THOMSON REUTERS ENDNOTE

[Mujawar* *et al.*, 5(12): December, 2016]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

THERMAL PERFORMANCE INVESTIGATION OF EVACUATED TUBE HEAT PIPE SOLAR COLLECTOR WITH NANOFLUID

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DOI: 10.5281/zenodo.221114

ABSTRACT

Solar energy, being abundant and widespread in its availability, makes it one of the most attractive sources of energies. Tapping this energy will not only help in bridging the gap between demand and supply of electricity but shall also save money in the long run. A Solar Water Heating System (SWHS) is a device that makes available the thermal energy of the incident solar radiation for use in various applications by heating the water. Solar energy is one of the cleaner forms of renewable energy resources. The conventional solar collector is a well-established technology with certain limitations. This has various applications such as water heating, space heating and cooling. However, the thermal efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical conventional solar evacuated tube collector. Recently usage of nanofluid, which is basically liquid- nanoparticles colloidal dispersion as a working fluid has been found to enhance evacuated tube heat pipe solar water heaters thermal efficiency.

The objective of this proposed work is to design and develop the heat pipe evacuated tube solar water heater which uses the circular heat pipes with their working fluid as CuO-H20 nanofluid. The project also aims to test the performance enhancement of nanofluid filled heat pipe ETC solar collector compared with conventional evacuated tube solar collector in forced convection mode. Both experimental results will be compared and interpreted accordingly.

KEYWORDS: Solar Collector, Evacuated tube Heat Pipe, Nanofluid.

INTRODUCTION

The solar energy is the most capable of the alternative energy sources. Due to increasing demand for energy and rising cost of fossil type fuels (i.e., gas or oil) solar energy is considered an attractive source of renewable energy that can be used for water hearing in both homes and industry. Heating water consumes nearly 20% of total energy consumption for an average family. Solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide most of hot water required by a family.

Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases.

HEAT PIPE

A heat pipe is an excellent heat conductor; one end of a heat pipe is the evaporation section, and the other end is the condensation section. When the evaporation section is heated, the liquid in the heat pipe evaporates rapidly. This vapor releases its heat at the condensation section, which has a small vapor pressure difference, and condenses back into liquid. The condensed liquid in the condensation section then flows back to the evaporation section along the inner wall of the heat pipe and undergoes endothermic evaporation in the evaporation section. The heat transfer of a heat pipe uses a working fluid that changes phases in a continuous endothermic and exothermic cycle, giving the heat pipe excellent heat transfer performance. Many researchers have used finned tubes, threaded tubes, sintered tubes, and grooved tubes to increase the contact area between the heat pipe and the internal working fluid, thus improving the heat pipe's thermal performance. Thus, replacing the traditional working fluid with a working fluid with a high heat transfer performance is worth considering.

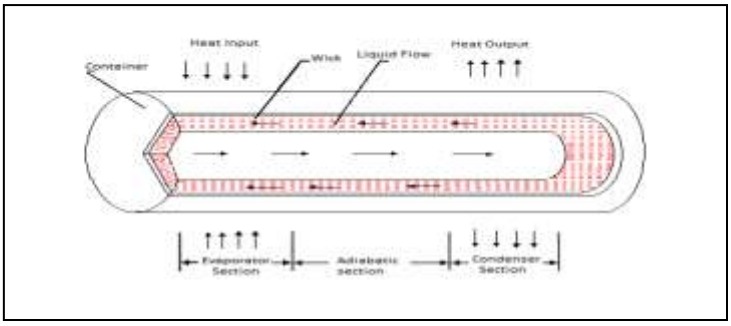

Fig.1- Construction and Operation of Heat Pipe

Reasons to Use Heat Pipe

1. Reduce cycle time
2. Eliminates hot spots
3. Reduce wastage
4. Improve product quality
5. Increase mould life
6. Eliminate core clogging
7. Cut mould and moulding cost
8. Upgrade old moulds
9. Use damaged moulds

