Effect of Filling Ratio on Thermal Characteristics of Heat Pipe using Titanium Oxide Nanofluid

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Abstract- **An experimental study was carried out to investigate the thermal characteristics of heat pipe using nanofluid and Deionized water (DI water) is presented in this work. The TiO2/water nanofluid is used as one of the working fluid in experimental heat pipe with concentration of 1.0% wt . The test section of the heat pipe is made of copper tube with outer diameter 16 mm, inner diameter 14 mm and length 1000 mm. The heat pipe is tested with (DI water) and nanofluid respectively. This study focused on the effects of heat input, fill ratio and angle of inclination on the thermal efficiency and thermal resistance of heat pipe. The experimental results indicate that the thermal efficiency increases when nanoparticles are added with the DI water (nanofluid) and also the heat pipe which uses nanofluid as working fluid shows lower thermal resistance value when compared to the heat pipe which uses DI water alone.**

***Keywords*: heat pipe, angle of inclination, nanofluid, efficiency.**

I. INTRODUCTION

Heat Energy is one of the important elements which governs life on earth. Heat transport has been one of the most difficult and inefficient tasks in thermal management. It often results in costly heat transfer losses and reduced overall efficiencies. Heat transfer by heat pipes is one of the fastest and most efficient methods for thermal management. It is a promising technology that has received significant research interest due to its simplicity in design and high cooling capacity. It is light in weight with no moving parts, silent in operation and having several hundred times the heat transport capacity as compared to the best metallic heat conductor like silver and copper. Grover et al. (1964) carried out Research and development activities that are generally concerned with new heat pipes development with improved thermal performances, i.e. higher thermal conductance, higher heat transport capacity and larger operating temperature range. Choi (1995) introduced the concept of dispersing the nanoparticle into the fluids which showed enhanced thermal conductivity compared to the fluids containing millimeter and micrometer sized particles. Y. Xuan and Li (2003) and You et al. (2003) studied the convective heat transfer characteristics of nanofluids and showed the enhancement of critical heat flux of nanofluids and pool boiling characteristics when compared with pure water.

Y.Xuan and Q. Li, (2000) developed a model for preparing the various nanofluids by directly mixing various nanoparticles with base fluids which increase the thermal conductivity of nanofluids. Sidi et al. (2005) investigated, by numerical simulation, the hydrodynamic and thermal characteristics of a laminar forced convection flow of nanofluids inside a straight heated tube and showed that the heat transfer enhancement increases considerably with an augmentation of the flow Reynolds number. Wang and Mujumdar (2007) has presented a detailed review on the heat transfer application of nanofluids and also given direction for future research directions. Esen (2004) studied experimentally about the working of solar cooking system by using vacuum tube collectors with heat pipes containing refrigerant as working fluid. Vasiliev (2008) carried out a detailed study about the application of micro and miniature heat pipes in modern heat exchangers for cooling electronic components and fuel cells cooling.Heris.et al.(2006) investigated the laminar flow convective heat transfer through circular tube for Cuo and Al2O3 oxide nanoparticles and showed the highest heat transfer enhancement for higher volume fraction. Jang (2007) studied the effects of various parameters that affected the thermal conductivity of nanofluids and also its influence on the particle volume fraction of the nanoparticles. Do et al. (2010) conducted experiment on the screen mesh wicked heat pipes using Al2O3 nanofluids and showed that the heat pipe performance has been increased up to 40%. Yang et al. (2008) showed that CuO nanofluid can improve the thermal performance of the heat pipe and also presented that an optimal mass concentration of 1.0 wt% is enough to achieve the maximum heat transfer enhancement. Teng et al (2010) conducted experiment and found that the optimal thermal efficiency occurred when the charge amount was 60%, also the added nanoparticles at the concentration of 1.0 wt.%, showed the optimum value of thermal efficiency can be enhanced by 16.8% when compared with based fluid. Senthilkumar et al. (2011) showed experimentally that the aqueous solution n-Hexanol based copper nanofluids enhances the thermal efficiency of the heat pipe and the effect of nanoparticles in the aqueous solution of n-Hexanol has a great effect on the reduction of the thermal resistance than that of DI water and copper nanofluid loaded heat pipes. The aim of the present work is to investigate, experimentally the thermal performance of the heat pipe by using DI water and nanofluid as the working fluids. The experimental parameters considered here are heat input, filling ratio and angle of inclination.

