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Thermal Performance Evaluation of Heat Pipe using Nanofluid

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ABSTRACT

The effect of filling ratio in heat pipe on the thermal performance like thermal efficiency was experimentally studied using copper nanofluid. Heat pipes are widely used for the thermal control of electronic device due to this high performance. In this experimental work three circular heat pipes are manufacture, one containing conventional working fluid (water) and remaining two containing 1% and 2% volume fraction of Cu/H2O nanofluid as working fluid. An experimental system is set up to measure the temperature distribution of heat pipes along the surface and calculate the thermal efficiency of copper nanofluid under different concentration. Concerning heat transport limitations, the copper nanofluid show the advantages over the conventional working fluids. The experimental results show that the higher efficiency of the heat pipe obtained with a concentration of 2% than the other concentration for all orientations.

Keywords— Heat pipe, copper nanofluid, efficiency, resistance.

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I. INTRODUCTION

Heat pipes are tremendously efficient heat transfer devices that utilize a phase change of the working fluid inside of the container and it quickly transport large amount of heat from evaporator section to the condenser section. In evaporator section, the heat is absorbed by the working liquid via evaporation and this vapour condenses at a condenser section to release the latent heat. The condensed liquid is then drawn back to the evaporator by the capillary force by means of wick structure which is kept at the inside of the heat pipe to complete a thermal cycle. A good heat pipe is characterized by a low thermal resistance and a high dry-out tolerance. The heat pipe has been widely applied for electronics cooling, air conditioning, power generation, chemical engineering and spacecraft cooling.

Due to the limitation of fossil fuel in the world, subject of energy consumption optimization in various industrial processes becomes very important. In chemical processes the most important devices related to energy and heat transfer are heat pipe. For decades, efforts have been done to enhance heat transfer, reduce the heat transfer time, minimize size of heat pipe, and finally increase energy and fuel efficiencies. Most of them are limited by inherent restriction of thermal conductivity of the conventional fluids (such as water, mineral oil and ethylene glycol). The poor heat transfer properties of the employed fluids in the industries are obstacles for using different types of heat exchangers.

Modern Nanotechnology provides new opportunities to process and produce materials with average crystallite sizes below 50nm. Fluids with nanoparticles suspended in them are called nanofluids, a term proposed in 1995 by Choi of the Argonne National Laboratory, U.S.A. (Choi, 1995). Nanofluids can be considered to be the next-generation heat transfer fluids because they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids. They are expected to have superior properties compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The much larger relative surface area of nanoparticles, compared to those of conventional particles, should not only significantly improve heat transfer capabilities, but also should increase the stability of the suspensions. Some of the common oxide nanoparticles being used in heat transfer research are Zinc Oxide (ZnO), Copper Oxide (CuO), Aluminum Oxide (Al2O3), and Titanium Oxide (TiO2) while some of the metal nanoparticles are Gold (Au), Silver (Ag), and Copper(Cu).Nanofluids can improve abrasion-related properties as compared to the conventional solid/fluid mixtures. Necessary studies need to be carried out before wide application can be found for nanofluids

II. LITERATURE REVIEW

M.G.Mousa et al [1] carried out an experimental study on an effect of nanofluid in Circular Heat Pipe. The nanofluid consisted of Al2O3 nanoparticles with a diameter of 100 nm. The experimental data of the nanofluids were compared with those of DI water including the wall temperatures and the total heat resistances of the heat pipe. Experimental results showed that if concentration of the nanofluid increasing, then the thermal resistance of heat pipe decreased.

Shang et al [2] investigated the heat transfer characteristics of a closed loop OHP with Cu–water nanofluids as the working fluid different filling ratios. The results were compared with those of the same heat pipe with distilled water as the working fluid. The experimental results confirmed that the use of Cu–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%. It was confirmed that directly adding nanoparticles into distilled water without any stabilizing agents had greater heat transfer enhancement compared to the case where a stabilizing agent was added to the distilled water.

