Experimental investigation of heat pipe solar collector to determine collector efficiency at different mass flow rate, inclination angle by using nanofluid at different concentration

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Abstract - **The basic aim of the experiments conducted was to determine the thermal performance of thermosyphon heat-pipe solar collector under real operating conditions using two different nanofluids (Al_2O_3 & CuO) at various concentrations (0.3 to 0.9 wt%) with serpentine shape thermosyphon. The Effect of coolant rate, effect of inclination angle, effect of type of nanomaterial and effect of nanomaterial concentration on performance of solar heat pipe collector were studied experimentally.**

In present study two identical setup of heat pipe solar flat plate collectors are made. Heat pipe was made by bending copper pipe (10 mm inner diameter and 12 mm outer diameter) in serpentine manner with 2 loops and gross length of single is 1350 mm i.e. each pipe length is 675 mm. From 675 mm 600 mm length of heat pipe acts as evaporator and 75 mm length acts as condenser. Area of Solar collector absorber is 0.288 m^2. The test was conducted by filling heat pipe with water, Al_2O_3-water nanofluid and CuO-water nanofluid one setup is charge with Al_2O_3-water nanofluid and another with CuO-water nanofluid after conducting test on water. The nanoparticles used having average size 30-50 nm and disperse in water with 0.3wt%, 0.6wt% and 0.9wt% concentration. The series of test are conducted by varying coolant rate (2 to 8 Kg/hr), inclination angle (20^o to 60^o), and nanofluid concentration (0.3 to 0.9 wt %). From result it is observed that nanofluid charged heat pipe solar collector gives better performance than water charge. Also performance of solar collector is increases with increase in concentration of nanomaterial. Al_2O_3 nanofluid gives better performance than CuO nanofluid. The maximum performance for both the nanofluid was obtained at 50^0 inclination angle and 0.9 wt% concentration.

Index Terms* – *Solar Collector, Heat Pipe, Nano Particles

I. INTRODUCTION

HEAT PIPE SOLAR COLLECTOR

Heat pipe has three main sections as shown in Fig 1, the evaporator, adiabatic and the condenser sections. With evaporator heat addition, the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization, while in the condenser section the working fluid vapor is condensed. The mass addition in the vapor core of the evaporator section and mass rejection in the condenser end results in a pressure gradient along the vapor channel which drives the corresponding vapor flow. Return of the liquid to the evaporator from the condenser is provided by the wick structure. As vaporization occurs in the evaporator, the liquid meniscus recedes correspondingly into the wick structure. Similarly, as vapor condenses in the condenser region, the mass addition results in an advanced meniscus. The difference between the capillary radii in the evaporator and condenser ends of the wick structure results in a net pressure difference in the liquid-saturated wick. This pressure difference drives the liquid from the condenser through the wick structure to the evaporator region, thus allowing the overall process to be continuous. In solar collectors, the evaporator is bonded with the absorber of the collector and the condenser section is inserted in to the heat exchanger. The heat picked by the evaporator sinks at the condenser section. Heat loss in the adiabatic section is mostly ignored for good insulation. The working fluid is maintained at lower pressure in the heat pipe. The working fluid evaporates at the evaporator section and creates a vapor pressure to flow to the condenser section to condense. The evaporation and condensation happens at saturated temperature. The wick develops a capillary pressure to pump condensed liquid from condenser to evaporator to complete the circulation. The pumping can also be done by gravitation in gravity assisted heat pipes which is also common in solar collectors.

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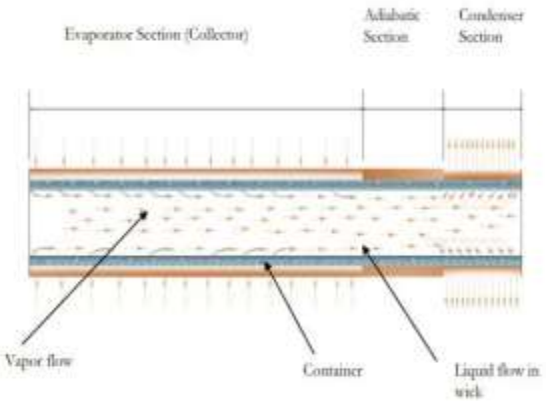

Figure 1schematic Diagram Of Heat Pipe Associate With Solar Collector

II. LITERATURE SURVEY

Recent work carried out for experimental and numerical analysis of Heat pipe with and without nanofluids reviewed as follows