Nanofluids

In the present work, nanofluids are prepared by two step method. Copper oxide (CuO) nanopowder are purchased from Sisco Laboratory, Mumbai. The average particle size (APS) of CuO nanopowder is 40nm. Both these nanopowder were mixed in calculated proportion in 500ml of distilled water. We added 32gm of CuO (1% by volume) in 500ml of distilled water. Then the nanofluid was stirred well for proper mixing of nanopowder. The prepared nanofluid was then delivered to Golden Star Technical Services Pvt. Ltd., Pune, the manufacturers of heat pipe, for charging the heat pipe with nanofluid.

Fig.2- CuO Nanopowder

Fig.3- CuO/Water Nanofluid

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EXPERIMENTAL SYSTEM

To study the thermal performance and enhancement of heat transfer rate of evacuated tube heat pipe solar collector using nanofluid, it is necessary to develop the system containing two evacuated tube heat pipe flat plate solar collector, one containing conventional fluid water and the other containing nanofluid along with other accessories and measuring instruments required for measuring required parameters to determine performance characteristics of both these collectors.

Objectives

(a) To study the effect on heat transfer rate and efficiency of evacuated tube heat pipe flat plate collector using nanofluid. The effects are to be compared with evacuated tube heat pipe containing conventional working fluid water.
(b) To study the effect of orientation of collector on its performance that is performance of solar collectors at various tilt angles.
(c) To study the effect of mass flow rate of water on its performance that is performance of evacuated tube solar collectors.

Description of system

The prepared system assists in determining the thermal performance of evacuated tube heat pipe flat plate solar collector with conventional fluid water and nanofluid. Hence the major component of the system is flat plate heat pipe solar collector with evacuated tube heat pipe.

The cold water to be heated is stored in the tank. The water is then passed to the inlet of the condenser section guide of both the evacuated tube flat plate solar collector. The guide is allowed to fill completely by closing the flow control valve connected after the outlet of the condenser section guide of both the evacuated tube flat plate solar collector. Once the guide is filled completely, flow control valve is opened to adjust the mass flow rate of the water by noting the time required to fill calibrated cylinder to volume calculated. Thus the mass flow rate of water is set. The outlet of condenser section guide of collector is connected to hot water storage tank. Set up has mechanism to vary the orientation that is the tilt angle of the collectors as discussed above to study its effect on performance of the system. The testing is carried out throughout the day from 10a.m to 4p.m. Readings are recorded at half an hour interval. The intensity of solar radiation is measured by using pyranometer. The inlet and outlet water temperature from both the collectors along with ambient air temperature are measured using RTD's.

Fig.4- Overall system photo

1. Water Storage Tank, 2.Cold Water Inlet of Evacuated Tube TPCT containing water, 3.Hot Water Outlet of Evacuated Tube TPCT containing water, 4.Cold Water Inlet of Evacuated Tube TPCT containing CuO-H2O Nanofluid, 5.Hot Water Outlet of Evacuated Tube TPCT containing CuO-H2O Nanofluid, 6. Evacuated Tube TPCT Collector containing water, 7. Evacuated Tube TPCT Collector containing Nanofluid, 8.RTD with multi channel temperature sensor.

Evacuated Tube heat pipe collector

System consists of two evacuated tubes flat plate collectors, one having water as working fluid in wickless heat pipe and other having CuO-BN/water nanofluid in the wickless heat pipe. Each collector consists of four evacuated tubes and each evacuated tubes contains one heat pipe filled with working fluid. The design parameters of various components evacuated tubes heat pipe collectors are summarized below. Evacuated tubes heat pipes were made of copper tubes, in order to enhance the ability to absorb the solar radiation.

Fig.5- Glass wool as wick material and Condenser section guide

Fig.6- Heat Pipe, Evacuated Tube, Aluminium strip and Insulated Manifold of condenser section guide.