S. Kang et al [3] carried out an experimental study of nanofluid is employed as the working medium for a conventional 211 lm wide. 217 lm deep grooved circular heat pipe. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nanoparticles. The experiment was performed to measure the temperature distribution and to compare the heat pipe thermal resistance using nanofluid and DI-water. The tested nanoparticle concentrations ranged from 1 mg/l to 100 mg/l. The condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constant-temperature bath maintained at 40^0C. At a same charge volume, the measured nanofluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of 30–60 W. The measured results also show that thermal resistances of the heat pipe decrease as the silver nanoparticle size and concentration increase

Wei et al [4] used a cylindrical micro-grooved heat pipe with the inner diameter and the length of 6 mm and 200 mm respectively .The width and the depth of the rectangular groove were 211 lm and 217 lm, respectively. The working fluid consisted of silver nanoparticles with an average particle size of 10 nm and pure water. They mainly measured the total heat resistance of the heat pipe filled with pure water and nanofluids. The total heat resistance of the heat pipe using nanofluids could decrease by 28%–44% compared with that of the heat pipe using water.

Tsai et al [5] performed an experiment concerning a cylindrical mesh wick heat pipe. The working fluid was an aqueous solution of various-sized gold nanoparticles. The inner diameter and the length of the test copper tube were 6 mm and 170 mm, respectively. A 200 mesh screen was distributed on the inner wall. The number of mesh layers was unknown. The experimental results showed that the total heat resistance of the heat pipe reduced 20%–37% due to the addition of nanoparticles. Result shows the total resistance of the heat pipe for nanofluids of various particle sizes.

Lin et al [6] investigated experimentally the thermal performance of a closed loop oscillating heat pipe using nanofluids. They applied water-based silver nanofluids at different volume fractions (100 ppm and 450 ppm) and various filling ratios (20%, 40%, 60%, and 80%). The silver nanoparticle had a diameter of 20 nm. Results showed that the thermal performance of the oscillating heat pipe using nanofluids was better than that using water. The best filling ratio was reported to be 60%.

Bhuwakietkum john et al [7] investigate the internal flow patterns and heat transfer characteristics of a closed-loop oscillating heat-pipe with check valves. The ratio of number of check valves to meandering turns was 0.2. Ethanol and a silver nano-ethanol mixture were used as working fluids with a filling ratio of 50%. Results show that the main flow pattern changes from a bubble flow with slug flow and annular flow to a dispersed bubble flow.

Cheng et al [8] experimentally and theoretically investigated the heat transfer performance of flat plate oscillating heat pipes, which were created by machining grooves on both sides of a copper plate. Acetone, water, diamond–acetone, gold–water, and diamond–water nanofluids were tested as working fluids. The thermal resistance was further decreased when the nanofluids was used as the working fluid. It was observed that high-volume fraction diamond–water nanofluids was not stable but settled with time and reduces thermal performance.

III.DESIGN AND EXPERIMENTATION

3.1 Design of heat pipe

Design parameter for heat pipe is the heat load, in this experimental work it is proposed to design the heat pipe which carry heat load of 500 W

Parameters regarding the proposed three heat pipes will be finalized such as material of the heat pipe, heat pipe diameter, length of heat pipe, length of evaporator, adiabatic and condenser section, filling ratio, wick material ,size of wick, vacuum in heat pipe and volume concentration of nanofluid for two heat pipes. The additional properties required to calculate the heat pipe working limits can be taken from the standard literature whereas the properties related to nanofluid can be calculated from the following correlations available in the literature.

Nanofluids Thermal and Flow Properties

The thermal and flow properties of nanofluid are calculated using different available correlations as below:

Thermal conductivity using Timofeeva correlations as below:

$$K_{nf} = [1+3\phi]K_w$$

Viscosity of nanofluid using Drew and Passman correlations as below:

$$\mu_{nf} = [1+2.5\phi]\mu_w$$

The density and specific heat using Pak and Cho correlations as below

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_w$$

$$Cp_{nf} = \phi Cp_{np} + (1-\phi)Cp_w$$

Design procedure for proposed heat pipe:-

Heat pipes undergo various heat transfer limitations depending on the working fluid, the dimensions of the heat pipe, and the heat pipe operational temperature.