Ozsoy et al. [1] has performed an experimental study to determine the thermal efficiency of thermo-syphon heat pipe (THP) evacuated tube solar collector using silver-water nanofluid for commercial applications. Firstly, the synthesis of silver-water nanofluid was carried out which can maintain its long-term stability. Secondly, the heat transfer properties of cylindrical copper THPs charged with silver-water nanofluid and pure water was investigated experimentally. It was observed that the THP charged with silver water nanofluid maintained its improved heat transfer characteristic in the THP experiments. Nanofluid working fluid increased the efficiency of solar collector between 20.7% and 40% compared with the pure water.

Hussen et al. [2] has given comprehensive review about the recent advances related with the application of the nanofluid in the heat pipe solar collectors. Papers reviewed including theoretical, numerical and experimental up to date works related with the nanotechnology applications in this type of the solar collectors. A lot of literature are reviewed and summarized to give a wide overview about the role of the nanofluid in improving the heat pipe solar collectors. It was found that the use of the nanofluid in the heat pipe solar collectors can play a significant role in increasing the efficiency of these devises.

K. B. Kshirsagar et al. [3] proposes that heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. Nanofluids are the new kind of heat transfer fluid containing a very small quantity of nano particles that are uniformly and stably suspended in fluids. Nanofluids are high thermal conductivity than conventional fluids. In this study the thermal performance of two different wickless heat pipe solar collectors were investigated by using pure water, CuO-BN/water nanofluid for different coolant mass flow rates and tilt angles (20^0, 31.5^0 and 50^0). First collector uses only pure water, the second one utilizes CuO and BN nano-particles with water as a base fluid. Experiments were carried out for the two collectors under the same experimental conditions. The wickless heat pipe flat plate solar collector containing nanofluid showed better performance. The optimum performance for both the collector was obtained at 31.5° tilt angle.

P M Sonawane et al. [4] gives the review that generally conventional fluids are used in heat pipes to remove the heat based on a temperature range for its particular operating conditions. The addition of the nano particles to the base fluid is one of the significant issues to enhance the heat transfer of heat pipes. This review article provides additional information for the design of heat pipes with optimum conditions regarding the heat transfer characteristics of Nanofluids in heat pipes.

Moravej et al. [5] investigated the effect of aluminum oxide nanofluid (pure water mixed with Al nanoparticles with 35 nm diameter) on the thermal efficiency enhancement of a heat pipe. The heat pipe was made of a straight copper tube with an outer diameter 8 mm. The tested concentration levels of nanofluid are 0%, 1% and 3%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. It also observed that Al203 nanofluid has remarkable potential as a working fluid for heat pipe and thermosyphon of higher thermal prefaces.

Hung et al. [6] studied the thermal performance of a heat pipe charged with nanofluid. The Al_2O_3-water nanofluid in this study was produced by the direct-synthesis method using a cationic chitosan dispersant. The Al_2O_3-water nanofluid served as the working fluid with three concentrations (0.5, 1.0, and 3.0 wt. %) in heat pipes. The heat pipe in this study is a straight copper tube with an outer diameter of 9.52 mm and different lengths of 0.3 m, 0.45 m, and 0.6 m .effect of charged volume ratio of the working fluid (20%, 40%, 60%, and 80%) , tilt angle (10°,40°,70°, and 90°), heating power (20 W, 30 W, and 40 W), and weight fraction of nano-particles on the overall thermal conductivity of the heat pipe was evaluate. Experimental results show that at a heating power of 40 W, the optimal thermal performance for Al_2O_3-water nanofluid heat pipes measuring 0.3 m, 0.45 m, and 0.6 m was 22.7%, 56.3%, and 35.1%, respectively, better than that of pipes using distilled water as the working fluid.

Chen et al. [7] has studied the effect of water-based SiO_2 functionalized nanofluid on the performance of loop thermosyphon. Functionalized nanofluid has unique dispersing ability and has no deposition on heated surfaces. Results show that, functionalized nanofluid deteriorates both the evaporating heat transfer coefficient and the maximum heat flux of the loop thermosyphon. The changes in the thermal properties of functionalized nanofluid mainly result in the heat transfer deterioration.

