Development of Wickless Heat Pipe Flat Plate Solar Collector

Siddhanath V. Nishandar[1] Rohan Pandurang Kesarkar[2] Sachin Tatoba Hegde[3]
[1]Lecturer [2,3]Student
[1,2,3]Department of Mechanical Engineering
[1,2,3]SITP, Yadrav, India, 416121

Abstract— Solar water heaters are the most developed renewable energy technologies used in the world. For the past several years, conventional flat plate collectors have been well studied and developed. Their relatively low cost, lower maintenance and easy of construction have made these systems very competitive and are widely used all over the world specially for low temperature thermal systems. In this paper, development of budget friendly and simple evacuated heat pipe collector is described. In this paper heat pipes are manufactured by integrating them with nanofluids.
Key words: Heat Pipe, ETC, nanofluids

I. Introduction

In past few years there is a huge increase in design improvement concepts of conventional flat plate collectors as the share of solar energy for hot water production increases. Due to the low energy density and variations in solar energy, designing appropriate heat exchanging system is very crucial task. Application of heat pipes for solar water heating application is at now its now common but extensive studies are required to integrate heat pipe in solar collector systems so as to improvement is needed for better heat transport. Since the invention of heat pipes, their importance in various applications such as solar collectors for domestic water heating, space heating and cooling has received increasing attention.

II. Evacuated Tube Collector

These collectors are efficient and equipped with heat pipes. Their performance is better than flat plate collector. Evacuate tube collectors are widely used in solar thermal systems[1]. Evacuated tube collectors are new and emerging trends in solar systems [2]. Evacuated tubes are developed for high temperatures and high volumes flow rates.

III. Dimensioning Heat Pipe Section

The heat collected at the evaporator (solar absorber) has to be dissipated in the condenser. This needs a careful design of evaporator and condenser length. The condenser length depends on the amount of heat collected and the condensation mechanisms. High heat transfer coefficient in condenser heat exchanger results small condenser length. This can be attained by increasing the velocity of the condensing fluid or any other mechanisms which can increase the heat transfer. The size of the evaporator and the cooling fluid temperature also determine the condenser length. Critical design values have to be considered in sizing the sections of the heat pipe. The adiabatic section depends on how long should be the heat transferred from the evaporator. In solar water heaters the length of adiabatic section doesn't have a merit mostly. Therefore, it is desirable to reduce the adiabatic length as small as possible to minimize the heat loss. For the heat collected from the solar absorber, the condenser length can be optimized:

$$\frac{\dot{Q}_{collector}}{h(T_{hf}-T_{w})} = \pi d_{o,hp} l_{cond} \quad \text{……………. (1)}$$

IV. Nanofluids

Cooling System Liquid Resistively Heated Crucible The thermal conductivity measurement of nanofluids was the main focus in the early stages of nanofluid research. Considering the application of heat transfer fluids, heat transfer coefficients of nanofluids in flow condition is also very important. The important properties other than thermal conductivity that affect the heat transfer coefficients are density, heat capacity and viscosity of dispersions. Since the nanoparticle concentration in nanofluids usually are very low (<1 vol.%), the particle effect on the density and heat capacity of the dispersions is not significant. However, due to the small particle size, the nanoparticle effect on the viscosity of the dispersions might be remarkable, especially for nanotube or other high or low aspect ratio nanoparticle dispersions.[4]

Fig. 1: Heat Pipes

The heat transfer resistance of a flowing fluid is often represented by a Nusselt number, which takes into account the fluid thermal conductivity directly and usually indirectly as well through the Prandtl number. Thus, a first assessment of the heat transfer potential of a nanofluid is to consider its thermal conductivity. To date, more research has been published in this area than in any other related to nanofluids for heat transfer purposes.

In examining the engineering literature, in each case, the thermal conductivity enhancement ratio has been calculated from the information given in the technical papers. The thermal conductivity enhancement ratio, or simply the "enhancement," is defined as the ratio of the thermal conductivity of the nanofluid to the thermal conductivity of the base fluid. The percent enhancement in thermal conductivity is the enhancement ratio, minus one, times 100%. For consistency in this study, the term "enhancement" refers to the enhancement ratio with regard to any parameter such as thermal conductivity, heat transfer coefficient, and Nusselt number.