Viscous limitation:

The viscous limit occurs at low operating temperatures, where the saturation vapor pressure may be of the same order of magnitude as the pressure drop required driving the vapor flow in the heat pipe. This results in an insufficient pressure available to drive the vapor. The viscous limit is sometimes called the vapor pressure limit

$$Q_{vp} = \frac{\pi . r_v^4 . h_{fg} . \rho_{v,e} . P_{v,e}}{12 . \mu_{v,e} . l_{eff}}$$

Sonic limitation :

The sonic limit is due to the fact that at low vapor densities, the corresponding mass flow rate in the heat pipe may result in very high vapor velocities, and the occurrence of choked flow in the vapor passage may be possible.

$$Q_s = 0{,}474 . A_v . h_{fg} . (\rho_v . P_v)^{0,5}$$

Entrainment limitation:

The entrainment limit refers to the case of high shear forces developed as the vapor passes in the counter flow direction over the liquid saturated wick, where the liquid may be entrained by the vapor and returned to the condenser. This results in insufficient liquid flow of the wick structure.

$$Q_e = A_v . h_{fg} . \left(\frac{\rho_v . \delta_l}{2 . r_{c,ave}} \right)^{0.5}$$

Boiling limitation:

The boiling limit occurs when the applied evaporator heat flux is sufficient to cause nucleate boiling in the evaporator wick. This creates vapor bubbles that partially block the liquid return and can lead to evaporator wick dry out. The boiling limit is sometimes referred to as the heat flux limit.

$$Q_b = \frac{4\pi . l_{eff} . \lambda_{ef} . T_v . \sigma_v}{h_{fg} . \rho_v . \ln \frac{r_i}{r_e}} . \left(\frac{1}{r_n} - \frac{1}{r_{c,e}} \right)$$

On the basis of the above correlations and the properties of heat pipe the above mentioned limits will be calculated and the proposed heat pipe will work within the temperature limit only when the heat load calculated for various limits will be greater than the proposed heat load capacity of single heat pipe.

TABLE I
SPECIFICATIONS OF HEAT PIPE

Parameters of Heat Pipe	Specifications
Heat pipe material	Copper (Cu)
Diameter of heat pipe	20 mm
Total length of heat pipe	600 mm
Length of evaporator section	150 mm
Length of adiabatic section	300 mm
Length of condenser section	150 mm
Wick	Internally grooved
Filling ratio	50%

3.1 Design of heat pipe

A schematic view of the experimental system is shown in Fig.1. The length, outer diameter and wall thickness of the heat pipe were 350 mm, 8 mm and 0.6 mm, respectively. The height, bottom width and top width of each trapezium groove were 0.14 mm, 0.16 mm and 0.20 mm, respectively. The evaporator section, adiabatic section and condenser section of the heat pipe were 100 mm, 100 mm and 150 mm long, respectively. The evaporator section was heated by an electrical heater surrounding at its circumference. The condenser section was cooled by cooling water circulating in a constant-temperature thermal bath. The temperature and flow rate of the cooling water were fixed at constant values for keeping steady cooling conditions in the condenser section for varying heat fluxes.

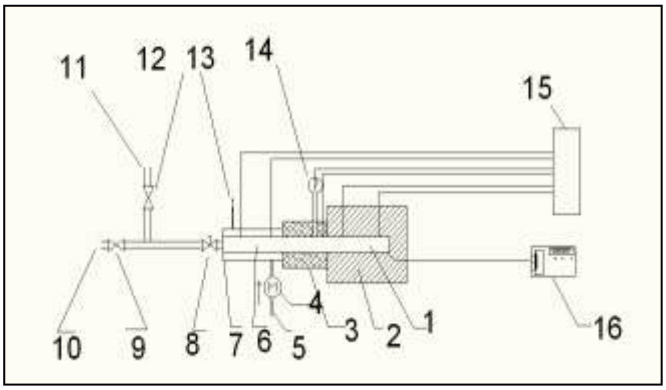

Fig 1.Schematic of experimental Set up

1.Electrical heater, 2,3.Insulation layer, 4.Flow meter, 5.Inlet of cooling water, 6.heat pipe, 7.Cooling jacket, 8,9.Vacuum valve, 10.Liquid filling inlet, 11.Vaccum pumping inlet, 12.Vaccum valve, 13.Outlet of cooling water, 14.Pressure transducer, 15.Data acquisition system, 16.Rctifier.