RESULTS AND DISCUSSION

During the testing procedure, both the solar collectors were held in tilted position facing South and tested in outdoor conditions of Pune, India (latitude 18.52°N and longitude 73.85°E). Experiments were carried out throughout the day from 11:00am to 5:00pm and values of solar intensity (It) as well as different temperatures were recorded at each one hour interval. Different temperatures measured include ambient air temperature (Ta), inlet water temperature (Ti), outlet water temperature for collector with water and nanofluid as working fluid (To,w and To,n resp.). It should be noted that each of these readings were obtained for a variable mass flow rate. Tests were carried out throughout the day for various tilt angles, namely, 25°, 30° and 35° and at flow rate 5 LPH, 10 LPH, 15 LPH and 20 LPH.

Comparison of Efficiency at Water and nanofluid

Experimentations were carried out throughout the day from 11.00a.m. to 5.00 p.m. for various tilt angles, namely 25°, 30° and 35° and at flow rate 5 LPH, 10 LPH, 15 LPH and 20 LPH. Efficiency of Evacuated tube heat pipe with water and nanofluid is calculated and compared at following graphical presentation.

Table 1- Comparison of Efficiency at Water and nanofluid at 25° & 5 LPH

Inclination angle 25° and flow rate 5 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	34.02	40.78
11.30	34.21	40.52
12.00	35.13	42.16
12.30	35.50	42.03

ISSN: 2277-9655
Impact Factor: 4.116
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1.00	36.55	42.48
1.30	39.99	43.00
2.00	37.19	42.17
2.30	37.22	42.05
3.00	34.07	42.02
3.30	35.45	41.08
4.00	34.16	41.12
4.30	33.95	40.27
5.00	32.81	40.53

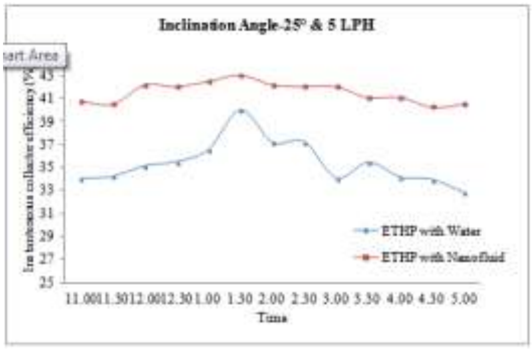

Fig 7 Comparison of Efficiency at Water and nanofluid at 25° & 5 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid is more than that of water, and it shows higher value at 1.30 p.m. maximum value of efficiency achieved by water and nanofluid are 39.99% and 43.0% respectively.

Table 2- Comparison of Efficiency at Water and nanofluid at 25° & 10 LPH

Inclination angle 25° and flow rate 10 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	42.36	48.44
11.30	43.07	49.38
12.00	44.80	51.76
12.30	44.59	52.75
1.00	44.67	52.64
1.30	45.46	51.45
2.00	44.80	51.56
2.30	43.18	52.16
3.00	44.74	51.83
3.30	43.58	50.39
4.00	42.16	49.52
4.30	42.81	48.36
5.00	41.87	48.04

ISSN: 2277-9655
Impact Factor: 4.116
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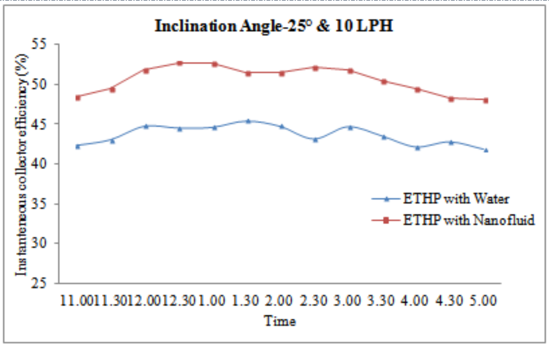

Fig 8 Comparison of Efficiency at Water and nanofluid at 25° & 10 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 25° inclination angle and 10 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 45.46% and 52.75% respectively.

