COMPARISON OF THERMAL PERFORMANCE OF CIRCULAR AND ELLIPTICAL FLAT PLATE TPCT SOLAR WATER HEATER WITH CuO-H_2O NANOFLUID

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ABSTRACT

The two phase gravity assisted closed thermosiphon (TPGAT) are highly efficient heat transfer devices which operate by re-circulating a fluid within a closed hollow tube. This device makes use of high heat transfer coefficients available during phase change of the working fluid and this facilitates a larger amount of heat transfer in a compact device. The recent pioneering advancement in the use of nanofluids as the working fluid in the two phase gravity assisted thermosiphon (TPGAT) significantly improves the heat transfer performance.
In this study the thermal performance of wickless elliptical heat pipe (TPCT) solar collectors is investigated by using CuO-H_2O nanofluid. The effect of different mass flow rates of water at constant tilt angle on collector efficiency is investigated. This results are compared with wickless circular heat pipe solar collectors. It is found that as compare to circular heat pipe, elliptical heat pipe collector is having higher collector efficiency at sa me collector angle. Also, as mass flow rate increases, efficiency also increases.

Keyword *TPCT, Nanofluids, Thermosyphon, Solar Intensity and Elliptical heat pipe*

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1. INTRODUCTION

Solar water heater is the most popular means of solar energy utilization because of technological feasibility and economic attraction compared with other kinds of solar energy utilization. The system can supply hot water at 50^{o}C to 80^{o}C which can be used for both domestic and industrial purposes. Heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. [1]
In a conventional solar collector, tubes containing water as working fluid are attached to the absorber plate. The drawbacks associated with conventional solar collectors include the pump and its power requirement, more space to obtain the natural circulation of working fluid, night cooling due to reverse flow of cooled water, pipe corrosion and limited heat carrying capacity of working fluid. Heat pipes are found to provide an alternative solution to the above problems. The recent pioneering advancement in the use of nanofluids as the working fluid in the two phase gravity assisted thermosyphon (TPGAT) significantly improved the heat transfer performance.
In this study the thermal performance of wickless elliptical heat pipe (TPCT) solar collectors is to be investigated by using CuO-H2O nanofluid. The effect of mass flow rate of water at constant tilt angle on collector efficiency can be investigated. The comparison can be made between the TPCT with circular and elliptical cross section solar collector.

1.1 Literature Review

Gabriela Huminic [1] This paper presents an experimental investigation regarding the use of solid nanoparticles added to water as a working fluid. Tests were made on a thermosyphon heat pipe. The experiment was performed in order to measure the temperature distribution and compare the heat transfer rate of the thermosyphon heat pipe with nanofluid and with DI-water. In this work, an experimental investigation employing iron oxide nanoparticles is performed in order to study the thermal performance of a thermosyphon heat pipe. The iron oxide nanostructures were obtained by the laser pyrolysis technique. Three cases, for iron oxide nanoparticles in water with volume concentrations 0%, 2%, and 5.3% are considered. The results are finally compared with the thermal performance of the thermosyphon heat pipe filled with DI-water. This paper deals with the thermal enhancement of the thermosyphon heat pipe performance, using iron oxide nanofluid as the working fluid. In the present case, the DI-water with diluted iron oxide nanoparticles in thermosyphon heat pipes was experimentally tested.

Noie S. H. [2] In this study the thermal performance of three different wickless heat pipe solar collectors were investigated by using pure water, water surfactant and CNT-water nanofluid for different coolant mass flow rates and tilt angles (200, 31.50, 400, 500 and 600). First collector uses only pure water, the second one utilizes CNT nanoparticle of diameter 10-12 nm and 0.1-10 µm length with water as a base fluid. While the third collector uses water with 150 ppm 2-ethyl-hexanol as coolant for the investigation. Experiments were carried out for the three collectors under the same experimental conditions. It is observed that the performance of the solar collector that uses 2-ethyl-hexanol surfactant with water as coolant is better compared to solar collectors that utilize pure water and CNT/water nanofluid.

M. Kannan [3] performed an experiment to measure the temperature distribution and compare the heat transfer rate of thermosyphon with diluted nanofluid (with 0%, 2% and 5.3% concentration) in DI-water. The thermosyphon was a copper tube with internal and external diameter of 13.6 mm and 15 mm respectively. The overall length of thermosyphon was 2000 mm (evaporator length-850mm, condenser length-850mm, adiabatic section-300). They obtained the results that the addition of 5.3% (by volume) of iron oxide nanoparticles in water improved th ermal performance of thermosyphons. This paper deals with the thermal enhancement of the thermosyphon heat pipe performance, using iron oxide – nanofluid as the working fluid.

