An Experimental Investigation on the Effect of Al_2O_3-H_2O and Cuo- H_2O Nanofluid on the Efficiency of Flat-plate Solar Collectors

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Abstract: ***In this research, the effect of using aluminum oxide and copper oxide nanofluid (pure water mixed with Cuo and Al2O3 nanoparticle with 35-50 nm diameters) on the thermal efficiency enhancement of a heat pipe on the different operating state was investigated. The heat pipe was made of a straight copper tube with an outer diameter of 12mm and inner diameter 10mm. In the heat pipe tube, there is a 90° curve between the evaporator and condenser sections. The tested concentration levels of nanofluid are 0.3%, 0.6% and 0.9%wt. Results show that by charging the nanofluid to the heat pipe, thermal performance is enhanced by reducing the thermal resistance and wall temperature difference. The thermal efficiency of heat pipe charged with nanofluid is compared in water, Al2o3 and Cuo.***

Keywords*:* Heat pipe Nanofluid Thermal performance Heat load

1. Introduction

Usually, conventional solar collectors use pipes attached to the collecting plate and a heat transfer fluid, such as water, to transfer by natural or forced circulation the heat captured by the solar collector to a storage tank. Some of the shortcomings associated with conventional solar collectors include extra expense of the forced circulation system due to the pump and its extracted power, extra space required for the natural circulation system due to the position limitations required, the night cooling due to the reverse flow of cooled water, freezing of the water on cold nights, pipe corrosion due to the use of water and the limited quantity of heat transferred by the heat transfer fluid. Heat pipes offer a promising solution to these problems. Heat pipes working under gravity with the condenser above the evaporator do not require external power or capillary action in order to return the heat transfer fluid to the evaporator. This type of heat pipe is known as the gravity assisted heat pipe, closed two-phase thermosyphon or wickless gravity assisted heat pipe. Closed two-phase thermosyphon solar collectors consist of heat pipes (or thermosyphon tubes) filled with a refrigerant and used in closed loop water heating systems. Closed loop solar heating systems are suitable for domestic solar water heating, solar swimming pool heating or solar space heating systems. They are also suitable for areas with questionable water quality and all climatic conditions. Furthermore, they are the preferred option for extremely cold areas. The basic heat Pipe is a closed container consisting of a small amount of vaporizable fluid. The heat pipe employs an evaporating-condensing cycle, which accepts heat from an external source, uses this heat to evaporate the liquid (latent heat) and then releases latent heat by reverse transformation (condensation) at a heat sink region. This process is repeated continuously by a return feed mechanism of the condensed fluid back to the heating zone. In the solar collector, the condensation zone is at a higher level than the evaporation zone. The transport medium condensed (in the condensation zone) returns to the evaporation zone under the influence of the gravity. The maximum operating temperature of a heat pipe is the critical temperature of the used heat transfer medium the idea of dispersing solid particles into liquids initially came from James Clerk Maxwell. The use of particles of nanometer dimension was first continuously studied by a research group at the Argonne National Laboratory around a decade ago. Compared with suspended particles of millimeter-or-micrometer dimensions, nanofluids show better stability, and rheological properties, dramatically higher thermal conductivities, and no penalty in pressure drop. Several published literature have mainly focused on the prediction and measurement techniques in order to evaluate the thermal conductivity of nanofluids

Recent works have shown that the presence of the nanoparticles in thermosyphons and heat pipes causes an important enhancement of their thermal characteristics. Different nanoparticles such as silver, oxide copper, alumina, diamond, titanium, nickel oxide, gold, and iron oxide have been utilized within the thermosyphons and heat pipe working fluid. The improved thermal performance is observed through a reduction in thermal resistance, a drop in the temperature gradient in the overall heat transfer coefficient.

2. Experiment

A.Nanofluid Preparation

Spherical aluminum oxide nanoparticles and copper oxide nanopartical 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_2O_3 nanoparticles and Cuo nanopartical 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. The length of evaporator, adiabatic and condenser section is 480mm, 50mm and 65mm respectively.

The heat pipe was filled with water and Al_2O_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.