Table 3- Comparison of Efficiency at Water and nanofluid at 25° & 15 LPH

Inclination angle 25° and flow rate 15 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	46.70	51.43
11.30	48.18	53.25
12.00	49.67	55.44
12.30	49.75	54.59
1.00	49.53	55.10
1.30	49.49	55.45
2.00	49.13	54.52
2.30	49.07	54.96
3.00	48.85	53.60
3.30	48.08	52.33
4.00	47.38	51.82
4.30	46.49	50.82
5.00	46.45	50.59

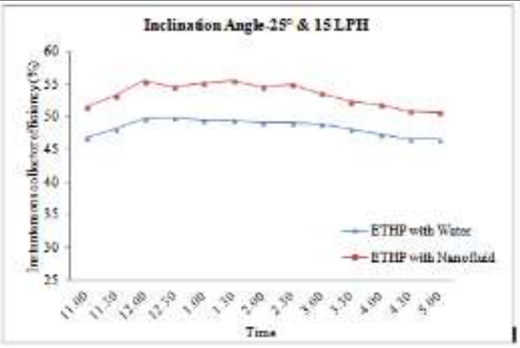

Fig 9 Comparison of Efficiency at Water and nanofluid at 25° & 15 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 25° inclination angle and 15 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 49.75% and 55.45% respectively.

Table 4- Comparison of Efficiency at Water and nanofluid at 25° & 20 LPH

Inclination angle 25° and flow rate 20 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	53.57	54.47
11.30	54.52	55.79
12.00	54.25	58.13
12.30	54.72	59.31
1.00	54.88	60.48
1.30	54.27	59.38
2.00	54.63	58.70
2.30	53.14	58.66
3.00	53.21	57.14
3.30	52.46	56.99
4.00	52.12	56.39
4.30	51.17	56.18
5.00	51.16	55.42

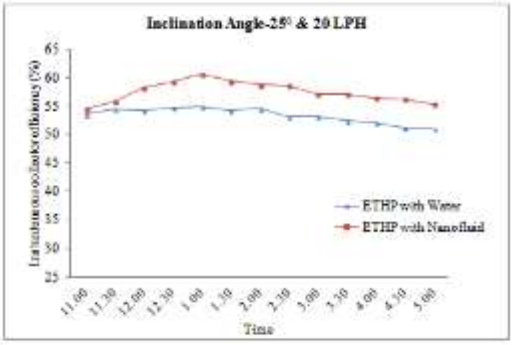

Fig 10 Comparison of Efficiency at Water and nanofluid at 25° & 20 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 25° inclination angle and 20 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 54.88% and 60.48% respectively.

Table 5- Comparison of Efficiency at Water and nanofluid at 30° & 5 LPH

Inclination angle 30° and flow rate 5 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	40.12	49.50
11.30	42.31	49.26
12.00	44.03	52.64
12.30	44.50	52.11
1.00	43.08	52.56
1.30	44.76	52.76
2.00	43.63	51.66
2.30	43.56	51.65
3.00	41.67	50.36

3.30	40.96	50.27
4.00	40.20	49.76
4.30	40.32	49.45
5.00	40.29	49.07

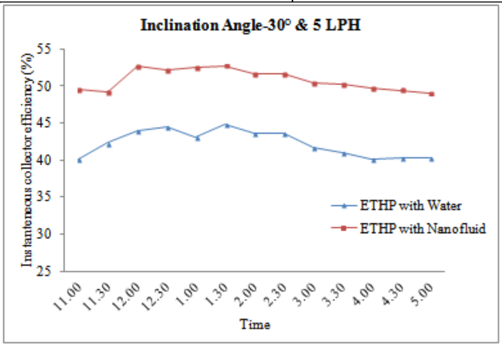

Fig 11 Comparison of Efficiency at Water and nanofluid at 30° & 5 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 30° inclination angle and 05 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 44.76% and 52.76% respectively.