II. EXPERIMENTAL SETUP AND PROCEDURE

2.1 Preparation and characterization of nanofluids

Zhu et al. (2011) studied that the nanofluids of different morphology can be obtained by changing the synthesis parameters. Hence the preparation of nanofluids is an important stage and should be prepared in a systematic and careful manner. A stable nanofluid with uniform particle dispersion is required and the same is used for measuring the thermo physical properties of nanofluids. Basically three different methods are available for preparation of stable nanofluids and are listed below.

a) By mixing of nano powder in the base liquid

In this method, the nanoparticles are directly mixed in the base liquid and thoroughly stirred. Nanofluids prepared in this method give poor suspension stability, because the nanoparticles settle down due to gravity, after a few minutes of nanofluid preparation. The time of particle settlement depends on the type of nanoparticles used, density and viscosity properties of the host fluids.

b) By acid treatment of base fluids

The PH value of the base fluid can be lowered by adding a suitable acid to it. A stable Nanofluid with uniform particle dispersion can be prepared by mixing nanoparticles in an acid treated base fluid. But acid treated nanofluids may cause corrosion on the pipe wall material with prolonged usage of nanofluids. Hence acid treated base fluids are not preferred for preparation of Nanofluids even though formation of stable nanofluids is possible with such base fluids.

c) By adding surfactants to the base fluid

In this method a small amount of suitable surfactant, generally one tenth of mass of nanoparticles, is added to the base fluid and stirred continuously for few hours. Nanofluids prepared using surfactants will give a stable suspension with uniform particle dispersion in the host liquid. The nanoparticles remain in suspension state for a long time without settling down at the bottom of the container. Single step synthesis via wet chemical method has been used for preparing Titanium oxide nanofluid.

2.2 Experimental setup

A schematic diagram of the experimental setup is shown in Fig.1.In this research work the water and TiO_2 nanofluids are used as working fluids and the average size of the nanoparticle used in this study is 50 nm .The concentration of the nanoparticle used in this study is 1% by weight. The body of the heat pipe is made out of copper with the length of 1000 mm, outside diameter 16 mm and the inside diameter 14 mm. Two layers of stainless steel screen mesh wick (number 160) is layered on the inner diameter of the heat pipe. The heat pipe consists of three sections namely evaporator section 350 mm, adiabatic section 300 mm and condenser section of 350 mm in length. An electric heater was applied on the evaporator region to provide the required heat supply and a wattmeter with the required power range and a variac has been integrated into the electric heater circuit to evaluate the exact power supplied. The evaporator and condenser regions were insulated using the glass wool (0.33W/m K) to prevent the heat loss from these regions. Six K-type thermocouples with uncertainty ± 0.10C were calibrated against quartz thermometer and soldered on the surface of the heat pipe to measure the wall temperature at different locations of the heat pipe including two at the evaporator region, two at the adiabatic region, two at condenser region.

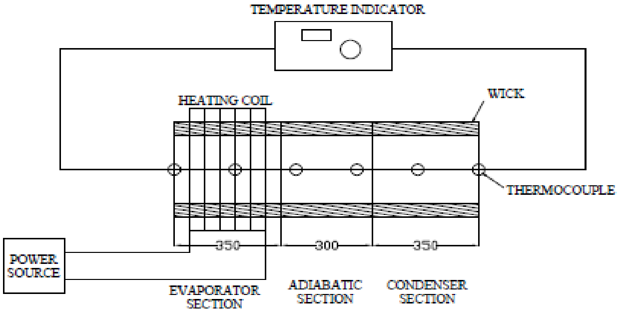

Fig. 1 Experimental setup

2.3 Experimental procedure

Before filling up the working fluid, the heat pipe is evacuated using the vacuum pump to remove the dissolved gases and after evacuation the heat pipe is initially filled with 46 ml (25% fill ratio) of the working fluid. The evaporator region is heated using the power supply to the required value with the help of auto transformer. The temperature rise was monitored for steady state condition and the temperatures are recorded at various locations of the heat pipe using the selector switch. Then the experiment is repeated for different fill ratios (25%, 50%, 75% and 100%) and angle of inclination (00,300,600 and 900).Filling ratio means the percentage of the evaporator section volume that is filled by the working fluids.

