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Thermal Performance of Wickless Heat Pipe Flat Plate Solar Collector with CuO-BN/Water Hybrid Nanofluid

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ABSTRACT

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. 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 nanoparticles 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.

Keywords: **Wickless heat pipe, Nanofluid, Flat plate solar collector, Heat transfer rate, Thermal conductivity**.

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I.INTRODUCTION

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. Flat-plate collectors are used extensively for domestic water heating applications. It is simple in design and has no moving parts so requires little maintenance. It is an insulated, weatherproofed box containing a dark absorber plate under one or more transparent covers. Flat-plate heat-pipe solar collectors have their own set of advantages, including simpler structure, lower cost, easier manufacture and simple operation. The lower efficiency of flat-plate collectors is mainly due to the heat loss via the cover surface due to conduction and convection. Standard flat-plate collectors have typical efficiencies of 50% or less, while evacuated devices have efficiencies of about 50–80%. It would be desirable to develop a new structure for flat plate collectors that would overcome heat loss problems and allow a high efficiency to be achieved, while its capital cost still remains low. Thermosyphons are enclosed, passive two phase heat transfer devices. They make use of the highly efficient heat transport process of evaporation and condensation to maximize the thermal conductance between a heat source and a heat sink. They are often referred to as thermal superconductors because they can transfer large amounts of heat over relatively large distances with small temperature differences between the heat source and heat sink. The amount of heat that can be transported by these devices is usually several orders of magnitude greater than pure conduction through a solid metal. They are proven to be very effective, low cost and reliable heat transfer devices for applications in many thermal management and heat recovery systems.

They are used in many applications including but not restricted to passive ground/road anti-freezing, baking ovens, heat exchangers in waste heat recovery applications, water heaters and solar energy systems and are showing some promise in high-performance electronics thermal management for situations which are orientation specific. A cross section of a closed two-phase thermosyphon is illustrated in Fig.1; the thermosyphon consists of an evacuated sealed tube that contains a small amount of liquid. The heat applied at the evaporator section is conducted across the pipe wall causing the liquid in the thermosyphon to boil in the liquid pool region and evaporate and/or boil in the film region. In this way the working fluid absorbs the applied heat load converting it to latent heat.The vapour in the evaporator zone is at a higher pressure than in the condenser section causing the vapour to flow upward. In the cooler condenser region the vapour condenses thus releasing the latent heat that was absorbed in the evaporator section. The heat then conducts across the thin liquid film and exits the thermosyphon through the tube wall and into the external environment. Within the tube, the flow circuit is completed by the liquid being forced by gravity back to the evaporator section in the form of a thin liquid film. As the thermosyphon relies on gravity to pump the liquid back to the evaporator section, it cannot operate at inclinations close to the horizontal position.

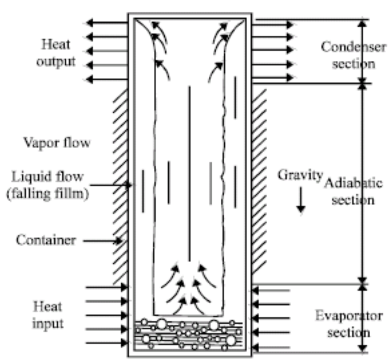

Fig. 1 Two Phase Closed Thermosyphon Fluid Flow

Since our experiment deals with thermal performance as well as thermal enhancement of flat plate solar collector, we have used conventional fluid water in first set of heat pipe flat plate solar collector. Second flat plate heat pipe solar collector consists of nanofluid whose composition consists of Copper oxide, CuO (0.63% by volume) and Boron Nitride, BN (0.47% by volume) in 0.5lit distilled water.

II. LITERATURE REVIEW

The developments are being carried out continuously in the field of cover materials, absorber plate materials, absorber and glazing coating etc. along with the changes in the design, fluid used for heat transfer. Numbers of studies have been carried out on thermal performance of solar water heater and found more increase in the thermal efficiency in comparison to conventional solar water heater. These studies include use of double side absorber plate, honeycomb material, nanomaterial'sand more efficient coatings.

