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EFFECT OF COPPER NANOFLUID CONCENTRATION ON THERMAL PERFORMANCE OF HEAT PIPES

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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. The nanofluid used in this study was copper nano particles of size 40 nm with a various concentrations of 25 mg/lit, 50 mg/lit, 100 mg/lit and 125 mg/lit. The base working fluid used in this experimental analysis was de-ionized water. 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 100 mg/lit than the other concentration for all orientations.

Keywords: *Heat pipe, copper nanofluid, efficiency, resistance.*

1. 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.

The heat transfer characteristics of the heat pipe have been studied by a number of researchers. Lin et al. (2001) experimentally analyzed the two-phase flow and heat transfer of R141b in a small tube. Song et al. (2004) discussed about the heat transfer performance of axial rotating heat pipes at steady state conditions. Xuan et al. (2004) performed experiment on a flat heat pipe under different heat fluxes, inclinations and the amount of the working fluid.

The requirements of high efficiency and compact size in such electronic devices strongly affect their thermal management that is critical and directly influences cost, reliability, and performances. A good heat pipe is characterized by a low thermal resistance and a higher dry-out limit in evaporator section. The type of heat pipe, thickness of wall, wick porosity and type of structure, and even the contact condition between the wick and the container wall will affect the performance of the evaporator (Mughal. 1996 ; Brautsch, 2002). The most important factor to be considered for the design of heat pipe is related to the characteristics of the evaporator.

All of the heat pipes, including conventional heat pipes and micro heat pipes have common problem of heat transfer limitation. The heat transfer limitations determine the maximum heat transfer rate for a particular heat pipe under the normal working conditions. The various limitations of the heat pipe are continuum flow limit, frozen startup limit, viscous limit, sonic limit, entrainment limit, capillary limit, condenser limit and the boiling limit. Among them the capillary limit and boiling limits are important for heat pipe under the normal working conditions. The heat transfer rate of heat transfer devices like heat pipe can be enhanced by adding additives to the working fluids to change the fluid transport properties and flow features.

One of the methods is to improve the heat transfer limitations use of the nanofluids in the heat transfer equipments to enhance the thermal performance of heat transfer devices. An innovative way to enhance liquid thermal conductivity is the dispersion of highly conductive solid nanoparticles within the base fluid. These new generations of conductive fluids with nanoparticles are referred to as nanofluids (Choi, 2005). The nanoparticles within the fluid change its thermal conductivity, viscosity and density. It has been shown experimentally that, for a given concentration level, the thermal conductivity of the nanofluids increases with a decrease in particle diameter (Anoop et al, 2009 ; Jung et al, 2009). Riehl (2006) has observed that a higher heat transfer coefficient can be seen when using nanoparticles in water under low heat input conditions. Tsaia (2004) investigated the influence of particle size on the heat pipe thermal performance using gold nano particles.

A theoretical model and an experimental setup are proposed to describe the heat transfer performance of nano-fluids flowing inside a tube. Xuan and Li (2000) studied experimentally that the thermal conductivity of nano-fluids remarkably increases as the volume fraction of ultra-fine particles increases. Dos et al. (2003) investigated the increase in thermal conductivity with temperature for nano-fluids with water as the base fluid and Al_2O_3 or CuO particles as suspension material. The results indicated an increase in enhancement characteristics with temperature, which makes the nano-fluids even more attractive for applications with high energy density. Wei et al. (2005) used a cylindrical micro-grooved heat pipe with the inner diameter and the length of 6 and 200 mm, respectively. The width and

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the depth of the rectangular groove were 221 and 217 lm, respectively. The working fluid consisted of silver nanoparticles with an average particle size of 10 nm and DI water. The total thermal resistance of the heat pipe using nanofluids could decrease by 28–44% compared with that of the heat pipe using DI water. Kang et al. (2006) employed the dilute dispersion of silver nanoparticles with 10 and 35 nm diameters into DI water as a working fluid. They showed that the total thermal resistance decreased 10–80% compared to DI water at a heat input of 30–60W under the fixed charge volume. Furthermore, they suggested that the heat pipes were properly operated at the higher power compared with the operating power of the heat pipes with DI water.

Xuan, Qiang Li (2003) studied the convective heat transfer feature and flow performance of Cu-water nanofluids in a tube has experimentally been investigated. The results shows the suspended nanoparticles remarkably enhance heat transfer process and the nanofluid has larger heat transfer coefficient than that of the original base liquid under the same Reynolds number.