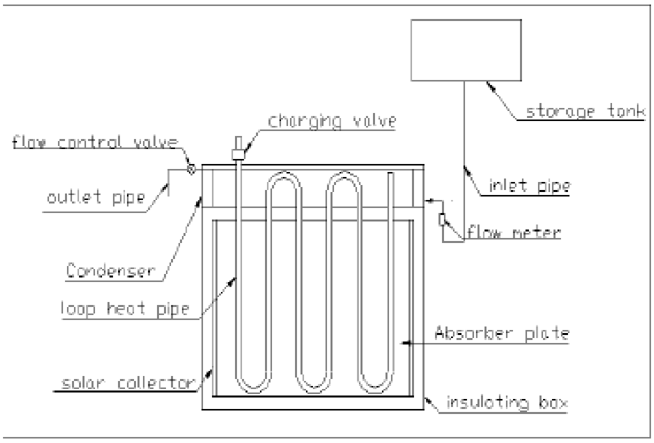

Figure 1: Experimental setup

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 (Twi), outlet cooling water temperature (Two), solar intensity (It), and ambient air temperature (Tamb) 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

η = Useful Heat Gain (Qw) / Heat supplied (Qs)………..(1)

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

$Qw = m \times Cp \times \Delta T$ ………………………….……….. (2)

Total heat supplied to collector is depend on solar intensity (It) and collector area (Ac)

$Qs = It \times Ac$………………………...………….. (3)

3. Result and Discussions

Here results include effect of coolant rate, tilt angle, working fluid and nanomaterial concentration on performance of heat pipe solar collector. These results are broadly classified on the basic of working fluid i.e. water and nanofluid

From Fig 2 to Fig 4 shows that the variation of average efficiency of solar heat pipe collector for different concentration of nanofluid. Result shows that instantaneous thermal efficiency increases with increasing the angle of inclination up to 50° afterwards it starts decreases. The efficiency is higher for 0.9wt% nanomaterial concentration than the other three concentrations. For all concentration Al_2O_3 nanofluid shows highest performance for all angle of inclination. Reason behind the enhancement in performance is 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 increases with nanofluids as compared to that of the base working fluids like water, ethylene glycol etc..

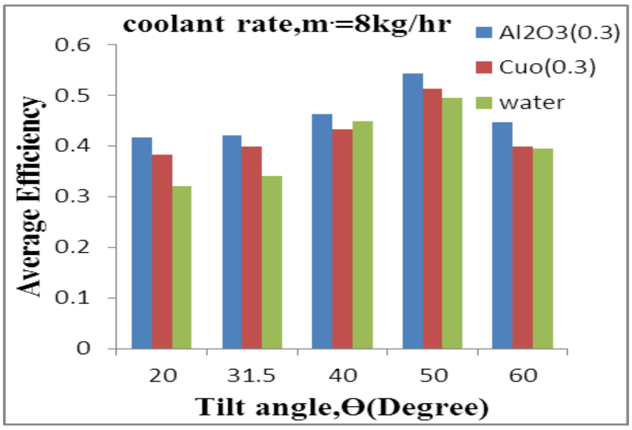

Figure 2: Variation of average efficiency for 0.3wt % nanofluid at various inclinations

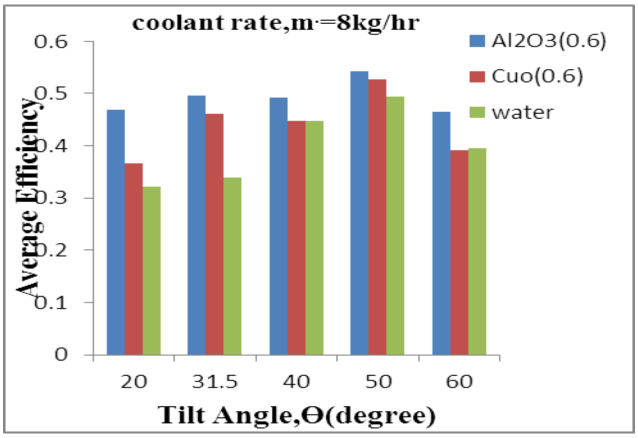

Figure 3: Variation of average efficiency for 0.6wt % nanofluid at various inclinations

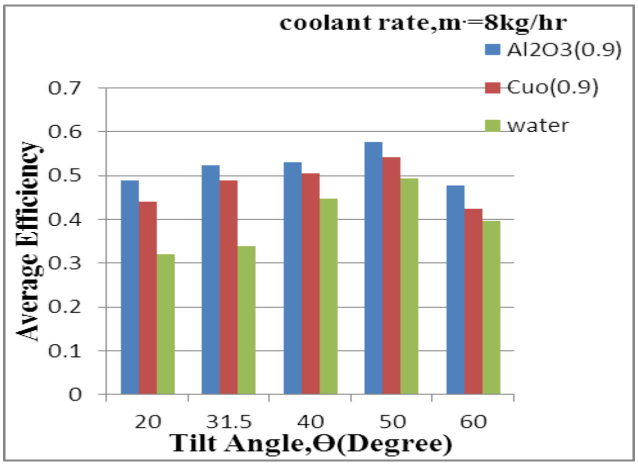

Figure 4: Variation of average efficiency for 0.9wt % nanofluid at various inclinations