3.2 Test Methodology

1. The heat pipe body is made up of copper, with a length of 600 mm, outside and inside diameter of 20 mm and 19.6 mm respectively.
2. The heat pipe is charged with 50% of working fluid, which approximately corresponds to the amount required to fill the evaporator. The distance between the evaporator and the condenser is normally called as the adiabatic section with a length of 300 mm.
3. The wall temperature distribution of the heat pipe in adiabatic zone is measured using five evenly spaced, at an equal distance from the evaporator.
4. The adiabatic section of the heat pipe is completely insulated with the asbestos material layer. The amount of heat loss from the evaporator and condenser surface is negligible.
5. The electrical power input is applied at the evaporator section using cylindrical electric heater attached to it with proper electrical insulation and the heater is energized with 230V AC supply and measured using a voltmeter and ammeter connected in parallel and series connections respectively.
6. The evaporator and condenser have a length of150 mm. In order to measure the average temperature of the

evaporator, two thermocouples are distributed along the length of evaporator.

7. Water jacket has been used at the condenser end to remove the heat from the pipe.

8. The heat pipe has the ability to transfer the heat through the internal structure. As a result, a sudden rise in wall temperature occurs which could damage the heat pipe if the heat is not released at the condenser properly. Therefore, the cooling water is circulated first through the condenser jacket, before the heat is supplied to the evaporator.

9. The condenser section of the heat pipe is cooled using water flow through a jacket with an inner diameter of 25.4 mm and outer diameter of 30 mm. The water flow rate is measured using a rotameter on the inlet line to the jacket, the flow rate is kept constant at 6.6 lpm, to measure the average temperature of the condenser, three equally spaced thermocouples distributed along the length of condenser.

10. The inlet and outlet temperatures of the cooling water are measured using two thermocouples.

11. The experiments are conducted using three identical heat pipes which are manufactured as per mentioned dimensions. One of the heat pipes is filled with distilled water, second one with 1% aqueous solution of nano fluid (CuO), third one with aqueous solution of 2% hybrid nano fluid.

12. The power input to the heat pipe is gradually raised to the desired power level. The surface temperatures at five different locations along the adiabatic section of heat pipe are measured at regular time intervals until the heat pipe reaches the steady state condition. Simultaneously the evaporator wall temperatures, condenser wall temperatures, water inlet and outlet temperatures in the condenser zone are measured.

13. Once the steady state is reached, the input power is turned off and cooling water is allowed to flow through the condenser to cool the heat pipe and to make it ready for further experimental purpose.

14. The steady state condition is defined as a state in which the variation of temperature is within 100C for 10 min. Then the power is increased to the next level and the heat pipe is tested for its performance.

15. Experimental procedure is repeated for different heat inputs (25, 50, 75 and 100 W) and different inclinations of pipe (0^0, 30^0, 60^0 and 90^0) to the horizontal position and observations are recorded. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow.

IV. RESULT AND ANALYSIS

4.1 Heat pipe data reduction/calculations:

The ultimate aim of the variation of inclination angle, heat input and volume concentration of hybrid nanofluid on circular heat pipe is to study its effect on thermal resistance. The overall thermal resistance of circular heat pipe is calculate by equation-

$$Rth = \frac{Te - Tc}{Q}$$

Where Te and Tc are the average wall temperatures of evaporator and condenser section and can be determined by following equations-

$$Te = \frac{1}{n}\sum_{i=0}^{n} Ti$$

$$Tc = \frac{1}{m}\sum_{i=0}^{m} Ti$$

Q is heat at evaporator section and calculated by following equation-

$$Q = VI$$

Where V and I are input voltage and current which is measured by digital voltmeter with resolution of 1 V and ammeter with resolution of 0.001 A respectively.