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Yousefi et al. [8] has studied the effect of Al_2O_3-water nanofluid, as working fluid, on the efficiency of a flat-plate solar collector. The weight fraction of nanoparticles was 0.2% and 0.4% and the particles dimension was 15 nm. Experiments were performed with and without Triton X-100 as surfactant. The results show that nano-fluids as working fluid increase the efficiency of solar collector. For 0.2 wt% of nanofluid the increased efficiency was 28.3%. From the results it also can be concluded that the surfactant causes an enhancement in heat transfer.

TYPES OF HEAT PIPE

1) Conventional heat pipe

2) Gravity assisted thermosyphon

3) Loop heat pipe

4) Micro heat pipe

5) Pulsating heat pipe

III. NANOMATERIAL

INTRODUCTION

The term nano-material, nano-crystal and nano-particle all refer to objects with nano-metric size (in at least one dimension) between 1 and 1000 nanometers (10^{-9} meter) but is usually 1—100 nm. The main feature of nano-material is that they are made up of a small number of atoms, from few hundred too few thousand. Due to their small dimension, the physical properties of these materials generally differ from those of bulk material.

TYPES OF NANO-MATERIAL

Most current nano-materials could be organized into four types:

1) Carbon Based Materials

2) Metal Based Materials

3) Dendrimers

4) Composites

NANOFLUID

Nanofluids are a new class of fluids engineered by dispersing nanometer-sized materials (nano-particles, nano-fibers, nano-tubes, nano-wires, nano-rods, nano-sheet, or droplets) in base fluids. In other words, nano-fluids are nano-scale colloidal suspensions containing condensed nano-materials. They are two-phase systems with one phase (solid phase) in another (liquid phase). Nanofluids have been found to possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water. It has demonstrated great potential applications in many fields. In recent years, nano-fluids have attracted more and more attention.

EXPERIMENTAL METHOD AND THEORETICAL ANALYSIS

Experimental setup consists of two identical solar flat plate two phase thermosyphon collectors used for studying effect of nanofluids. For the base test the water is used is charged the system and then one is charge with Al_2O_3 nanofluid and other with CuO nanofluid to avoid mixing of both single setup is used. Experiments are carried out by varying tilting angle, coolant rate.

TEST SETUP

Fig. 2 shows a schematic diagram and photograph of the experimental setup of solar heat pipe collector. The heat pipe solar collector setup consist of serpentine shape heat pipe with charging valve, glass cover, insulating box, absorber plate, condenser jacket, tilting arrangement, flow control valve, temperature indicator, temperature sensors etc. single heat pipe is made up with copper tube. As it is gravity assisted heat pipe since it has no weak structure. The copper tube is bent in serpentine manner to form loop structure. One end of pipe is sealed and charging valve is fitted at other end. To increase heat input (i.e. absorbed solar radiant energy), the evaporator section of tube is finned with a thin copper plate. The outer surface of the evaporator (fin) section exposed to the sun was treated to have selective optical characteristics by spraying black paint with selective optical characteristics.

The condenser portion of heat pipes is place in rectangular box, which is made up aluminum sheet which acts as heat exchanger. Condenser has one inlet pipe at one side of it and one outlet pipe at another side. In the condenser coolant fluid (i.e., water in this case) comes from inlet pipe and exchanges heat with the working fluid and goes out though outlet pipe. Coolant comes from storage tank. There is flow meter and flow control valve is fitted in inlet line of condenser to measure and control the coolant rate. All assembly is insulated from back and side by using glass wool and place into the box made up of GI sheet. Box is insulated with glass cover at the top to avoid convective heat loss. Tilting arrangement is fixed at the bottom side of GI box and whole collector is fixed on stand. Data logging is done by using temperature indicator, thermocouple and pyranometer. There was Four Thermocouple used for measurement of temperature at different location. Measurement is done at cooling water inlet, cooling water outlet, plate and ambient condition.

FIG. 2 TEST SETUP

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TEST PROCEDURE

The first step before starting experimentation was, to charge heat pipe with appropriate amount of nanofluid. Filling could either be done by first evacuating the heat pipe and then admitting the desired quantity of working fluid through a calibrated pipette and the metering valve. All experiments are done by filling heat pipe about 70% of total evaporator volume.