Lee et al. [1] performed research specifically on nanofluids with oxide particles at Argonne National Laboratory. This experiment examined Al2O3 and CuO nanoparticles dispersed in both deionised water and ethylene glycol and their related thermal conductivities as measured by the transient hot-wire method. A strong dependence on particle size and an almost linear increase of conductivity with volume fraction of the particles were found. CuO nanoparticles were found to have a greater heat transfer effect than Al2O3 particles, which was suggested to be due to the CuO particles being smaller.

Abreu and Colle [2] focused on the experimental analysis of the thermal behaviour of two-phase closed thermosyphons with an unusual geometry characterized by a semi-circular condenser and a straight evaporator.

Noie[3] presented in his work an experimental studyof a thermosyphons of (980 mm length and25 mm internal diameter) made of smoothcopper tube, with distilled water as aworking fluid. The goal of the study was toobtain the thermal characteristics of thethermosyphon (temperature distribution inthe outer wall along the tube, boiling heatcoefficient and the maximum heattransfer rate), at: heat supply ($100 < Q < 900$W), filling ratios ($30\% \leq FR \leq 90\%$) andlength of the evaporator (varying the lengthof electrical resistance).

Negishi and Sawada[4] made an experimental study on the heat transfer performance of an inclined two-phase closed thermosyphon. They used water and ethanol as working fluids. The highest heat transfer rate was obtained when the filling ratio (ratio of volume of working fluid to volume of evaporator section) was between 25% and 60% for water and between 40% and 75% for ethanol. The inclination angle was between 20° and 40° for water, and more than 5° for ethanol.

Zuo and Gunnerson[5] studied the heat transfer of an inclined two-phase closed thermosyphon. They showed that the minimum amount of working fluid remains almost constant from 20º to 90º, with respect to the horizontal axis, and then significantly increase by decreasing the inclination angle. They also found that the highest flooding limit is at an inclination angle ranging from 45º to 60º.

Gabriela Humnic, Angel Huminic, Ion Morjan and Florian Dumitrache [6] 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 and DI-water. The thermosyphon was a copper tube with internal and external diameter of 13.6mm and 15 respectively. The overall of length of thermosyphon was 2000mm (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 thermal performance of thermosyphons.

M. A. El-Nasr, S. M. El-Haggar[7] 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.

Hussein [8]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 section 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.

Sandesh.S.Chougule, S.K.Sahu and Ashok T. Pise[9] A solar heat pipe collector was designed and fabricated to study its performance of the outdoor test condition. The thermal performance of the wickless heat pipe solar collector was investigated for pure water and nanofluid with varied range of CNT nanofluid concentration (0.15%, 0.45%, 0.60%, and 1% by volume) and various tilt angles (20^0, 32^0, 40^0, 50^0, and 60^0). CNT nanoparticles with diameter 10–12nm and 0.1–10μm length are used in the present experimental investigation. The optimal value of CNT nanofluid concentration for better performance is obtained from the investigation. The thermal performance of the heat pipe solar collector with CNT nanofluid is compared to that of pure water.

III. EXPERIMENTAL METHOD

3.1 Experimental setup

To study the thermal performance and enhancement of heat transfer rate of heat pipe flat plate solar collector using nanofluid it is necessary to develop the system containing two 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.Planned objectives are :

(a)To study the effect on heat transfer rate and efficiency of wickless heat pipe flat plate collector using nanofluid. The effects are to be compared with wickless 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.

The prepared system assists in determining the thermal performance of wickless 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 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 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.

3.2 Experimental Procedure

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 10:00am to 4:00pm 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 given mass flow rate 0.00125 kg/sec.

TABLE 1
SPECIFICATION OF DIFFERENT COLLECTOR COMPONENT DIMENSIONS

1. Gross Dimensions
- Length: 0.940 m
- Width: 0.375 m
- Depth: 0.086 m

2. Transparent Cover
- Material: White Glass

3. Absorber Plate
- Material: Copper
- Length: 0.910 m
- Pitch Distance: 0.1 m
- Thickness: 0.001 m
- Coating: Black

4. Wickless Heat Pipes
- Material: Copper
- Outer Diameter: 0.0127 m
- Inner Diameter: 0.0117 m
- Evaporator Length: 0.910 m
- Condensor Length: 0.075 m
- Adiabatic Length: 0.015 m
- Total Length: 1m
- No. of Heat Pipes in each collector: 3
- Working Fluid: Collector No.1: Distilled Water
  CollectorNo.2:CuO-BN/water Nanofluid

