Experimental Study of Loop Thermosyphon Solar Water Heater Using Water and Al$_2$O$_3$ Nanofluid as Working Fluid

Ravindra Kolhe$^{1}$ J.H.Bhangale$^{2}$ Kishor Kumbharde$^{3}$

$^{1,2}$Savitribai Phule Pune University $^3$Matoshri College of Engineering & Research Centre Eklahare RIT Indore

Abstract— The basic aim of conducted experiments was to investigate the thermal performance of thermosyphon heat-pipe solar collector under real operating conditions using distil water and Al$_2$O$_3$-water nanofluid as a working fluid with serpentine shape thermosyphon. The Effect of coolant rate, effect of inclination angle, effect of nanomaterial concentration on performance of solar heat pipe collector was studied experimentally. The nanoparticles used having average size 30-50 nm and disperse in water with 0.3wt%, 6wt% and 0.9wt% concentration. Magnetic string, Ultrasound and surfactant (0.01 wt % SDS) technique is used to enhance stability of nanoparticle in water. From result it is observed that nanofluid charged heat pipe solar collector gives better performance than water charge. Also performance of solar collector was increases with increase inclination of collector and concentration of nanomaterial. Increase in coolant rate also increases the performance of solar collector up to certain level.

Key words: Solar Collector, Heat Pipe, Efficiency, Inclination Angle, Thermosyphon

I. INTRODUCTION

Solar energy is one of the typical renewable energy in the form of radiation received from the sun. Since it is sustainable, eco-friendly and unlimited source of renewable energy, it can be a good alternative to solve the problem of the depletion of fossil fuels. Solar Energy utilized, shall not only bridge the gap between demand and supply of electricity, but shall also save money since running cost of appliances working on solar energy is negligible. It will also help in reducing pollution and maintenance of eco balance. Heat pipe solar collector has higher efficiency than conventional solar water heater so this work has aim to investigate the performance of heat pipe solar collector with change in shape and working fluid. A Thermosyphon (Wickless heat pipe) is a heat transfer device of very high thermal conductance in which working fluid circulates. Heat pipe firstly evacuated and then partially fill with a working fluid. An operating Thermosyphon may be divided into three distinct sections, namely the evaporator, adiabatic and condenser sections. Energy is added into the evaporator section where the working fluid reaches its boiling temperature and begins to boil. The buoyant vapor of working fluid rises through the adiabatic section to the condenser, where it condenses. The condensate then drains back into the evaporator section by gravitation. This process of evaporation and condensation of the working fluid repeats itself continuously, as long as heat is supplied to the evaporator and an opportunity for its removal from the condenser exists.

II. EXPERIMENT

A. Nanofluid Preparation

Spherical aluminum oxide nanoparticles (with 30-50 nm nominal diameter, density 3.97 g/cc) are utilized and deionized water was used as the base fluid to prepare the nanofluid, and the required amount of the nanoparticles to attain a 0.9, 0.6 and 0.3% volume concentration solution is calculated. Then the nanoparticles are dispersed in the deionized water and the solution is vibrated in an ultrasound device for 90 min in order to obtain a uniformly dispersed solution. Al$_2$O$_3$ nanoparticles were produced by using a catalytic chemical vapor deposition method. The mixture was created by using an ultrasonic homogenizer.

B. Experimental Set-up

Fig 1 shows the actual photograph of experimental setup. The heat pipe was made by bending copper tube having ID 10mm and OD 12mm (2 turn). The length of evaporator, adiabatic and condenser section is 480mm, 50mm and 65mm respectively.

The heat pipe was filled with water and Al$_2$O$_3$/water nanofluid. A black painted 0.5mm thick copper plate having dimension 480 mm wide and 560 mm long is braze from bottom side of heat pipe which work as a absorber plate. At the top section, condenser of rectangular cross-section (25mm*65mm) is made for water heating. Bottom and side wall of setup is insulated with 30 mm thick glass wool and top side is cover with transparent glass cover to reduce convention heat loss. The collector was installed on tilted stand facing south at yeola nashik, India (latitude 20.0420° N, longitude 74.4890° E) and tested at outdoor condition with continuous drain off type test. The experiment is carried throughout the day with coolant (Water) flow rate 4kg/hr, 8kg/hr and 5 different angle of inclination (20°, 31.5°, 40°, 50°, 60°) of collector. Fig. 1 shows photograph of experimental setup.