3. RESULTS AND DISCUSSION

3.1 Effect of fill ratio on the thermal efficiency of the heat pipe

Figures 3 and 4 indicate the variation of filling ratio in the evaporator region on the thermal efficiency of the heat pipe under various angles of inclinations for both DI water and nanofluids. Choi (1995) studied that the addition of nanoparticles to the base fluid will leads to the increase of thermal conductivity of the working fluid which lead to the increase in heat transfer capability. The heat pipe thermal efficiency can be calculated from the ratio of cooling capacity of water flowing at the condenser section to the heat supplied at the evaporator section. In general the efficiency of the heat pipe increases as the fill ratio of the evaporator region increases due to the reason that fluid absorption capacity greatly depends on the filling ratio of the working fluid and more space for the working fluid.

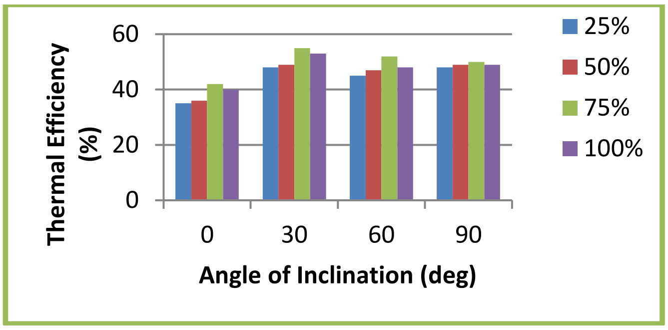

Fig. **3** Efficiency vs. angle of inclination of DI water for various fill ratio at 30W

The results indicates that the efficiency reaches a maximum value for a fill ratio of 75% and gradually decreases when the fill ratio is increased for both the working fluids due to the reason that higher fill ratio leads to lower space for vapour in the condenser area which leads to the decrease of heat transfer rate of the working fluid at the evaporator section.

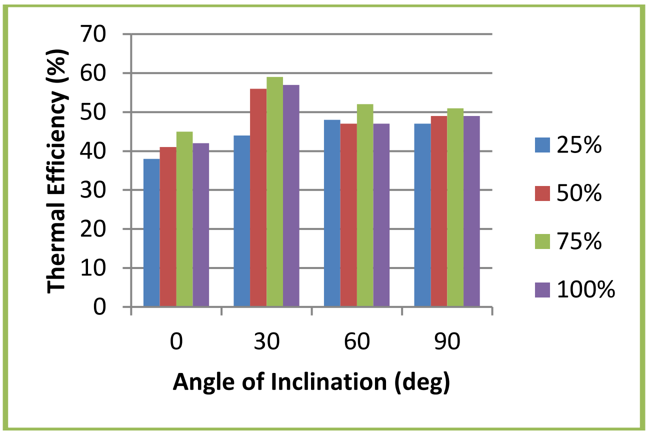

Fig.**4** Efficiency vs. angle of inclination of nanofluids for various fill ratios at 30W

3.2 Influence of fill ratio on the thermal resistance of heat pipe

The thermal resistance (R) of the heat pipe can be calculated by the relation

$$R = \frac{T_e - T_c}{Q}$$

where Te and Tc are the evaporator and condenser surface temperature of the heat pipe respectively and Q is the heat supplied at the evaporator region of the heat pipe. Figures 5-8 shows the variation of thermal resistance for two different working fluids that occur at different heat pipe inclination and fill ratio.

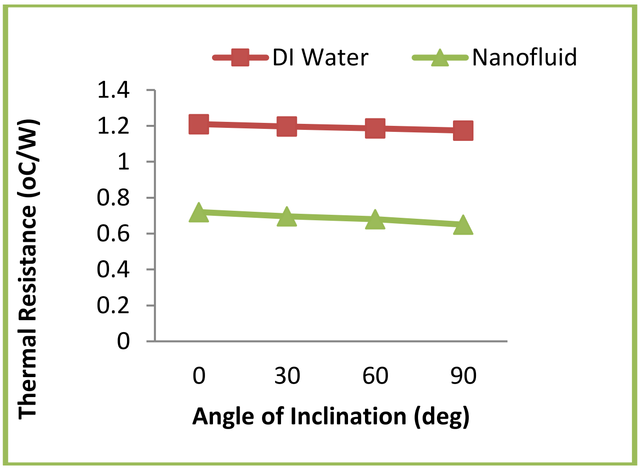

Fig. 7 Thermal resistance distributions for different angle of inclination at 25% fill ratio