Hussein [4] studied the performance of wickless heat pipe flat plate solar collector having different cross section geometries and filling ratios. They investigated the water filling ratio to the flooding limit of the elliptical cross section and referred that it is very close to 35% for circular section so that an elliptical cross s ection significantly improves the performance of wickless heat pipe flat plate solar collectors at low water filling ratios.
Theoretical and experimental studies on wickless heat pipe solar collectors for water heating have been reported Hussein. These studies use cross flow condenser heat exchanger. Distilled water was used as working fluid in heat pipes. The performance of wickless heat pipe solar collector was found to be sensitive to cooling water inlet temperature, absorber plate material and thickness and condenser length. It was also possible to know the optimum cooling water mass flow rate for best efficiency of the system.

M. A. El-Nasr[5] The purpose of the study was to obtain a comprehensive understanding of the thermal performance of a wickless heat pipe solar collector on the basis of heat-transfer analysis using R-11, acetone, or water as a working fluid at different charging pressures. Also the effect of angle of inclination and the effect of liquid fill on the performance of the wickless heat pipe solar collector were studied. The experimental results show that the maximum efficiency occurs at 45° tilt angle. The optimum liquid fill in the wickless heat pipe with solar applications is 0.7, where the temperature flattening phenomenon occurred in the collector. The most suitable working fluid for wider temperature flattening is R-11 compared with acetone or water. The predicted theoretical results, using R-11, were compared with the experimental data and proved the validity of the theoretical analysis.

1.2 Concluding Remark from literature review

The final remarks made from the literature review reveals that there is a large scope for investigating the thermal performance of TPCT solar water heater along with copper oxide as a nanofluid at various parameters which are summaries as,

1. Number of experimental studies have been reported to investigate the effects of heat pipes for performance evaluation in solar water heating system.
2. Researcher works on use of heat pipe and various base fluids for enhancement in heat transfer of solar collector.
3. Also number of research is performed for various mass flow rates. From literature survey it is found that as mass flow rate increases collector efficiency also increases.
4. Most of the researcher have used copper oxide as a nanofluid due to its higher thermal conductivity compared with other nanofluids. Also the most commonly used material for heat pipe is Copper.

From above it is clear that number of experimental studies have been reported for nanofluids for enhancement of heat transfer. However, all these research work is performed on circular shaped TPCT solar water heater. The purpose of this project is to focus on Elliptical shaped TPCT solar water heater due to increased surface area as compared to circular heat pipe. However, there is need to study experimentally the combine effect of elliptical heat pipe and copper oxide nanofluid. Keeping this aspect in the mind copper oxide nanofluid with water as a base fluid and elliptical pipes are been selected for this work.

1.3 Objectives of the Study

1. To analyze the effect on heat transfer rate and efficiency of elliptical shape wickless heat pipe flat plate collector using CuO/H2O nanofluid. The effects are to be compared with circular shape wickless heat pipe containing nanofluid.
2. To evaluate the effect of mass flow rate of water on thermal performance of elliptical and circular cross section heat pipe solar collector with nanofluid as working fluid in TPCT at collector angle of 20^0.
3. Comparison between the thermal performances of wickless heat pipe solar collector with particular attention towards shape of the TPCT.

2. EXPERIMENTAL METHOD

To study the thermal performance and enhancement of heat transfer rate of elliptical shaped heat pipe flat plate solar collector using nanofluid it is necessary to develop the system containing two heat pipe flat plate solar collector, one with circular shape and the other with elliptical shape both containing nanofluid. Also along with other accessories and measuring instruments required for measuring required parameters to determine performance characteristics of both collectors.