V. Effect of Nanoparticle Material

The particle material has essentially no effect on the enhancement for relatively low thermal conductivity particles. The situation changes when higher conductivity particles are used,

The metal particles produce the same enhancement as the oxide particles but at much lower volume concentration. It was expected that metal particles would outperform oxide particles owing to the higher thermal conductivity of the former. It is difficult to create metal particle nanofluids without the particles oxidizing during the production process.

The effect of particle size on thermal conductivity enhancement is considered the smallest particles would show the least enhancement,. largest particles would show the most enhancement the thermal conductivity enhancement is largest for the intermediate-sized particle.

Thermal conductivity enhancement in nanofluids was compared with respect to the geometric shape of the particles. When spherical and cylindrical particle shapes are compared. The cylinders show an increase in thermal conductivity enhancement, and this result is thought to be due to a mesh formed by the elongated particles that conducts heat through the fluid. However, elongated particles are superior to spherical for thermal conductivity enhancement. This result points to a direction for nanofluid research and production although spherical particles are often most readily available at the best prices.

The influence of base fluid itself (such as water, ethylene glycol, and pump oil) on the enhancement in thermal conductivity of nanofluids .The results show increased thermal conductivity enhancement for poorer (lower thermal conductivity) heat transfer fluids. the least enhancement for water, which is the best heat transfer fluid with the highest thermal conductivity of the fluids compared. Ethylene glycol alone is a relatively poor heat transfer fluid compared with water, and mixtures of ethylene glycol and water fall between the two in heat transfer effectiveness.

Thus, nanoparticles in ethylene glycol and water mixtures show good potential for engine cooling applications.

VI. DEVELOPMENT OF EXPERIMENTAL SYSTEM

To study the thermal performance and enhancement of heat transfer rate of heat pipe flat plate solar collector it is necessary to develop the system containing heat pipe flat plate solar collector , containing nanofluid along with other accessories and measuring instruments required for measuring required parameters to determine performance characteristics of the collector. Planned objectives are:

1) To study the effect on heat transfer rate and efficiency of wickless heat pipe flat plate collector using nanofluid.
2) 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 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.

Fig. 2: Experimental setup

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. Then the observations are tabulated for further analysis.

VII. COMPONENTS IN THE SYSTEM

A. Wickless Heat Pipe Flat Plate Collector:

System consists of two flat plate collectors, having nanofluid as a working fluid in wickless heat pipe. Each collector consists of three absorber plate and each absorber plate contains one heat pipe filled with working fluid. The design parameters of various components heat pipe flat plate collectors are summarized below. Wickless heat pipes were made of copper tubes with an outer diameter of 12.7 mm and length of 1000 mm. In order to enhance the ability to absorb the solar radiation, the absorber plates were painted dull black in the present investigation. Each individual wickless heat pipe was brazed to the absorber plate at 0.1m pitch. The three absorber plates with heat pipes were housed in a collector case of 940 mm length, 375 mm width and 86 mm depth. Thick insulation glass wool behind the absorber plate was used in order to avoid any loss of energy to the surroundings. Transparent glass was used as the upper glazing for the collector.

Fig. 3: Glass wool as wick material

B. Specifications of Collector Components:

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
Condenser Length: 0.075 m
Adiabatic Length: 0.015 m
Total Length: 1m
No. of Heat Pipes in each collector: 3
Working Fluid: Nanofluid/water

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

6) Box Material:
Frame: Aluminium

VIII. NANOFLUID PREPARATION

Modern fabrication technology allows the fabrication of materials at the nanometer scale. Nanoparticles are a class of materials that exhibit unique physical and chemical properties compared to those of larger (micron scale and larger) particles of the same material. Nanoparticles used in nanofluids have been made out of many materials, and the fabrication of nanoparticles can be classified into two broad categories: physical processes and chemical processes.