Table 6- Comparison of Efficiency at Water and nanofluid at 30° & 10 LPH

Inclination angle 30° and flow rate 10 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	45.85	52.66
11.30	49.14	54.65
12.00	49.57	57.25
12.30	49.28	58.19
1.00	49.92	58.12
1.30	49.45	57.43
2.00	49.16	56.60
2.30	48.88	56.24
3.00	48.70	54.95
3.30	47.34	53.78
4.00	46.62	53.11
4.30	46.21	52.67
5.00	45.83	52.22

Fig 12 Comparison of Efficiency at Water and nanofluid at 30° & 10 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 30° inclination angle and 10 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 49.92% and 58.19% respectively.

Table 7- Comparison of Efficiency at Water and nanofluid at 30° & 15 LPH

Inclination angle 30° and flow rate 15 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	50.39	61.96
11.30	52.62	64.67
12.00	54.25	64.59
12.30	55.10	65.43
1.00	54.88	65.51
1.30	54.74	65.04
2.00	54.24	64.60
2.30	53.25	63.40
3.00	52.87	63.31
3.30	52.07	62.35
4.00	51.53	61.69
4.30	50.56	61.67
5.00	50.29	61.24

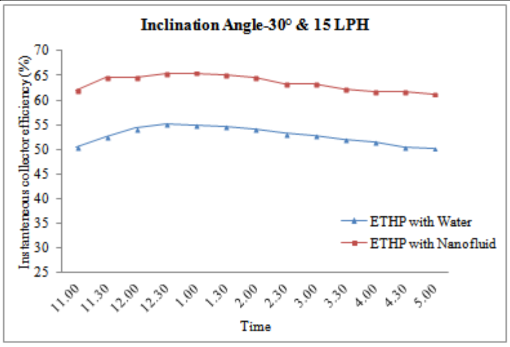

Fig 13 Comparison of Efficiency at Water and nanofluid at 30° & 15 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 30° inclination angle and 15 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 55.10% and 65.51% respectively.

Table 8- Comparison of Efficiency at Water and nanofluid at 30° & 20 LPH

Inclination angle 30° and flow rate 20 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	55.04	68.13
11.30	58.33	69.31
12.00	59.29	71.23
12.30	59.89	72.02
1.00	60.11	73.84
1.30	59.27	73.31
2.00	59.18	71.01

2.30	59.17	70.16
3.00	58.94	69.93
3.30	58.83	68.48
4.00	57.68	68.25
4.30	56.96	67.13
5.00	55.16	66.51

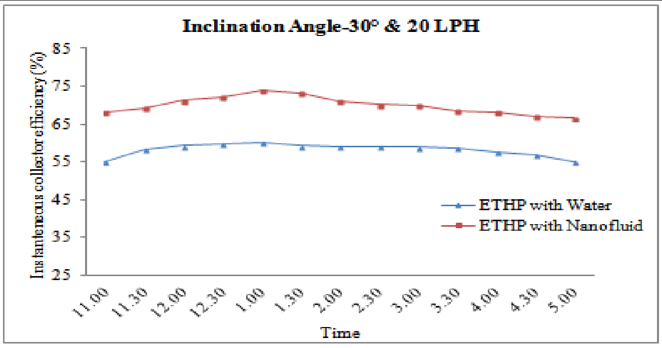

Fig 14 Comparison of Efficiency at Water and nanofluid at 30° & 20 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 30° inclination angle and 20 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 60.11% and 73.84% respectively.