V. RESULT AND DISCUSSION

Graphs show variation in thermal resistance with power for different angle of inclination of heat pipe for water, 1%, 2% volume fraction of nanofluid.

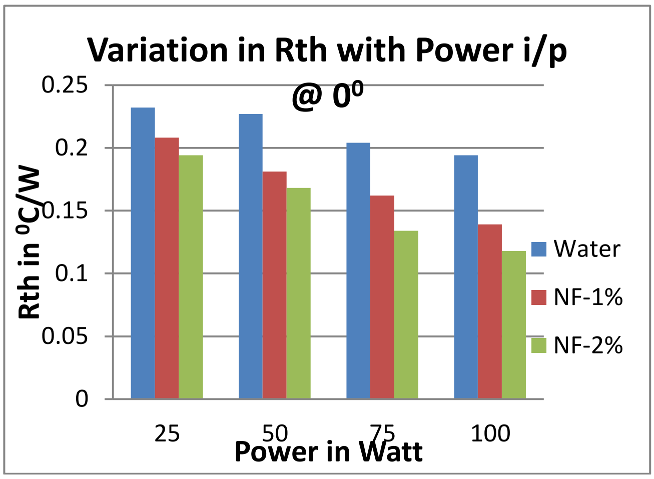

Fig. No. 01: Variation in Thermal resistance with Power input for 0^o inclination angle

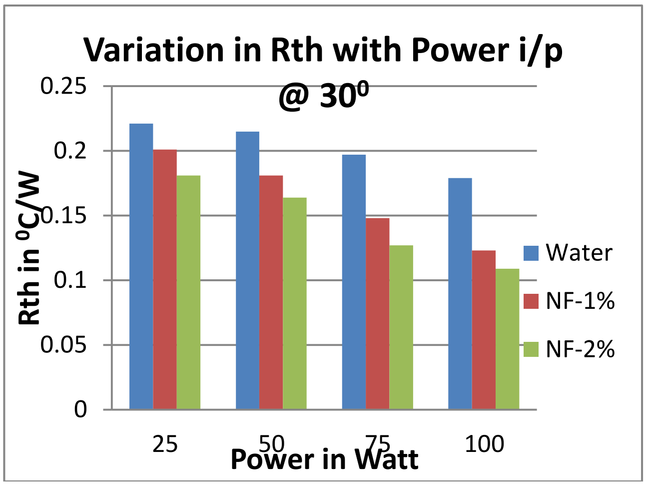

Fig. No. 02: Variation in Thermal resistance with Power input for 30^o inclination angle

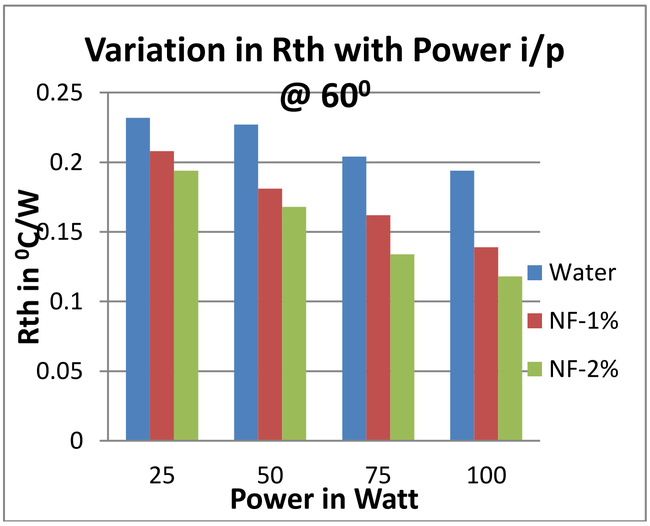

Fig. No. 03: Variation in Thermal resistance with Power input for 60^{o} inclination angle