From the analysis, the nano fluids have a better thermal performance than the conventional working fluids like water, ethylene glycol etc. The heat pipes are made up of copper container with a two-layered stainless steel wire is used as a wick material. The concentrations of copper nanofluid in the DI water are 25 mg/lit, 50 mg/lit, 100 mg/lit and 125 mg/lit. The nanofluids are prepared using the ultrasonic homogenizer for copper nanofluid and size of the copper particle are 40 nm. The experiments are conducted for various inclinations of heat pipe to the horizontal with different heat inputs. The objective of this work is to study about the effect of nanofluid concentration in thermal efficiency improvement of heat pipe using copper nanofluid.

Table 1. Specification of the heat pipe

Heat pipe material	Copper
Wick material	Stainless steel
Total length of pipe	0.6 m
Evaporator length	0.15 m
Adiabatic length	0.3 m
Condenser length	0.15 m
Outer diameter of the pipe	0.020 m
Inner diameter of the pipe	0.0176 m
Wire mesh Diameter	0.183 mm
Heat Input	30, 40, 50, 60 and 70 W
Heat pipe inclination	0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o
Wick mesh size, m	2365
Type of thermocouple	copper constantan (T type)
Condenser outer diameter, mm	36
Condenser inner diameter, mm	30
Flow rate of water in the condenser jacket, kg/min	0.08

Table 2. Limitations of heat pipe

Limitation	Values in W
Capillary Limit	77
Sonic Limit	65400
Entrainment Limit	4638
Boiling Limit	642

2. EXPERIMENTAL SETUP

The schematic diagram of experiment is shown in fig.1 and the thermocouple locations are shown in fig. 2. The amount of working fluid needed to fill the heat pipe is nearly 40 ml, which is nearly equal to the amount required to fill the evaporator**.** The surface temperature of

Table 3. Operating parameters and its uncertainties

Variable	Unit	Operating range	uncertainty
Water flow meter	kg/sec	0.01 - 1.0	± 1%
Temperature indicator	°C	0 - 200	± 1°C
Power transducer	W	0 - 300	± 1 W

temperature distribution along the evaporator surface (three locations), the condenser section (three locations), inlet and outlet of the condenser jacket also measured using thermocouples. 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 using a variac and measured using a power transducer.

Concentric type of water jacket has been used as a condenser at the end to remove the heat from the pipe. The condenser section of the heat pipe is cooled using water flow through a jacket from the overhead. The water flow rate is measured using a rotameter on the inlet line to the jacket. The inlet and outlet temperatures of the cooling water are measured using thermocouples. The surface of the heat pipe is fully insulated with the glass wool in order to reduce temperature impact from the environment. The heat pipes have their vacuum pumped out, and are charged with the copper nanofluids. The amount of heat loss from the evaporator and condenser surface is negligible. The initial vacuum pressure inside the heat pipe is 70 to 75 cm of Hg.

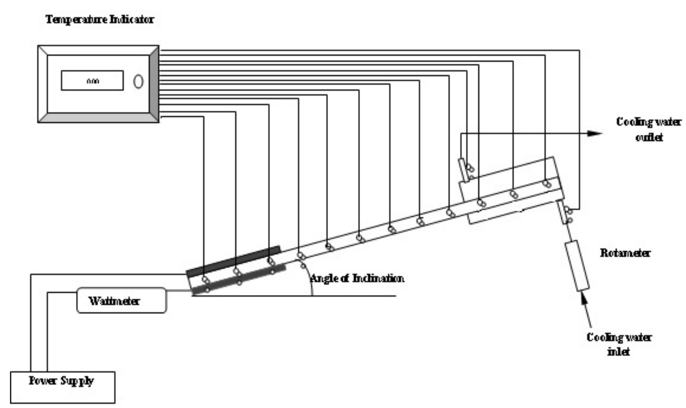

Fig. 1 Experimental setup

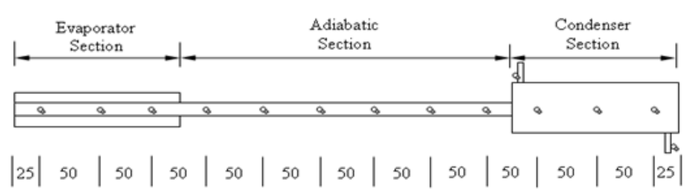

Fig. 2 Thermocouple locations of heat pipe

The experiments are conducted using five identical heat pipes filled with different working fluids which are manufactured as per mentioned dimensions. The power input to the heat pipe is gradually raised to the desired power level. The surface temperatures at six different locations along the adiabatic section of heat pipe, the evaporator wall temperatures, condenser wall temperatures, water inlet and outlet temperatures in the condenser zone are measured at regular time intervals of five minutes until the heat pipe reaches the steady state condition. 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. Then the power is increased to the next level and the heat pipe is tested