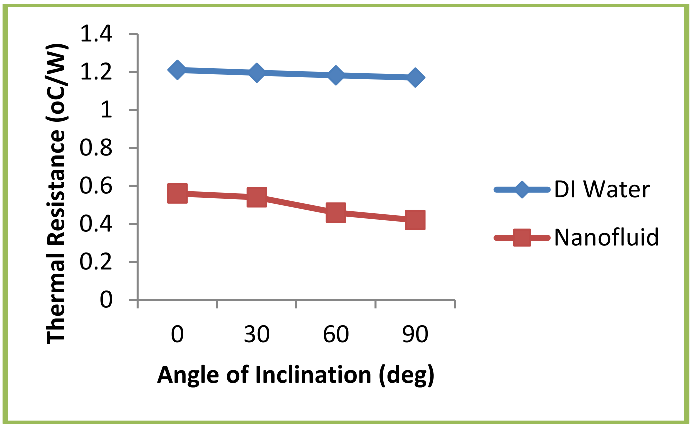

Fig. 8 Thermal resistance distributions for different angle of inclination at 50% fill ratio

The graphs indicate that the thermal resistance of the heat pipe decreases when the inclination angle increases for both the working fluids. Also the heat pipe which uses nanofluid as working fluid shows lower thermal resistance when compared to that of the heat pipe which uses DI water alone. An optimum thermal resistance value of 0.45oCK/W is obtained when the heat pipe is operated under 75% by using nanofluid as a working fluid and the maximum decrease of thermal resistance was about 52 % when compared to DI water. The suspension of nanoparticle in the base fluid increases the thermal conductivity of working fluid. Wen and Y. Ding, (2005) and Patel et al. (2005) studied the formation of molecular nanolayer on the surface of nanoparticle occurs due to the absorption of liquid molecules by the nanoparticles which has higher thermal conductivity compared to the base fluid (DI water).

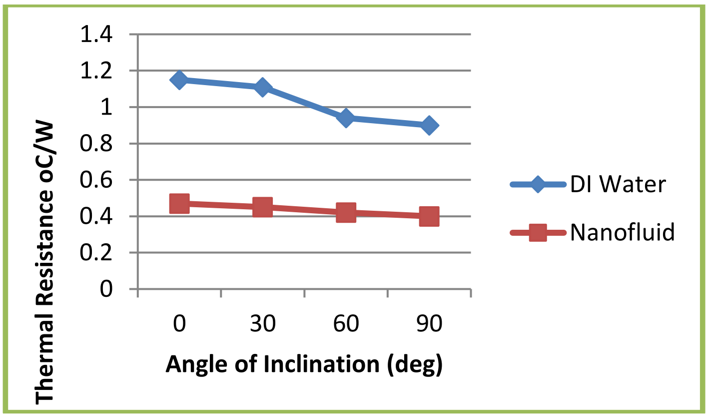

Fig. **9** Thermal resistance distributions for different angle of inclination at 75% fill ratio

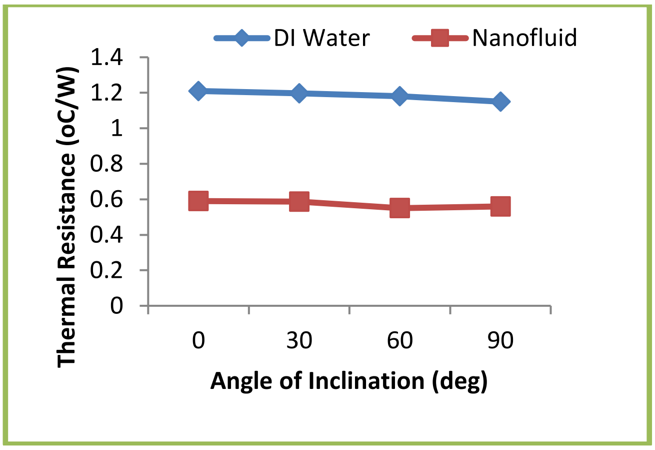

Fig. **10** Thermal resistance distributions for different angle of inclination at 100% fill ratio

II. CONCLUSION

The experiment has been conducted on the heat pipe for various parameters such as angle of inclination and fill ratio. The thermal efficiency for DI water and nanofluid increases when the fill ratio increases and the maximum efficiency is obtained for 75% fill ratio and for an angle of 30o.Comparatively the heat pipe which uses nanofluid as the working fluid shows higher efficiency than the heat pipe using DI water. As far as thermal resistance is concerned the value decreases when the angle of inclination increases and optimum thermal resistance is obtained at 75% fill ratio when the heat pipe is operated by using nanofluid as working fluid with maximum decrease of 62% when compared with heat pipe using DI water alone. From the above results it can be said that nanofluids have higher potential for heat transfer enhancement and can be used for practical heat transfer application process.

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