Fig. 1: Experimental setup
C. Experimental Procedure
The test is conducted with water and nanofluid with varying concentration (0.9, 0.6, and 0.3 wt %) as a working fluid. The continuous drain of test was conducted from 9 a.m. to 5 p.m. on sunny days. During the whole test inlet cooling water temperature (Tw), outlet cooling water temperature (Ttwo), solar intensity (I), and ambient air temperature (Tam) was measured with the interval of half hour. Water supplied to condenser was measured by using rotameter having accuracy ±0.1 l/min and control by using flow control valve. Inlet and outlet temperature of condenser water and ambient air was measured by using K-type thermocouple having accuracy ±0.1°C. solar intensity was measure by using pyranometer.

D. Solar Collector Efficiency
Performance evaluation of solar collector can be done by calculating efficiency, which can be calculated
\[ \eta = \frac{\text{Useful Heat Gain (Qw)}}{\text{Heat supplied (Qs)}} \] 

Amount of useful heat gain can be calculated by considering water temperature variation flowing though condenser, taking into account the water flow rate and its specific heat
\[ Q_w = m \times C_p \times \Delta T \] 

Total heat supplied to collector is depend on solar intensity (I) and collector area (Ac)
\[ Q_s = I_t \times A_c \] 

III. RESULT AND DISCUSSIONS
Here results include effect of coolant rate, tilt angle, working fluid and nanomaterial concentration on performance of heat pipe solar collector. Finally experimental results are validated by using theoretical analysis. These results are broadly classified on the basic of working fluid i.e. water and nanofluid

A. Water
Figure 2 shows the variation of solar intensity for different angle of inclination with horizontal. It shows that solar intensity is increasing with time and reaches its maximum value and then falls down with time. It shows nearly same nature as a parabola. The maximum value of solar intensity was observed at 31.5° at yeola location (latitude 20.0420° N, longitude 74.4890° E) and reduces as angle increases.

B. Effect of Coolant Rate
Figure 3 shows that variation of instantaneous efficiency with respect to time for various coolant rates with water as working fluid at standard inclination angle 31.5° at yeola location. From nature of graph it is seen that efficiency of collector is minimum at coolant rate was 2 kg/hr and it increased with coolant rate. Maximum performance were observed at coolant rate 8 kg/hr and it nearly same for further increase in coolant rate. Large enhancement was observed when coolant rate increase to 4 kg/hr from 2 kg/hr. It happens because of high coolant rate draws large heat from condenser section and avoids raising pressure inside the pipe which reduces its working temperature and then reduces loss. Maximum efficiency observed at mid of the day because the thermal efficiency of the heat pipe increases with increasing the heat input in the evaporator section.

C. Effect of Inclination Angle
Figures 5-7 show the effect of inclination angle on collector instantaneous efficiency. It shows the performance of collector with coolant rate 4 kg/hr and 8 kg/hr respectively for various tilt angle. The efficiency for both the coolant rates is low at lower tilt angle and it increases with increase...
in tilt angle upto 50° inclination. The average collector efficiency variation for 4 and 8 kg/hr coolant rate at 20°, 31.5°, 40°, 50° and 60° tilt angle are shown in Fig 7. It increases with angle upto 50° inclination and then decreases. Maximum efficiency is found to be at 50° tilt angle with values are 44% and 49% at 4 and 8 kg/hr coolant rate. The maximum instantaneous efficiency obtained at 4 kg/hr are 54% and at 8 kg/hr is 63% at tilt angle 50° and further increase in tilt angle reduces efficiency.

E. Effect of Coolant Rate

Maximum performance of heat pipe solar collector was observed at 50° tilt angle. So graph of effect of coolant rate at 50° and 31.5° (yeola latitude) tilt angle is drawn for nanomaterial concentration 0.3, 0.6, and 0.9 wt%. Figures 8-10 show the comparison between the instantaneous efficiency of collector at different coolant rates at tilt angle 31.5° and 50°. These indicate that the maximum instantaneous efficiency of the collector is at the coolant rate 8 kg/hr for all the working fluids because at high coolant rate condensation process of working fluid is better which enhance the performance. Efficiency of collector with Al2O3 nanofluid for all concentration is higher than water.

D. Nanofluid

Experimentation is carried out to study effect of Al2O3 nanomaterial added into distill water. These results are broadly discussed in comparisons with nanofluid of anAl2O3 with water.

After extensive experimentation the result obtained were broadly classified into effect of coolant rate, Effect of nanomaterial concentration and effect of angle. The experimentation were carried out with nanomaterial concentration varies from 0.3 wt% to 0.9 wt% and two different coolant rate. With the nanomaterial, difference in inlet and outlet temperature of water is increase which increases the performance of collector compare to water as a working fluid.