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for its performance. This procedure is repeated for different heat inputs and different inclinations of pipe to the horizontal and observations are recorded. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow. The vacuum pressure in the inner side of the heat pipe is monitored by vacuum gauge, which is attached in the condenser end of the heat pipe.

3. RESULTS AND DISCUSSION

The heat pipe thermal efficiency is calculated from the ratio to the cooling capacity rate of water at the condenser section and supplied power at the evaporator section (Senthil et al., 2011). Fig. 3-7 shows that the variations of thermal efficiency of the heat pipe with inclination angle. The thermal efficiency increases with increasing the angle of inclination up to 45° afterwards it starts decreases. The efficiency is higher for 100 mg/lit concentration than the other three concentrations. The reason behind that is the formation of the liquid film in the inner side of condenser section which is at higher rate results in the increased values of the thermal resistance between the vapour of the working fluid and the cooling medium (water) in the condenser. Even though adding the more nanoparticles in the working fluid, the thermal efficiency is decreases due to the set down of the nano particles inside of the container of the heat pipe and also it gives the higher resistance to the fluid flow. Therefore the required pumping power increased and its performance deteriorates.

Figures 8 to 14 show that the variations of thermal efficiency of the heat pipe with heat input given to the evaporator section. The thermal efficiency of the heat pipe increases with increasing the heat input in the evaporator section. It is due to the fact that the temperature difference between the evaporator and condenser sections increases which results in higher evaporation heat transfer rate of working fluid. At higher heat input in the evaporator section, the heat transfer from its surface to the working medium is higher and it causes the working medium which is in the form of vapour to move strongly into the condenser section. The cooling water in the condenser absorbs this excessive heat from the working fluid and as a result the efficiency of the heat pipe increases. Generally, the 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, ethylene glycol etc..

The trial results reveal that the heat pipe efficiency gets reduced when the heat pipe is kept in vertical direction. 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. This problem may not arise if the condenser section is at the base and evaporator at the top and only the capillary action, forces the liquid to move upward towards the evaporator.

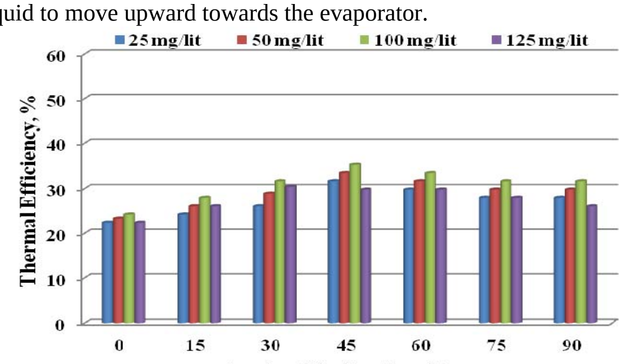

Fig. 3 Variations of heat pipe efficiency for various inclinations at 30 W heat input

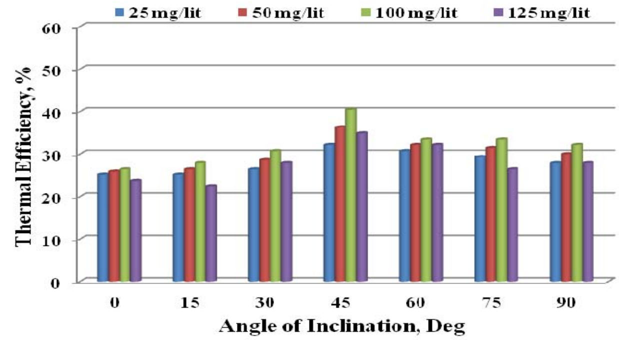

Fig. 4 Variations of heat pipe efficiency for various inclinations at 40 W heat input