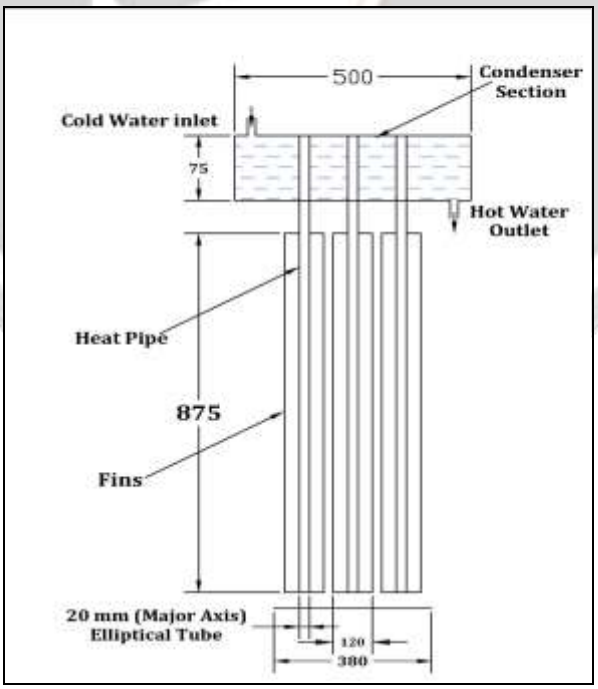

Fig. 2.1 Layout of Elliptical TPCT collector

2.1 Summary of flat plate collector dimensions

Collector No. 1: Elliptical TPCT collector with nanofluid

a) Gross Dimensions

Length: 0.875 m
Width: 0.380 m
Depth: 0.086 m

b) Transparent Cover
Material: White Glass

c) Absorber Plate
Material: Copper
Length: 0.810 m
Pitch Distance: 0.1 m
Thickness: 0.001 m
Coating: Black

d) Wickless Heat Pipes
Material: Copper
Major axis Diameter: 0.02 m
Inner Diameter: 0.019 m
Minor axis diameter: 0.01 m
Inner diameter: 0.009 m
Evaporator Length: 0.875 m
Condenser Length: 0.075 m
Adiabatic Length: 0.050 m
Total Length: 1m
No. of Heat Pipes in each collector: 3
Collector No.1: Elliptical heat pipe with nanofluid

e) Insulation
Material: Glass wool, Asbestos
Thickness: 0.025m
Position: Back and sides

f) Box Material
Frame: Aluminum

Collector No.2: Circular heat pipe with nanofluid
Diameter of heat pipe= 16 mm
All other parameters are same as that of collector 1.

2.2 Description of system

The prepared system assists in determining the thermal performance of wickless heat pipe flat plate solar collector with nanofluid. Hence the major component of the system is flat plate heat pipe solar collector with wickless 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 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 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 to study its effect on performance of the system. The testing is carried out throughout the day from 10 a. m to 4 p.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. Then the observations are tabulated for further analysis

2.3 Properties of CuO nanofluid

The properties of CuO, nanofluids are different from the properties of conventional heat transfer fluids. For determining the thermal performance of heat pipe various thermal properties of the fluid are required to be known. The properties of water are well known from the steam tables or from the literature different relations proposed by many researchers are used for finding the properties nanofluid.

Table 2.1 Properties of CuO nanoparticle

Chemical Formula	Alpha CuO
Colour	Black
Morphological	Spherical
Specific surface area, m^2/g	90-160
Density, g/cc	3.69
Average particle size, nm	40-60
Thermal Conductivity, W/mK	60

Detail procedure for determining few properties of copper oxide nanofluid are discussed below,

1. Density

From the literature review it is found that the density obtained by the correlation is very nearer to the experimentally determined value. Hence for finding the density value of all the concentrations of CuO nanofluid, the following correlation is used.

$$\rho_{nf} = \phi \rho_p + (1-\phi) \rho_w$$

2. Specific Heat

The specific heat is one of the important properties and plays an important role in influencing heat transfer rate of nanofluids. The specific heat of CuO nanofluids decreases with increase in the concentration of nanofluids. Hence for finding the Specific heat of CuO nanofluid, following correlation is used.

$$Cnf = \frac{\emptyset(\rho C)p + (1-\emptyset)(\rho C)w}{\emptyset \rho p + (1-\emptyset)\rho w}$$

3. Thermal Conductivity

Experimental studies on nanofluids containing nanoparticles are expected to give more thermal conductivity and lower specific heats over conventional fluids. There are many reasons for higher thermal conductivity of CuO nanofluid. Brownian motion of the particles and large surface area is one of the factors for enhanced thermal conductivity of nanofluids. Surface to volume ratio for nanoparticles is very high and this ratio increases with decrease in nanoparticle size. Probably this could also be one of the reasons for rise in the thermal conductivity of nanofluids. Thermal conductivity of nanofluid is obtained from the Maxwell model,

$$\frac{Knf}{Kw} = \frac{Kp + 2\,Kw - 2\emptyset\,(Kw - Kp)}{Kp + 2\,Kw + \emptyset\,(Kw - Kp)}$$