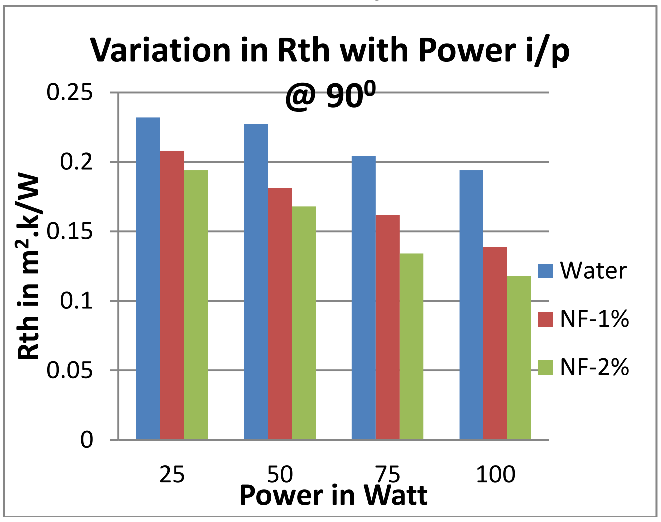

Fig. No. 04: Variation in Thermal resistance with Power input for 0^{o} inclination angle

VII CONCLUSIONS

This analysis discusses the thermal enhancement of circular heat pipe performance using CuO/Water hybrid nanofluid as working fluid. For that purpose the effect of different concentration of nanofluid, inclination angle, heat input on thermal resistance of circular heat pipe is studied. From the experimentation the following conclusions can be drawn.

- Thermal resistance of circular heat pipe decreases with increase in volume concentration of nanofluid, increase in heat input and increase in inclination angle compared with distilled water as working fluid.
- With increase in the volume concentration of nanofluid the thermal resistance of circular heat pipe for 2% volume concentration of nanofluid as working fluid reduces by an amount of 16.37% compared with distilled water as working fluid.
- With increase in the inclination angle of circular heat pipe the thermal resistance reduces. For 2% volume concentration and variation in inclination angle from 0^0 to $90^0$for hybrid nanofluid as working fluid thermal resistance reduces by an amount of 11.20 % compared with distilled water as working fluid.
- With increase in the heat input of nanofluid the thermal resistance of circular heat pipe reduces. For variation in heat input from 25W to 100W and inclination angle of 0^0 for 2% volume concentration of hybrid nanofluid as working fluid it reduces by an amount of 16.37 % compared with distilled water as working fluid.

From the above experimentation it is concluded that the circular heat pipe using hybrid nanofluid as working fluid can give the promising results compared with water as working fluid.

REFRENCES

1. S. Choi, Nanofluids for improved efficiency in cooling systems, in: Heavy Vehicle Systems Review, Argonne National Laboratory, April 18-20, 2006.
2. K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator), Appl. Therm. Eng. 30 (2010) 2685-2692.
3. R.S. Vajjha, D.K. Das, P.K. Namburu, Numerical study of fluid dynamic and heat transfer performance of Al2O3 and CuO nanofluids in the flat tubes of a radiator, Int. J. Heat Fluid Flow 31 (4) (2010) 613-621.
4. M.G. Khan, A. Fartaj, D.S.K. Ting, An experimental characterization of cross flow cooling of air via an in-line elliptical tube array, Int. J. Heat Fluid Flow 25 (2004) 636-648.
5. C. Cuevas, D. Makaire, L. Dardenne, P. Ngendakumana, Thermo-hydraulic characterization of a louvered fin and flat tube heat exchanger, Exp. Therm. Fluid Sci. 35 (2011) 154-164.
6. A.A. Avramenko, D.G. Blinov, I.V. Shevchuk, Self-similar analysis of fluid flow and heat-mass transfer of nanofluids in boundary layer, Phys. Fluids 23 (2011)082002.
7. S.M. Peyghambarzadeh, S.H. Hashemabadi, M. Seifi Jamnani, S.M. Hoseini, Improving the cooling performance of automobile radiator with Al2O3/water Nanofluid, Applied Thermal Engineering 31 (2011) 1833-1838.