Table 9- Comparison of Efficiency at Water and nanofluid at 35° & 5 LPH

Inclination angle 35° and flow rate 5 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	37.86	43.85
11.30	39.47	46.95
12.00	40.83	48.58
12.30	41.08	49.07
1.00	41.60	49.40
1.30	40.16	48.84
2.00	40.09	48.28
2.30	39.55	46.29
3.00	39.43	45.96
3.30	38.84	43.89
4.00	38.30	43.84
4.30	38.53	43.82
5.00	37.57	43.17

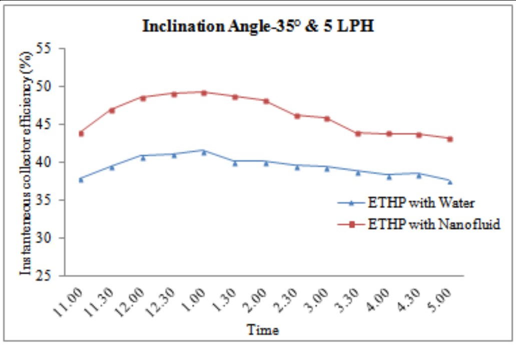

Fig 15 Comparison of Efficiency at Water and nanofluid at 35° & 5 LPH

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 35° inclination angle and 05 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 41.60% and 49.40% respectively.

Table 10- Comparison of Efficiency at Water and nanofluid at 35° & 10 LPH

Inclination angle 35° and flow rate 10 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	41.96	49.18
11.30	43.96	51.35
12.00	45.82	53.90
12.30	44.73	53.83
1.00	44.15	52.69
1.30	44.36	53.31
2.00	44.37	52.18
2.30	43.87	52.04
3.00	43.26	51.20
3.30	42.94	51.16
4.00	42.81	50.42
4.30	41.29	50.14
5.00	41.20	50.07

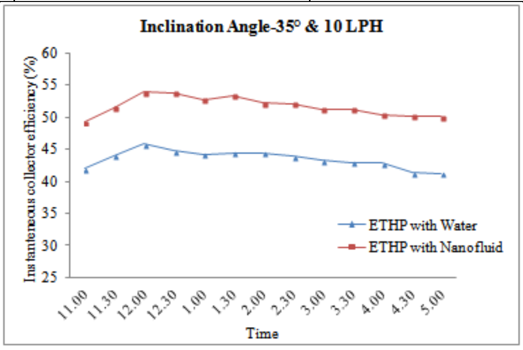

Fig 16 Comparison of Efficiency at Water and nanofluid at 35° & 10 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 35° inclination angle and 10 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 44.73% and 53.90% respectively.

Table 11- Comparison of Efficiency at Water and nanofluid at 35° & 15 LPH

Inclination angle 35° and flow rate 15 LPH		
Time	Instantaneous collector Efficiency (%)	
	Evacuated Tube Heat Pipe with Water	Evacuated Tube Heat Pipe with Nanofluid
11.00	45.68	56.59
11.30	46.97	59.66
12.00	49.77	60.19
12.30	50.04	60.27
1.00	49.74	61.19
1.30	49.55	61.05
2.00	49.80	60.51
2.30	48.90	59.33
3.00	48.25	58.31

3.30	47.69	58.06
4.00	46.75	57.98
4.30	46.71	56.43
5.00	45.96	56.35

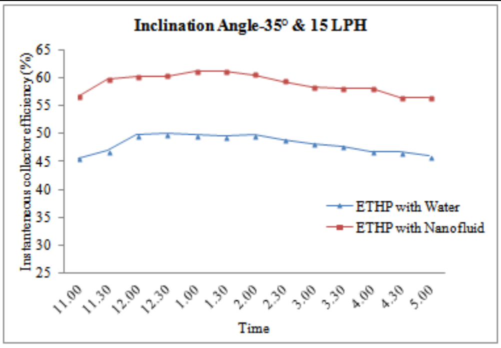

Fig 17 Comparison of Efficiency at Water and nanofluid at 35° & 15 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 35° inclination angle and 15 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 49.80% and 61.19% respectively.