From Fig 5 to fig 10 shows the variation of instantaneous efficiency for nanomaterial and water at 50° inclination and different mass flow rate. Results are drawn at 50° inclination because it shows highest performance. From the graph it is observed that same concentration of Al_2O_3 and CuO nanofluid Al_2O_3 nanofluid shows higher performance. Highest performance is observed at 0.9 wt% Al_2O_3 nanofluid. As Performance of thermosyphon heat pipe is 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 and for same concentration Al_2O_3 nanofluid has larger number of nanoparticle because of lower density of aluminum oxide than copper oxide. Also enhancement in performance is 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.

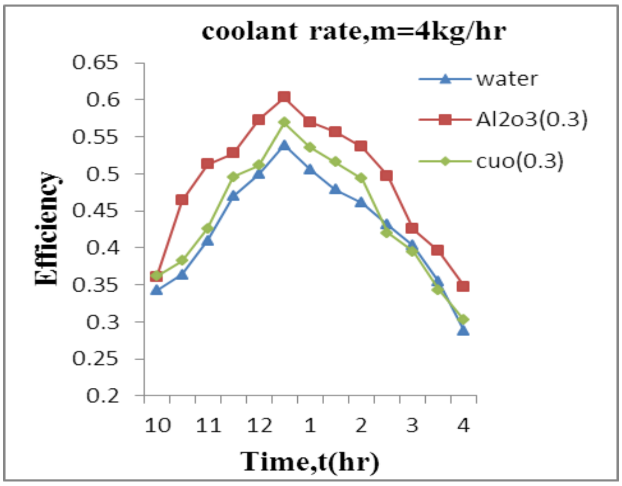

Figure 5: Variation of instantaneous efficiency for 0.3wt % nanofluid at 50° inclination and m=4kg/hr

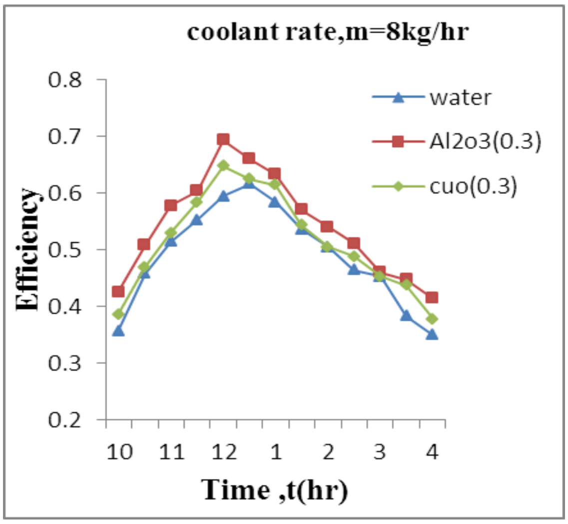

Figure 6: Variation of instantaneous efficiency for 0.3wt % nanofluid at 50° inclination and m=8kg/hr

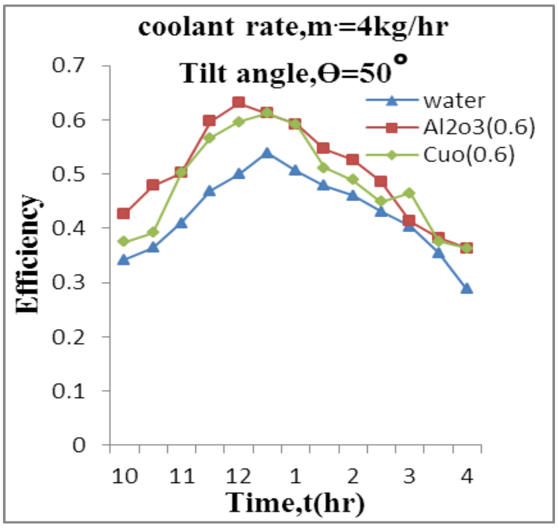

Figure 7: Variation of instantaneous efficiency for 0.6wt % nanofluid at 50° inclination and m=4kg/hr

