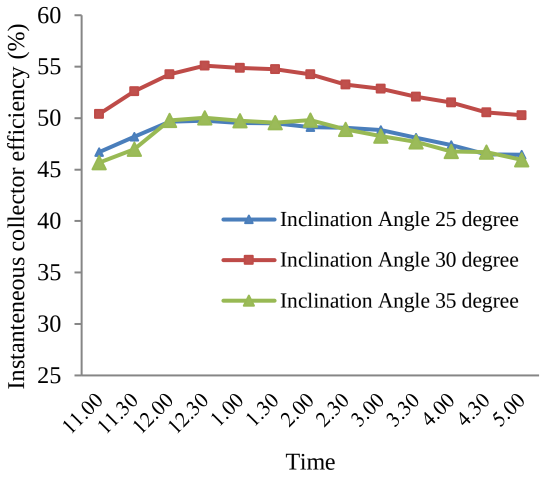


Fig. 15: Variation of instantaneous collector efficiency with time at 15 LPH with different inclination angle when Evacuated Tube Heat Pipe covered with PTC

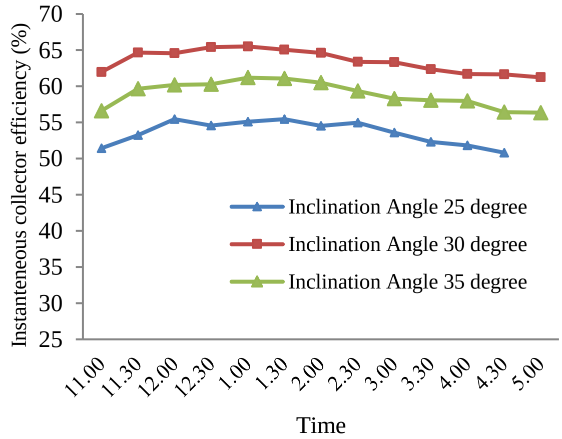


Fig. 16: Variation of instantaneous collector efficiency with time at 15 LPH with different inclination angle when Evacuated Tube Heat Pipe with Nanofluid covered with PTC

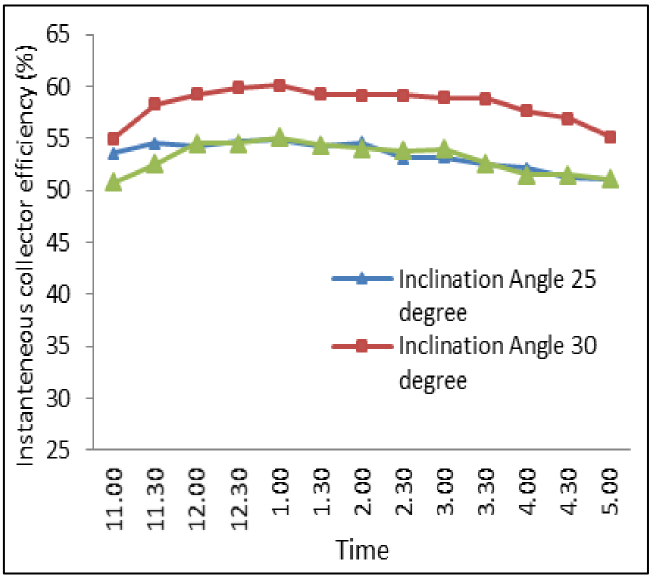


Fig. 17: Variation of instantaneous collector efficiency with time at 20 LPH with different inclination angle when Evacuated Tube Heat Pipe covered with PTC

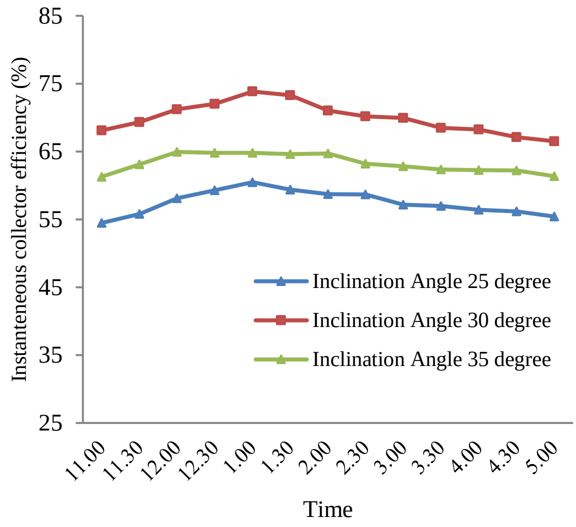


Fig. 18: Variation of instantaneous collector efficiency with time at 20 LPH with different inclination angle when Evacuated Tube Heat Pipe with Nanofluid covered with PTC