The two-phase thermosyphon solar collector was installed on a tilting stand and tested under outdoor conditions of Kopargaon, Maharashtra, India (latitude 20.0420° N, longitude 74. 4890° E. The test was conducted by setting collector at fixed tilt from horizontal (i.e. 20°,31.5°,40°, 50° and 60°) and facing towards south. After that with the help of water flow meter and flow control valve required quantity of cooling water was discharge through condenser from overhead tank. The coolant flow rate of each collector was adjusted by using flow control valve and measured by using a water flow meter and stopwatch. Day long experiments were carried out from 10:00 a.m. to 4:00 p.m. and data were recorded at half hour intervals. During each test run, the solar radiation intensity (It), ambient air temperature (Ta), inlet cooling water temperature (Ti) and outlet cooling water temperature (To) and absorber plate temperature (Tp) of each collector were recorded for fixed mass flow rate. The temperature of the inlet and outlet cooling water, plate and ambient air were measured by using PT-100 thermocouples with an accuracy of ±0.1°C. A pyranometer (Model-DWR 8101, Make-Dyna Lab) was used to measure instantaneous value of global solar radiation intensity. First test was conducted with thermosyphon heat pipe charge with water and coolant rate 2, 4, 6, 8, 10 kg/hr for optimization of coolant flow rate at 31.5° inclination. This optimize mass flow rate is used for further testing. Afterward test conduct on thermosyphon charge with nanofluid.

PERFORMANCE ANALYSIS

SOLAR COLLECTOR EFFICIENCY

Performance evaluation of solar collector can be done by calculating efficiency, which can be calculated,

$$\eta = \frac{\text{usefull heat gain(Qw)}}{\text{heat supplied(Qs)}}$$

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 $Qw = m \times Cp \times \Delta T$

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

$$Qs = I_t \times A_c$$

RESULT AND DISCUSSIONS

Experimentation is carried out to study effect of Al_2O_3 and CuO nanomaterial added into distil water. These results are broadly discussed in comparisons with nanofluid of CuO and Al_2O_3 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 0.9wt% and two different coolant rate.

PART I- WATER AS A WORKING FLUID

EFFECT OF COOLANT RATE

Figure 3 shows that variation of instantaneous efficiency with respect to time for various coolant flow rate with water as working fluid at standard inclination angle 31.5° at Kopargaon location. From nature of graph it is seen that efficiency of collector is minimum at coolant rate was 2 kg/hr. and it increases with coolant rate. Maximum performance were observed at coolant rate 8 kg/hr and it nearly same for further increase in coolant rate. 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.

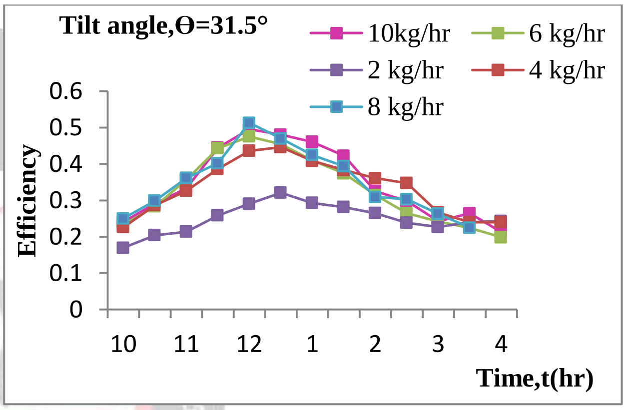

Fig. 3 Variation Of Instantaneous Efficiency With Respect To Time For Various Coolant Rates

EFFECT OF INCLINATION ANGLE

Figure 4 shows the effect of inclination angle on collector efficiency. The efficiency for any coolant rates is low at lower tilt angle and it increases with increase in tilt angle. The average collector efficiency for 4kg/hr coolant rate at 20°, 31.5°, 40°, 50°and 60° tilt angle are 29%, 33%, 38%, 44% and 33% respectively. The maximum instantaneous efficiency obtained at 4 kg/hr are 54% at tilt angle 50° and further increase in tilt angle reduces efficiency. 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.