F. Effect of Inclination Angle

Figures 11-13 show the effect of inclination angle on collector efficiency with Al2O3 nanofluid as a working fluid for varying concentration. Performance of collector with coolant rate 4 and 8 kg/hr for various tilt angles shows similar nature of performance. The efficiency for both the coolant rates is low at lower tilt angle and it increases with increase in tilt angle. The average collector efficiency for 0.9 wt% Al2O3 nanofluid with 4 kg/hr coolant rate at 20°,
31.5°, 40°, 50° and 60° tilt angle are 46%, 42%, 48%, 52% and 38% respectively. The average collector efficiency for 8 kg/hr coolant rate at 20°, 31.5°, 40°, 50° and 60° tilt angle are 48%, 52%, 53%, 57% and 39% respectively for 0.9wt% Al₂O₃ nanofluid. Figure 14 shows effect of inclination for all working fluid. Maximum efficiency is found to be at 50° tilt angle which is higher than at water as a working fluid for same angle. It may be because of increasing the tilt angle increases buoyancy force on up going vapour and gravity force on down coming liquid which gives rise to enhancement in performance with angle. But after 50° increase in angle (60°) reduces the performance of collector because, the gravitational force which assists the flow of working fluid to flow back to the evaporator may accelerate the process which may hinder the heat transfer process at the condenser end and the fluid might have returned to the evaporator section with higher temperature end. This may be the reason why the performance of heat pipe deteriorates when the inclination was increased.

Fig. 11: variation of instantaneous efficiency with time for 0.3 wt% Al₂O₃ nanofluid

Fig. 12: variation of instantaneous efficiency with time for 0.6wt% Al₂O₃ nanofluid

Fig. 13: variation of instantaneous efficiency with time for 0.9wt% Al₂O₃ nanofluid

Fig. 14: Effect of angle and nanofluid concentration on average efficiency for Al₂O₃

G. Effect of Concentration

Figures 15 - 16 show the variation of instantaneous efficiency for water and different concentration of Al₂O₃ nanofluid with 4 and 8kg/hr coolant rate. Figure 14 shows effect concentration on average efficiency at different inclination. Result shows that increase in concentration of nanomaterial in base fluid enhances the performance of solar collector. 8 kg/hr coolant rate shows higher performance than 4kg/hr. water shows lower performance and 0.9 wt% nanofluid shows highest performance for both coolant rates. Average efficiency for 0.3, 0.6, 0.9wt% are 48%, 50%, 52% respectively at 4 kg/hr coolant rate and similarly 54%, 54.3%, and 57% respectively for 8 kg/hr coolant rate. Figure 17 shows the variation of average efficiency for 50° tilt angle. It shows that increase in concentration increases the average efficiency of collector. This may be due to performance of thermosyphon heat pipe governed by the formation of vapor bubble at the liquid–solid interface. A larger bubble nucleation size creates a higher thermal resistance that prevents the transfer of heat from the solid surface to the liquid and retard the performance. The suspended nanoparticles tend to bombard the vapor bubble during the bubble formation. Therefore, it is expected that the nucleation size of the vapor bubble is much smaller for the fluid with suspended nanoparticles than that without them which cause enhance the performance. Also the nanoparticles suspension in the fluid has significant effect on the enhancement of heat transfer due to its higher heat capacity and higher thermal conductivity of working fluid. Therefore, the heat pipe thermal efficiency heat pipe increases with nanofluids as compared to that of the base working fluids like water, ethylene glycol etc.

Fig. 15: Variation of instantaneous efficiency for Al₂O₃ nanofluid with 4kg/hr coolant rate
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Fig 16 Variation of instantaneous efficiency for Al2O3 nanofluid with 8kg/hr coolant rate.

Fig 17 variation of average efficiency for Al2O3 at 50° tilt angle

IV. CONCLUSION

The main aim of the experiments conducted was to determine the thermal performance of thermosyphon heat-pipe solar collector under real operating conditions using water and Al2O3 nanofluids at various concentrations. The effect of various parameters i.e. coolant rate, inclination angle, nanomaterial and its concentration on performance of solar heat pipe collector were experimentally studied.

From the experimental investigation of the present type of two phase thermosyphon wickless heat pipe flat plate solar collector following conclusion are drawn:

A. For Water

- Performance of heat pipe solar collector depends on coolant flow rate, heat flux at evaporator, working fluid and inclination angle.
- Increasing the coolant rate up to certain level increases the thermal performance of heat pipe collector after that increase in coolant rate has no effect on performance.
- The heat transfer rate through heat pipe collector with water as a working fluid is increases as inclination angle increases from 20° to 50° while further increase in angle reduces the heat transfer rate.

B. For Nanofluid

- Increasing the coolant rate increases the thermal performance of heat pipe collector.
- The heat transfer rate with nanofluid as a working fluid is decreased as inclination angle increased from 20° to 31.5° while further increase in angle up to 50° increased the heat transfer rate and found to decrease beyond 50°.

- Increase in concentration of nanomaterial increase the thermal performance of solar collector for both nanomaterials.

REFERENCES