Table 12- Comparison of Efficiency at Water and nanofluid at 35° & 20 LPH

Inclination angle 35° and flow rate 20 LPH		
Time	**Instantaneous collector Efficiency (%)**	
	Evacuated Tube Heat Pipe with Water	**Evacuated Tube Heat Pipe with Nanofluid**
11.00	50.84	61.28
11.30	52.53	63.12
12.00	54.56	64.93
12.30	54.59	64.82
1.00	55.14	64.82
1.30	54.39	64.63
2.00	54.05	64.70
2.30	53.81	63.21
3.00	53.98	62.83
3.30	52.66	62.36
4.00	51.56	62.26
4.30	51.51	62.22
5.00	51.14	61.37

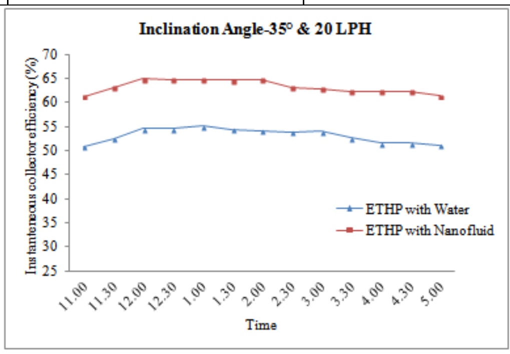

Fig 18 Comparison of Efficiency at Water and nanofluid at 35° & 20 LPH

Above graph shows that efficiency of Evacuated tube heat pipe with nanofluid at 35° inclination angle and 20 LPH, Graph shows that efficiency nanofluid is more than efficiency of water, and it shows maximum value of efficiency achieved by water and nanofluid are 55.14% and 64.93% respectively.

CONCLUSION

An experimental study has been carried out to investigate the thermal performance of Evacuated tube heat pipe solar collector by using different working fluids for heat pipes such as: pure water, CuO/water nanofluid. Following conclusions are made from the experimental study and is detailed below:

- The thermal performance of wickless evacuated tube heat pipe solar collector is higher by using CuO/water nanofluid followed by conventional working fluid pure water.
- The solar collector instantaneous efficiency is found to increase by increasing the tilt angle from 20° to 30° for cases, pure water and CuO/water nanofluid. While, the heat transfer rate decreases by increasing the tilt angle beyond 30° to 35°.
- The optimum performance is obtained at 30° for both the collectors.
- The average increase in instantaneous efficiency by using nanofluid at various tilt angles varied from 10% to 15%.
- The solar collector instantaneous efficiency is found to increase by increasing the flow rate from 5 LPH to 20 LPH for cases, pure water and CuO/water nanofluid.
- The solar collector instantaneous efficiency is found to be increase by using CuO/Water nanofluid as a working fluid as compare to pure water.

SCOPE FOR FUTURE WORK

There can be many promising techniques and research areas for enhancing thermal performance of solar water heating systems. Improvement in current technique by experimentations may also prove beneficial. Some of the possible improvements and future developments are stated below:

- Innovation of new heat transfer enhancement techniques.
- Use of new efficient, minimum global warming potential and eco friendly fluids and refrigerants.
- Develop Mathematical model considering multiple factors so that experimental investigation can be minimized.
- Develops methods of producing non agglomerating Nanoparticles measuring < 10 nm in size and preventing oxidations of metallic nanoparticles. One of the challenges is to improve dispersion stability without affecting the thermal properties.
- Measure and predict the transport properties (thermal conductivity and viscosity) of nanofluid.
- Develop nanofluids that are environmental friendly and wear resistant.
- Optimization of operating parameters like orientation of the collector, fluid flow rate can also increase the efficiency and it can be applied to conventional FPC.
- Using of tracking system for orientation of collector.
- Cost-effectiveness and the payback period for a solar domestic water heating system that depends on the design, installation and consumption of energy can be investigated in future work.

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ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

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