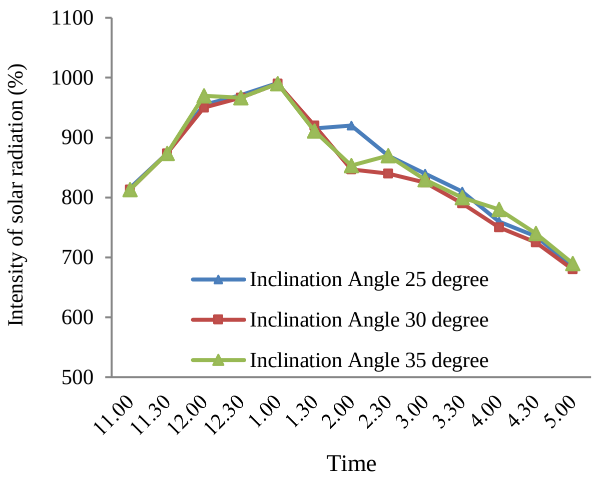


Fig. 19: Variation of intensity of solar radiation with time at 5 LPH with different inclination angle

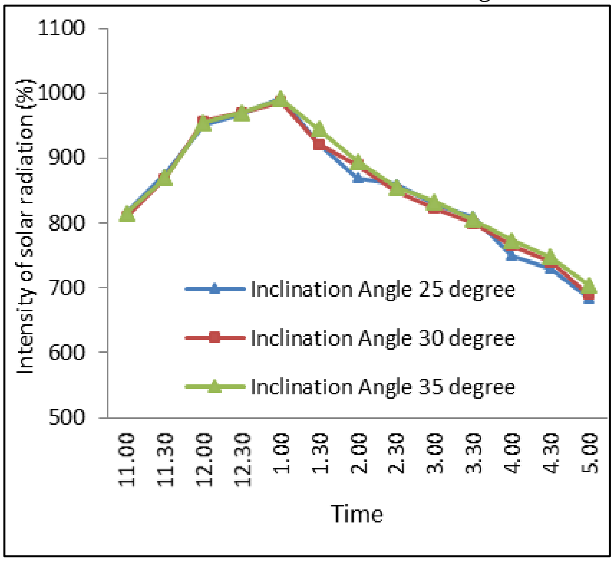


Fig. 20: Variation of intensity of solar radiation with time at 10 LPH with different inclination angle

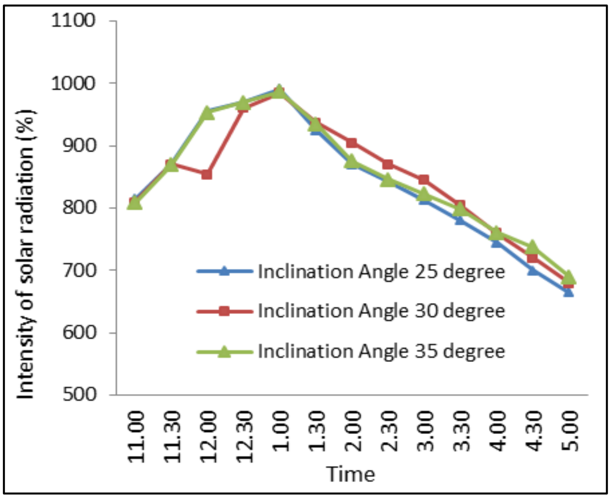


Fig. 21: Variation of intensity of solar radiation with time at 15 LPH with different inclination angle

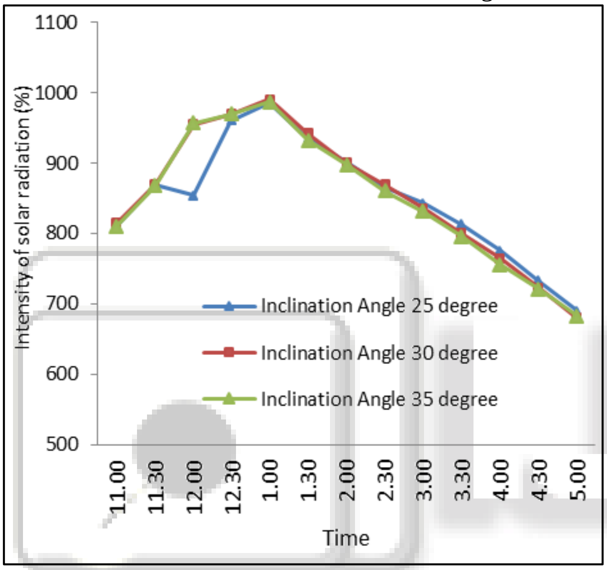


Fig. 22: Variation of intensity of solar radiation with time at 20 LPH with different inclination angle

From the above four graphs it is clear that the intensity of the solar radiation remained approximately same for the everyday of the experiment performance. The temperature varies in relation with the solar radiation intensity. The average solar radiation intensity considered for the energy calculations is 800 W/m$^2$.

## VI. Conclusions

An experimental study has been carried out to investigate the thermal performance of two phase closed thermosyphon evacuated tube solar collector with working fluid in heat pipe as conventional fluid water and $Al_2O_3$-$H_2O$ nanofluid coupled with parabolic trough concentrator .Following conclusions are made from experimental study and are detailed as below:

1) The thermal performance of solar collector with heat pipe containing nanofluid is better than that of conventional heat pipe collector. There is 19-21% rise in instantaneous collector efficiency due to nanofluid as a working fluid.
2) Experimental results also revealed that the collector tilt angle had crucial effects on thermal performance of evacuated tube collector. The optimum performance is obtained at 30° for both the collectors

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