4. Viscosity

From the literature review it is found that the viscosity value obtained by the correlation is very nearer to the experimentally determined value. Hence for finding viscosity value of all the concentration of nanofluid the following correlation is used. It is found that as the (%) concentration increases the viscosity of nanofluid also increases.

$$\frac{\mu nf}{\mu w} = 1 + 2.5\,\emptyset$$

3. TEST METHODOLOGY

3.1 Introduction

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). The collector angle is fixed at 20^0. Experiments were carried out throughout the day from 10:00 am to 4:00 pm and values of solar intensity (I_t) as well as different temperatures were recorded at each one-hour interval. Different temperatures measured include ambient air temperature (Ta), 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 obtained for a fixed mass flow rate. Tests were carried out throughout the day for various tilt angles, namely, 20°, 31.5 and 50° for a mass flow rate of 2.5 LPH, 5 LPH, 7.5 LPH and 10 LPH.

3.2 Calculation procedure

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

$Q_{in} = I \times A_{coll}$ .... (1)

Where,

A_{coll} = Area of collector, m^2

I = Intensity of Radiations, W/m^2

Measuring the collector area on which solar radiations fall we get,

$A_{coll} = 0.31\ m^2$

$Q_g = m\ C_w\ (T_o - T_i)$ …….... (2)

Where,

m = Mass flow rate, Kg/sec

Cw = Specific heat of water, J/KgK

$\eta_{inst} = Qg / Q_{in}$ ………. (3)

Where η_{inst} is the instantaneous efficiency

4. RESULTS AND DISCUSSIONS

4.1 Efficiency of circular and elliptical TPCT collector at 2.5 LPH mass flow rate

Fig. 4.1 shows comparison between efficiencies for circular and elliptical TPCT at 2.5 LPH mass flow rate. The maximum efficiency obtained for elliptical TPCT is 45 % and as that of circular TPCT is 35 %.

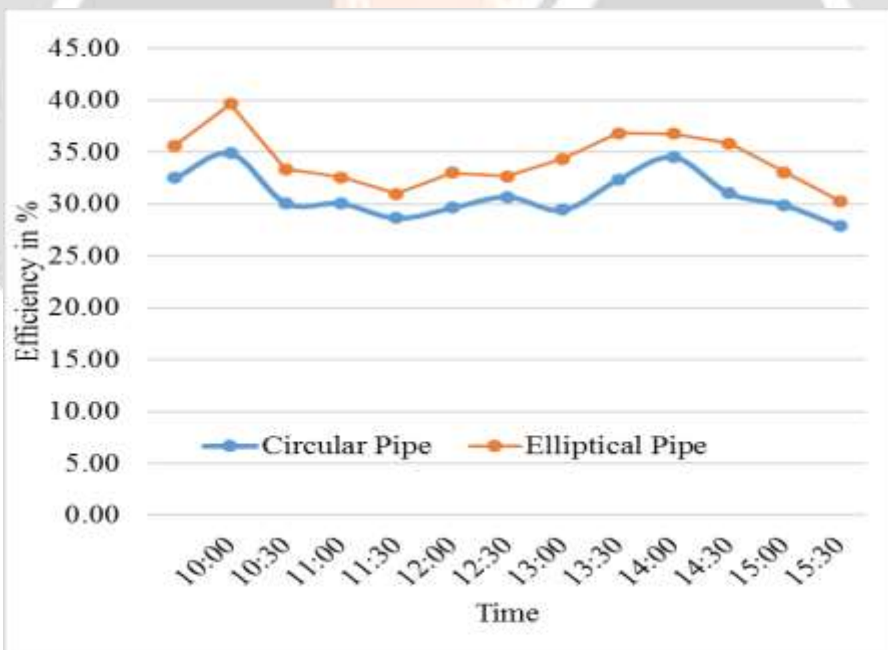

Fig. 4.1 Efficiency at 2.5 LPH mass flow rate

4.2 Efficiency of circular and elliptical TPCT collector at 5 LPH mass flow rate

Fig. 4.2 shows comparison between efficiencies for circular and elliptical TPCT at 5 LPH mass flow rate. The maximum efficiency obtained for elliptical TPCT is 55 % and as that of circular TPCT is 48 %.