Some nanoparticles materials that have been used in nanofluids are oxide ceramics (Al_20_3, Cu0), nitride ceramics (AIN, SiN, BN), carbide ceramics (SiC, TiC), metals (Ag, Au, Cu, Fe), semiconductors ($Ti0_2$), single, double or multi-walled carbon nanotube (SWCNT, DWCNT, MWCNT), and composite materials such as nanoparticles core-polymer shell composites. In addition, new materials and structures are attractive for use in nanofluids where the particle- liquid interface is doped with various molecules.

Nanoparticles in most materials discussed are most commonly produced in the form of powders. In powder form, nanoparticles can be dispersed in aqueous or organic host liquids to form nanofluids for specific applications. To date, many types of host liquids have been used, but ethylene glycol and water mixtures are the most desirable for automotive applications. Several materials for the nanoparticles seem to have good potential for such applications.

In the present work, nanofluids are prepared by two step method. Copper oxide (CuO) nanopowder is purchased from SISCO. The average particle size (APS) of CuO nanopowder is 40nm. This nanopowder was mixed in calculated proportion in 500ml of distilled water. We added 20gm of CuO (0.63% by volume) and in 500ml of distilled water. Then the nanofluid was stirred well for proper mixing of nanopowder. The prepared nanofluid was then delivered to Golden Star Technical Services Pvt. Ltd., Pune, the manufacturers of heat pipe, for charging the heat pipe with nanofluid.

Fig. 4: CuO and BN Nanopowder

Fig. 5: CuO-BN/water Nanofluid

IX. CONCLUSION

This work has been carried out to develop heat pipe solar collector by using working fluids for heat pipes such as CuO/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/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/water nanofluid. While, the heat transfer rate decreases by increasing the tilt angle beyond 31.5° to 50°.
- The average increase in instantaneous efficiency by using hybrid nanofluid is observed.

REFERENCES

[1] I.Budihardjo, G.L.Morrison, M.Behnia, "Natural circulation flow through water-in-glass evacuated tube solar collectors", Solar Energy ,vol. 81, pp. 1460-1472, 2007.
[2] D.Y.Goswami, S.Vijayaraghavan, S.Lu, G.Tamm, "New and emerging developments in solar energy", Solar Energy, vol.76, pp.33-43, 2004.
[3] P.D. Dunn, D.A. Reay, Heat Pipe, third ed., Pergamon Press, New York, 1982.
[4] Faghri, Heat Pipe Science and Technology, Taylor & Francis, London, 1995.
[5] U. Ortabasi, W.M. Buehl, An internal cusp reflector for an evacuated tubular heat pipe solar thermal collector, J. Solar Energy 25 (1) (1980).
[6] Georgie, Simulation and experimental results of a vacuum solar collector with storage, J. Energy Conv. Manage. 462 (2005) 1423–1442.
[7] S.L. Abreu, S. Colle, An experimental study of two-phase closed thermosyphons for compact solar domestic hot water systems, J. Solar Energy 76 (2004) 141–145.
[8] S.B. Riffat, X. Zhao, P.S. Doherrty, Developing of a theoretical model to investigate thermal performance of a thin membrane heat pipe solar collector. Appl. Therm. Eng. 25 (2005) 899–915.
[9] S.B. Riffat, X. Zhao, A novel hybrid heat pipe solar collector/CHP system, J.Renew. Energy 29 (2004) 2217–2233.
[10] J. Facao, A.C. Oliveira, Analysis of a plate heat pipe solar collector, Int. Conf.Sustain. Energy Tech. Nottingham, UK (2004) 28–30.
[11] S.A. Nada, H.H. El-Ghetany, H.M.S. Hussain, Performance of two-phase closed thermosyphons solar collector with shell and tube heat exchanger, J. Appl.Therm. Eng. 24 (2004) 1959–1968.
[12] T.Y. Bong, K.C. Ng, H. Bao, Thermal performance of a flat-plate heat pipe collector array, J. Solar Energy 50 (6) (1993) 491–498.