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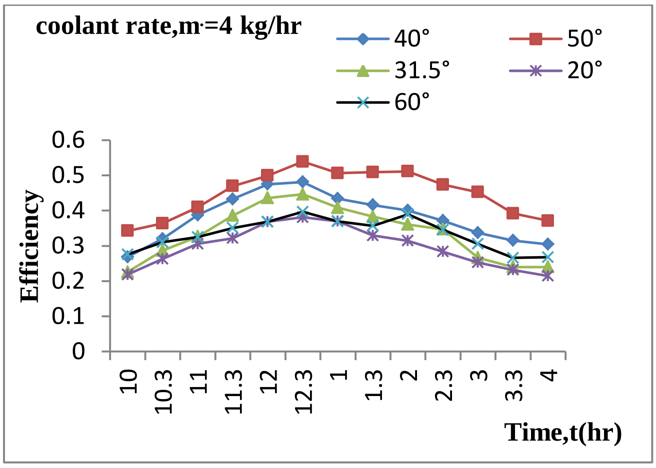

Fig.4 Effect Of Inclination Angle On Collector Efficiency

PART II- WATER-AL_2O_3 NANOFLUID

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° tilt angle is drawn for nanomaterial concentration 0.9 wt %. Fig 5 shows the comparison between the instantaneous efficiency of collector at different coolant rates at tilt angle 50°. Theses 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.

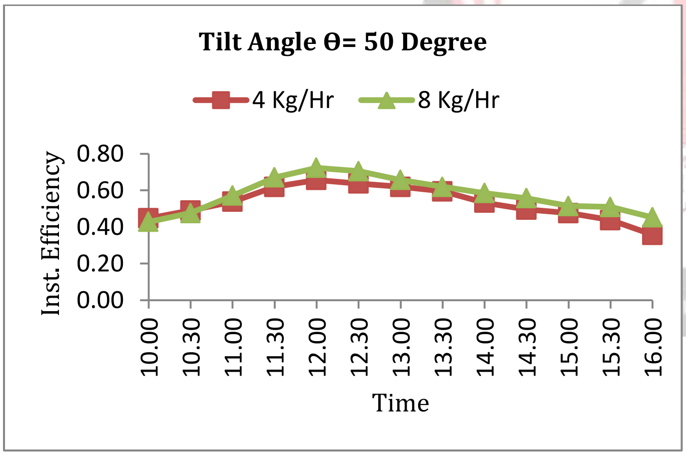

Fig. 5 Variation Of Efficiency With Time For 0.9 Wt% Al_2o_3 Nanofluid At 4 And 8 Kg/Hr Coolant Rate

EFFECT OF INCLINATION ANGLE & NANOFLUID CONCENTRATION

Fig 6 shows effect of inclination & nanofluid concentration for coolant rate 4 kg/hr. Maximum efficiency is found to be at 50° tilt angle. 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. Result shows that increase in concentration of nanomaterial in base fluid enhances the performance of solar collector. 0.9 wt% nanofluid shows highest performance for both coolant rates.

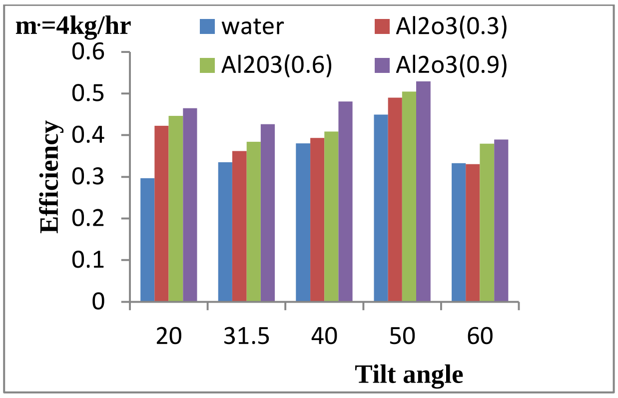

Fig.6 Effect Of Angle And Nanofluid Concentration On Average Efficiency For Al_2o_3

PART III- WATER-CUO NANOFLUID

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° tilt angle is drawn for nanomaterial concentration 0.9 wt %. Fig 7 shows the comparison between the instantaneous efficiency of collector at different coolant rates at tilt angle 50°. Theses 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.