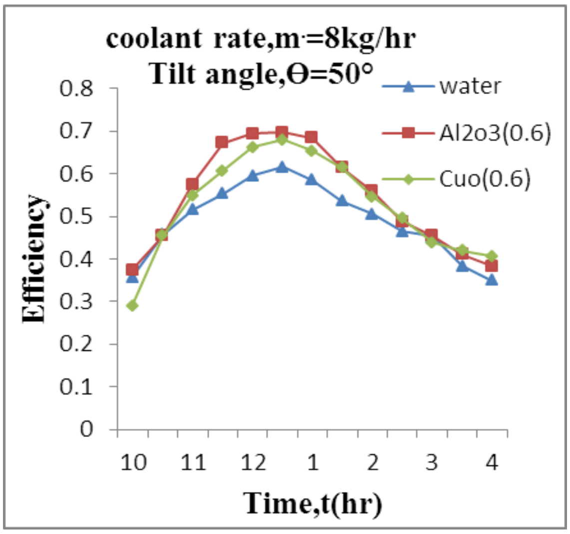

Figure 8: Variation of instantaneous efficiency for 0.6wt % nanofluid at 50° inclination and m=8kg/hr

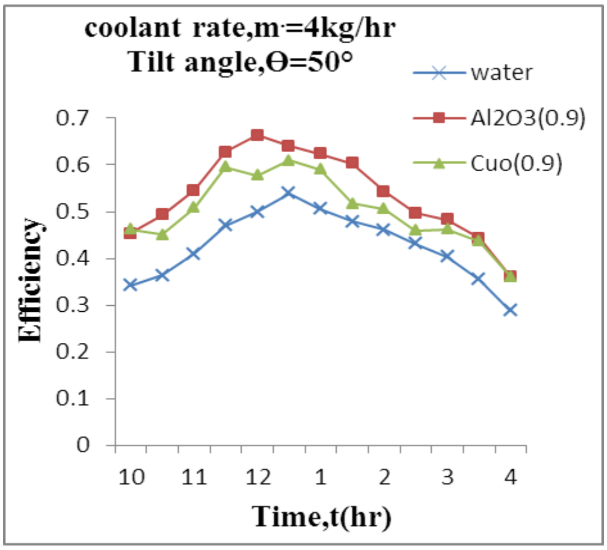

Figure 9: Variation of instantaneous efficiency for 0.9wt % nanofluid at 50° inclination and m=4kg/hr

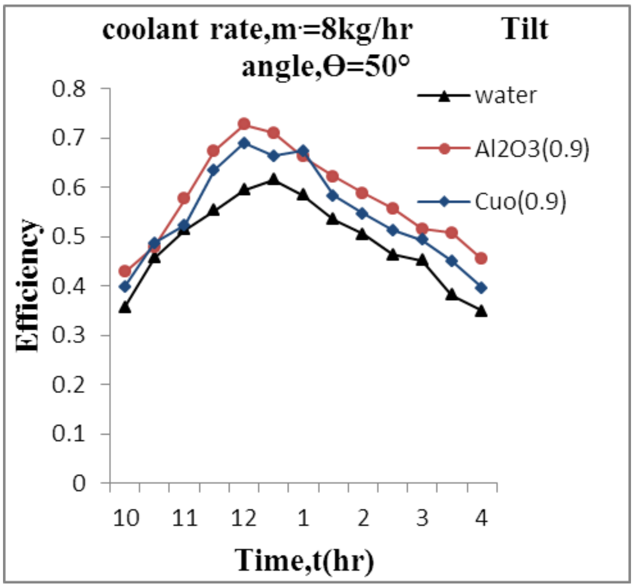

Figure 10: Variation of instantaneous efficiency for 0.9wt % nanofluid at 50° inclination and m=8kg/hr

4. 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 Al_2O_3 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:

- 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.
- The heat transfer rate through heat pipe collector with nanofluid as a working fluid is decreases as inclination angle increases from 20° to 31.5°while further increase in angle up to 50° increases the heat transfer rate and found to decrease beyond 50°.
- Increase in heat flux at evaporator section of the collector performance of solar collector increases.
- Increase collector efficiency can be achieved by using nanofluid as a working fluid rather than water.
- Al_2O_3 nanofluid has greater potential to enhance the performance of heat pipe collector than that of Cuo nanofluid and water.
- Thermal efficiency of solar collector is increase as concentration of nanomaterial increase for both nanomaterial i.e. Al_2O_3 and CuO.
- Serpentine shape of heat pipe work better likewise thermosyphon and it can reduce manufacturing cost.

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