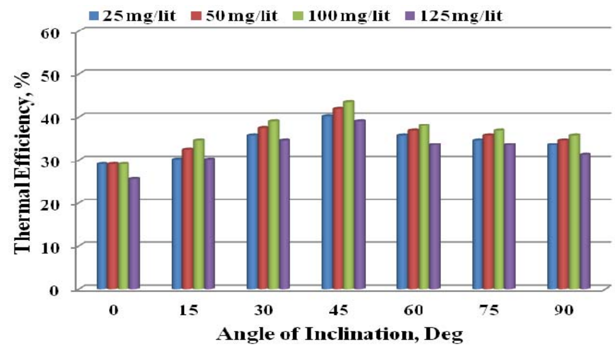

Fig. 5 Variations of heat pipe efficiency for various inclinations at 50 W heat input

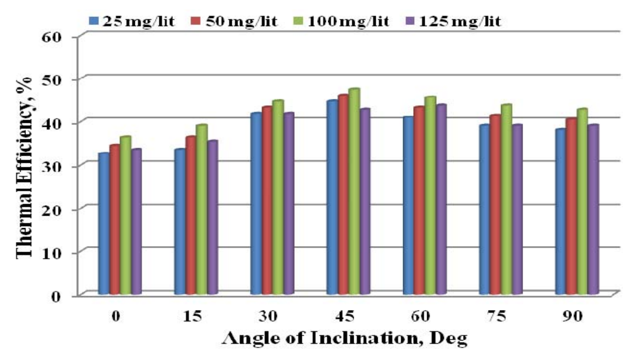

Fig. 6 Variations of heat pipe efficiency for various inclinations at 60 W heat input

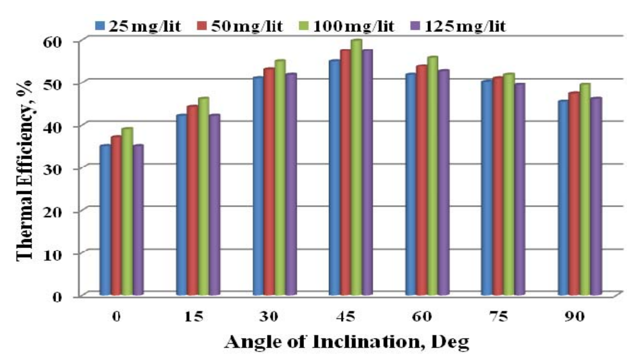

Fig. 7 Variations of heat pipe efficiency for various inclinations at 70 W heat input

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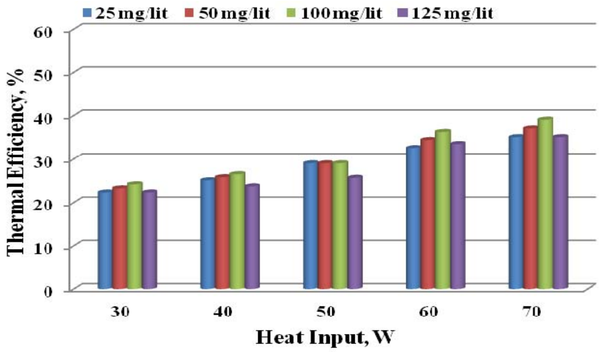

Fig. 8 Variations of heat pipe efficiency with different heat inputs at 0° inclination

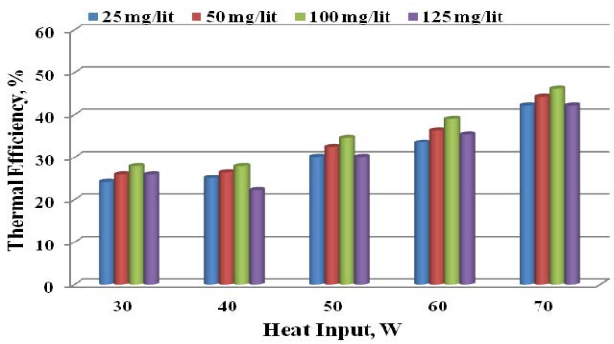

Fig. 9 Variations of heat pipe efficiency with different heat inputs at 15° inclination

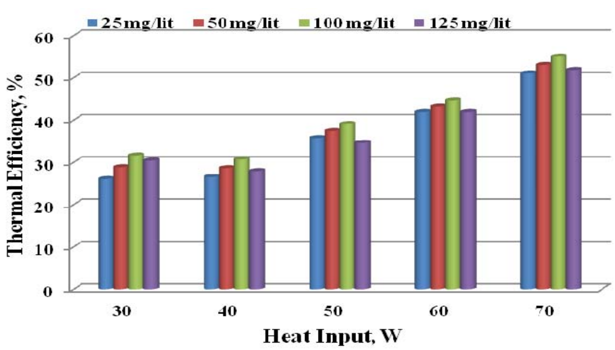

Fig. 10 Variations of heat pipe efficiency with different heat inputs at 30° inclination