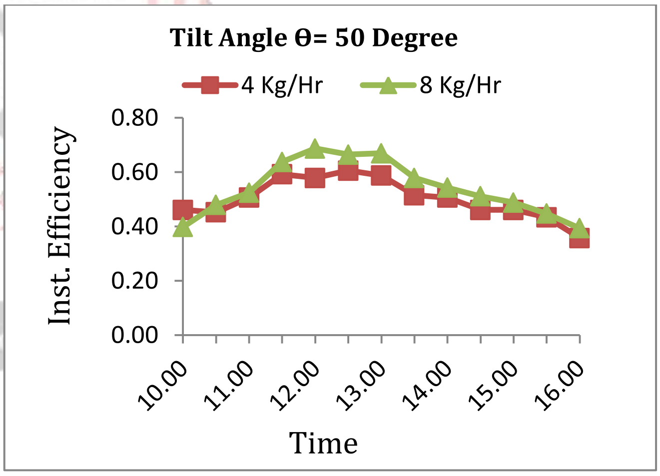

Fig. 7 Variation Of Efficiency With Time For 0.9 Wt% Cuo Nanofluid At 4 And 8 Kg/Hr Coolant Rate

EFFECT OF INCLINATION ANGLE & NANOFLUID CONCENTRATION

Fig 8 shows effect of inclination & nanofluid concentration for coolant rate 4 kg/hr. Maximum efficiency is found to be at 50° tilt angle. 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. Result shows that increase in concentration of nanomaterial in base fluid enhances the performance of solar collector. 0.9 wt% nanofluid shows highest performance for both coolant rates.

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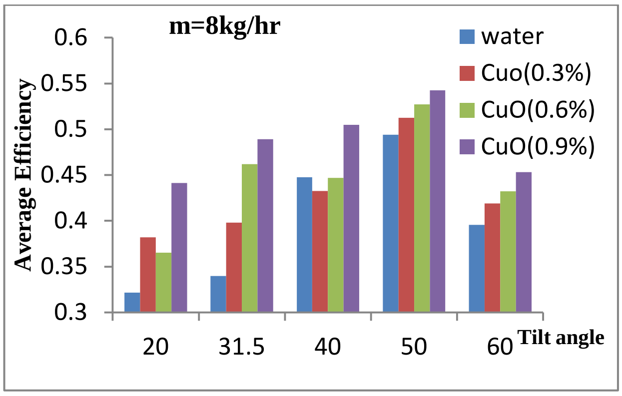

Fig.8 Effect Of Angle And Nanofluid Concentration On Average Efficiency For Al_2o_3

COMPARATIVE STUDY

From Fig. 9 shows that the variation of average efficiency of solar heat pipe collector for 0.9 wt% nanofluid concentration. 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

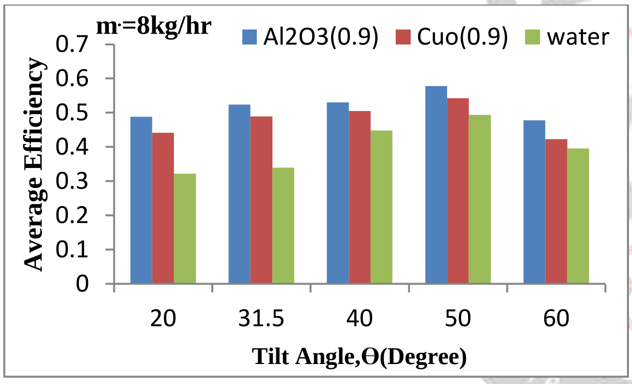

Fig. 9 Variation Of Average Efficiency For 0.9 Wt % Nanofluid & Water At Various Inclinations

IV. CONCLUSION

From the experimental investigation of heat pipe solar collector following conclusion are drawn:

FOR WATER

1) Efficiency of heat pipe solar collector depends on working fluid, coolant flow rate, heat flux at evaporator and inclination angle.

2) When coolant rate is increases up to 8 Kg/hr, collector efficiency of heat pipe solar collector increases but after that increase in coolant rate has no effect on collector efficiency.

3) Collector efficiency of heat pipe solar collector is increases as inclination angle increases from 20^0 to 50^0. While further increase in inclination angle, reduces the collector efficiency.

COMPARATIVE CONCLUSION

1) From the experimentation it is observed that, Collector efficiency increases by using nanofluid as a working fluid rather than water.

2) Al_2O_3 nanofluid has greater potential to enhance the collector efficiency of heat pipe solar collector than that of CuO nanofluid.

3) Collector efficiency of heat pipe solar collector is increases as concentration of nanomaterial increase from 0.3 wt% to 0.9 wt% for both nanomaterials.

4) Collector efficiency of solar collector is increases as angle of inclination increases up to 50^0. But further increase in inclination angle, collector efficiency decreases.

5) The maximum efficiency for both the nanofluid was obtained at 50^0 inclination angle and 0.9 wt% concentration.

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