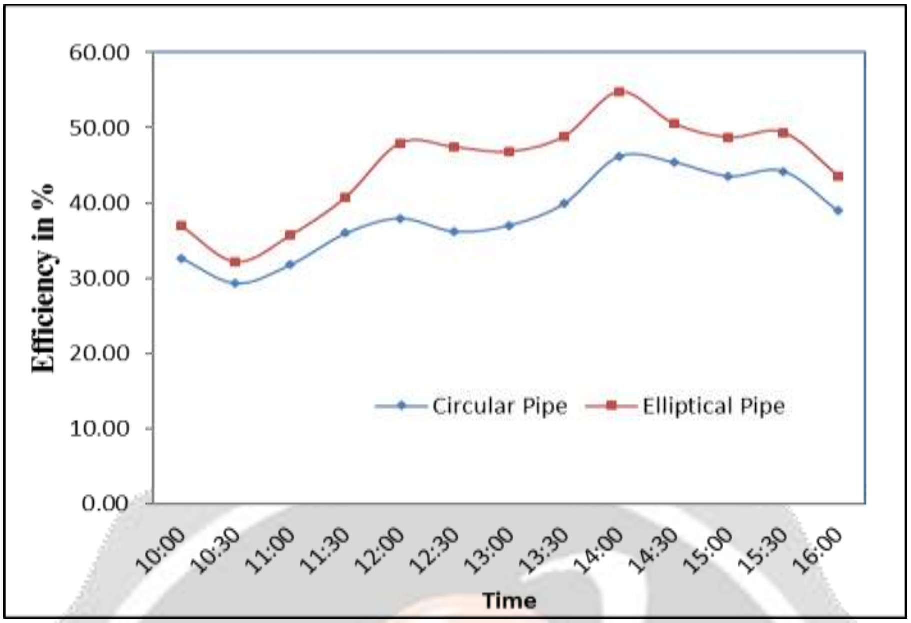

Fig. 4.2 Efficiency at 5 LPH mass flow rate

4.3 Efficiency of circular and elliptical TPCT collector at 7.5 LPH mass flow rate

Fig. 4.2 shows comparison between efficiencies for circular and elliptical TPCT at 7.5 LPH mass flow rate. The maximum efficiency obtained for elliptical TPCT is 60 % and as that of circular TPCT is 52 %.

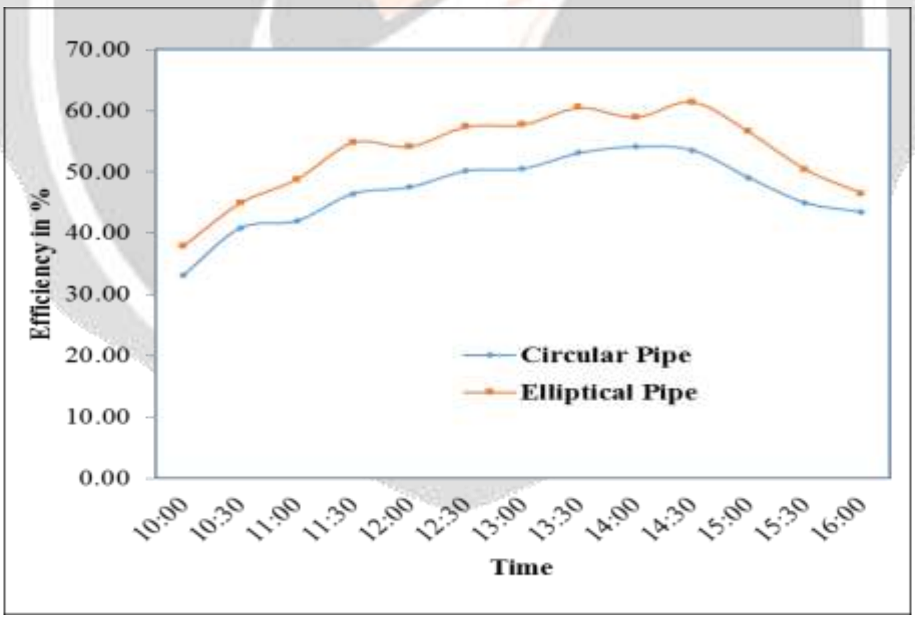

Fig. 4.3 Efficiency at 7.5 LPH mass flow rate

4.4 Efficiency of circular and elliptical TPCT collector at 10 LPH mass flow rate

Fig. 4.2 shows comparison between efficiencies for circular and elliptical TPCT at 10 LPH mass flow rate. The maximum efficiency obtained for elliptical TPCT is 69 % and as that of circular TPCT is 55 %