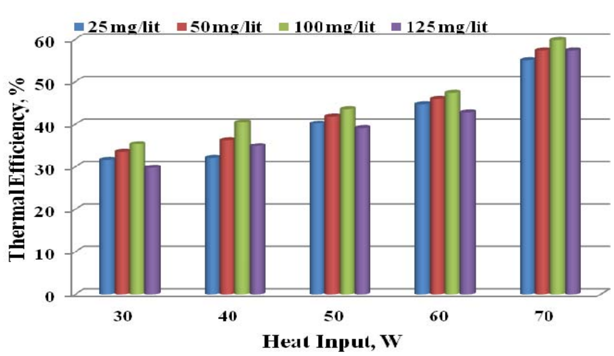

Fig. 11 Variations of heat pipe efficiency with different heat inputs at 45° inclination

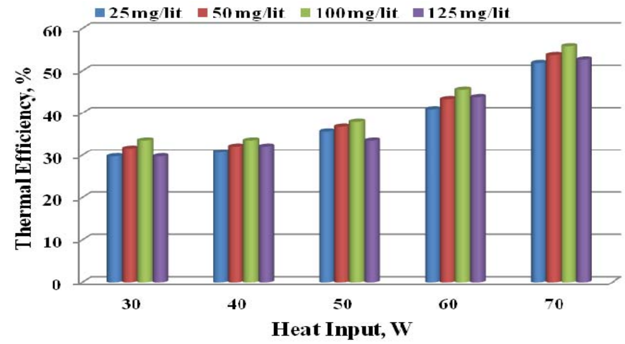

Fig. 12 Variations of heat pipe efficiency with different heat inputs at 60° inclination

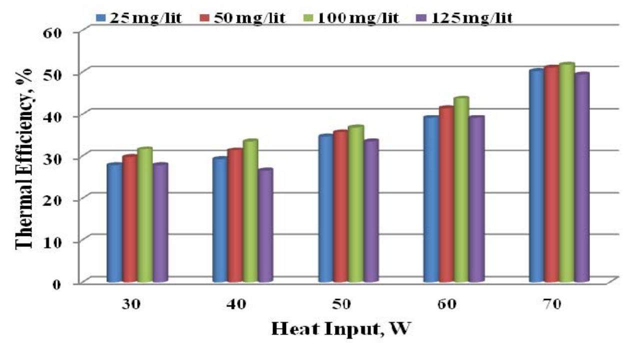

Fig. 13 Variations of heat pipe efficiency with different heat inputs at 75° inclination

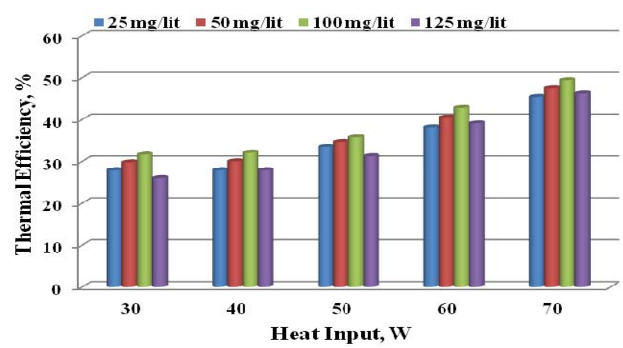

Fig. 14 Variations of heat pipe efficiency with different heat inputs at 90° inclination

4. CONCLUSION

The main aim of this work is to highlight the importance of the copper nanofluid concentrations in the heat pipe under various loads and angle of inclinations. The experiments are conducted with different heat loads and angle of inclinations. The experimental results show that the optimum level of copper nanofluids in the base fluid (DI water). At higher concentrations the copper nanofluids are agglomerates with water; hence its sizes are increased**.** The agglomerated nano particles get deposited gradually and reduce the stability and heat transfer capabilities of the nanofluid. This increased size particles gives the higher resistance to the fluid flow. As a result, the higher thermal performances of nanofluids indicate nano-fluid potential as a substitute for conventional pure water in heat pipes. This finding makes nano-fluids more attractive as a cooling fluid for devices with high energy density. To reveal this phenomenon, further studies on nano-fluid behavior in heat pipes and the properties of nano-fluids may be performed.

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