5. Insulation
- Material: Glass wool
- Thickness: 0.025m
- Position: Back and sides

6. Box Material
- Frame: Aluminium

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:

$$Q_{in} = I_t.A_{coll} \qquad \text{............. (1)}$$

Where A_{coll} is the area of collector.
Measuring the collector area on which solar radiations fall we get ,
A_{coll} =0.31m^2

$$Q_g = m\, C_w\, (T_o\text{-}T_i) \qquad \text{……….. (2)}$$

Where m is mass flow rate and Cw is specific heat of water

$$\eta_{inst} = Q_g \,/\, Q_{in} \qquad \text{……….. (3)}$$

Where η_{inst} is the instantaneous efficiency

I. RESULTS AND DISCUSSION

Experiments were carried out to investigate the thermal performance of heat pipe solar collector by using various working fluids for heat pipes such as: pure water, CuO-BN/water nanofluid. The results are depicted in Figs. 2-6. The variation of various parameters , namely, the rate of solar energy input, ambient air temperature, inlet water temperature and outlet water temperature for two different wickless heat pipe flat plate solar collectors is shown in Figs. 2-3. It is observed that the solar intensity increases, reached maximum and then falls with time (Fig 2). Peak value of solar radiation intensity is found to be different for various tilt angles. The maximum value average solar intensity was observed at 20°.

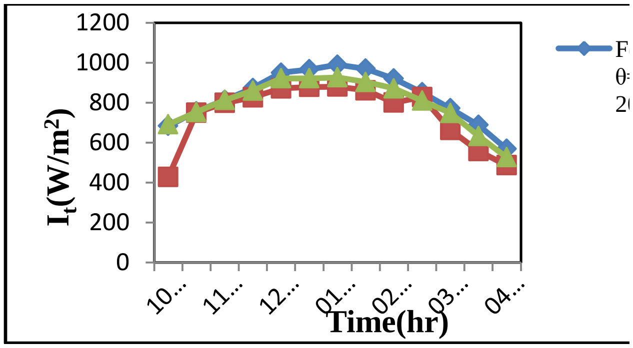

Fig. 2 Variation of solar intensity with time for various tilt angle

In the below Figure 2 we can see the variation of different temperatures namely ambient air temperature, inlet temperature of water to both the collectors, outlet temperature of water from both the collectors.

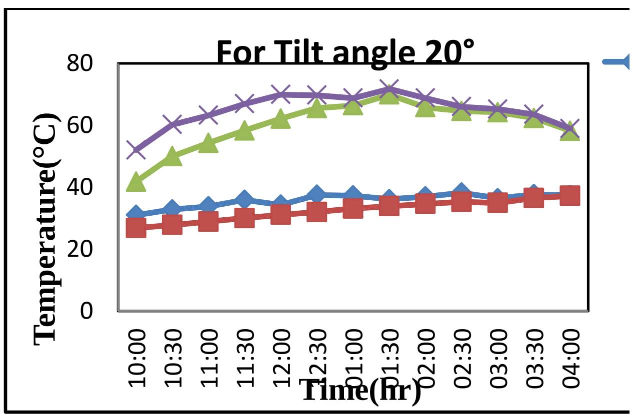

Fig. 3 Variation of temperatures with time for 20° tilt angle

Temperature of water from outlet of solar collector with wickless heat pipe containing nanofluid is greater than that of the solar collector with wickless heat pipe containing pure water. Hence we can conclude about the improvement in performance of wickless heat pipe flat plate solar collector with nanofluid.