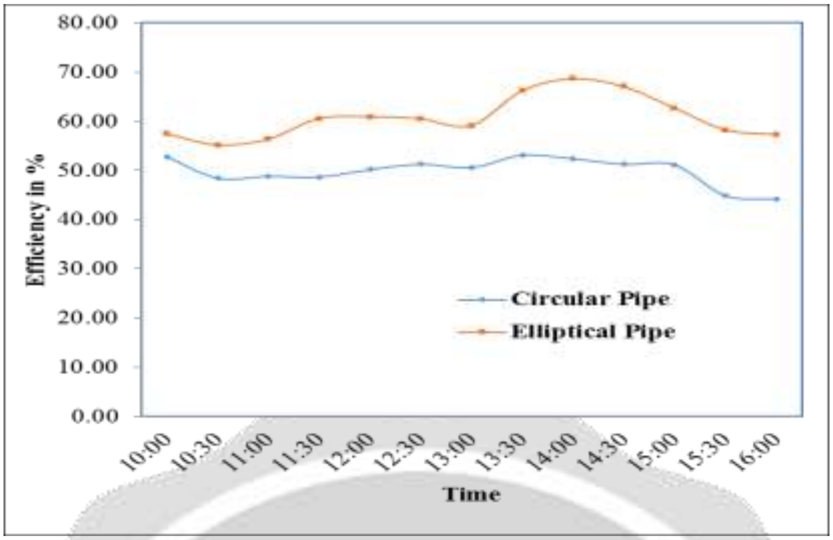

Fig. 4.4 Efficiency at 10 LPH mass flow rate

5. CONCLUSIONS

After performing experimental study on flat plate elliptical TPCT solar water heater following conclusions can be made,

1. As inlet cold water mass flow rate increases efficiency of the collector increases for both Circular and Elliptical solar collectors. Because with increase in mass flow rate thermal heat gain also increases which results in increase in efficiency.
2. As compared to flat plate circular solar collector, elliptical solar collector has more efficiency. The reason behind higher efficiency is, in case of circular pipe there is a point contact and in elliptical pipe there is line contact. Due to line contact the area available for heat transfer increases which results in higher efficiency.
3. Flat plate Elliptical solar water heater is having much higher efficiency than conventional solar water heater with water as working fluid, due to superior properties of nanofluid and heat pipe.

5. REFERENCES

[1] Gabriela, H., Angel, H., Ion, M., Florian, D., 2011, “Experimental Study of the Thermal Performance of Thermosyphon Heat Pipe Using Iron Oxide Nanoparticles”, International Journal of Heat and Mass Transfer, 54, 656–661

[2] M. Abo El-Nasr and S.M. El Haggar, "Performance of a Wickless Heat Pipe Solar Collector ". Energy Sources, Volume 15, pp. 513-522 (1993).

[3] M. Kannan, R. Senthil, R. Baskaran and B. Deepanraj, “An experimental study on heat transport capability of two phase close thermosyphon charged with different working fluids”, American Journal of Applied Sciences 11 (4): 584-591, 2014, ISSN: 1546-9239.

[4] Hussein HMS “Transient investigation of a two-phase closed thermosyphon flat plate solar water heater”, Energy Conversion Manage. (2002)., 43: 2479-2492.

[5] Noie, S. H. (2005). Heat transfer characteristics of a TPCT. Applied Thermal Engineering, Vol. 25, pp. 495-506.

Salah R. Agha, “Heat Pipe Performance Optimization: A Taguchi Approach”, IJRMET Vol. 1, Issue 1, Oct. 2011, S S N: 2249 - 5762.

[6] Zuo, Z. J. & Gunnerson, F. S. (1995). Heat transfer analysis of an inclined two-phase thermosyphon. Journal of Heat Transfer, Vol. 117, pp. 1073-1075