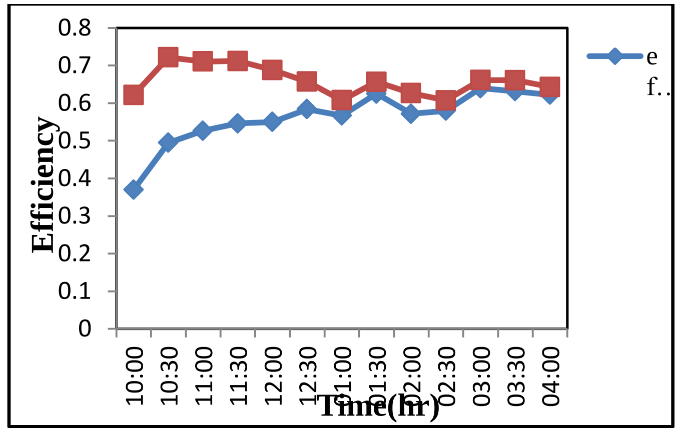

Fig. 4 Variation of efficiency with time for 20° tilt angle

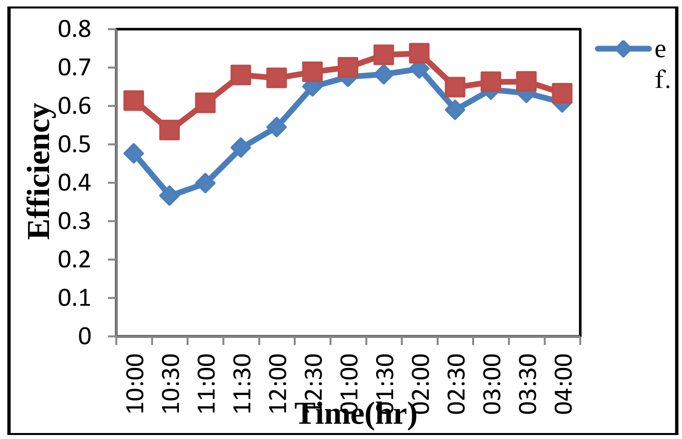

Fig. 5 Variation of efficiency with time for 31.5° tilt angle

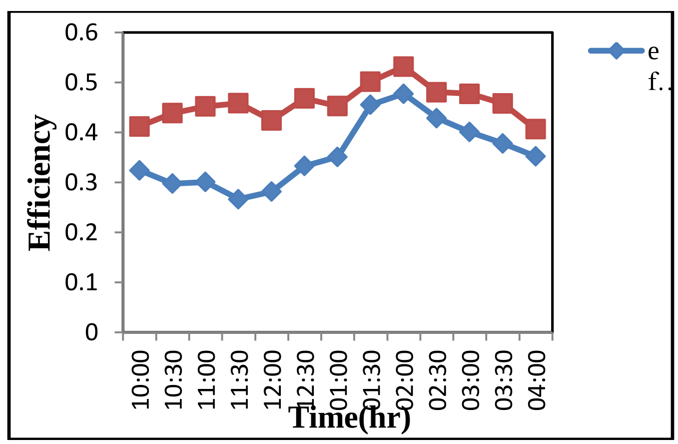

Fig. 6 Variation of efficiency with time for 50° tilt angle

Effect of Tilt Angle:

Tests were performed at tilt angle 20°, 31.5° and

50° in two different solar heat pipe collectors under same climatic conditions. The average collector efficiency of solar collector that uses hybrid nanofluid as a working fluid increases with tilt angle varying from 20°- 31.5° and then decreases from 31.5° -50°tilt angle. The average efficiencies of the collector that uses nanofluid as working fluid are 65.96%, 66.01% and 45.85% at 20°, 31.5° and 50° tilt angle resp. The average collector efficiency of solar collector that uses water as a working fluid increases with tilt angle varying from 20°-31.5° and decreases from 31.5°-50° tilt angle. The average efficiencies of the collector that uses water as working fluid are 56.21% , 57.37% and 35.51% at 20°, 31.5° and 50° resp.The percent increase in instantaneous efficiencies are 9.75% , 8.63% and 10.34% at 20°, 31.5° and 50° tilt angles resp. Thus, we get optimum instantaneous efficiency at tilt angle 31.5° in both the solar collectors.

II. CONCLUSION

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

- The thermal performance of wickless heat pipe flat plate solar collector is higher by using CuO-BN /water hybrid nanofluid followed by conventional working fluid pure water.

- The heat transfer rate is found to increase by increasing the tilt angle from 20° to 31.5° for both cases, namely, pure water and CuO-BN/water nanofluid. While, the heat transfer rate decreases by increasing the tilt angle beyond 31.5° to 50°.

- The optimum performance is obtained at 31.5° for both the collectors.

- The average increase in instantaneous efficiency by using hybrid nanofluid at various tilt angle varied from 10% to 15%.

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