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Research Article

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Experimental investigation of grooved heat pipe using nanofluids

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ABSTRACT

In the present study, an experimental investigation is performed to determine the performance of the grooved heat pipe using DI water and Iron Oxide nanofluid as the working fluid. The average diameter of DI water and Fe_2O_3 *nanoparticles is 50 nm. In this analysis the parameters considered are heat input, angle of inclination and filling ratio of the working fluid in the evaporator section. The experiment has been conducted with varying heat inputs from 30 to 70 W with 10 W intervals, inclination angle varies from 0° to 90 ° with 15° interval, filling ratio is 75 % with constant flow rate of coolant in the condenser section as 0.08 kg/min. The efficiency and thermal resistance of the grooved heat pipe has been determined and it was observed that* Fe_2O_3 *nano fluids produces better results when compared to the DI Water and 45°orientation of the heat pipe has more excellent performance.*

Keywords: Grooved Heat pipe, Nanofluids, Heat transfer, Thermal Performance, Efficiency.

INTRODUCTION

In a modern era enhancement of heat transport technology has been improved by heat pipes. When compared to conventional methods, the main advantage of heat pipe is to transport very huge quantities of heat through small cross sectional area with desirable distance and it does not requires any external source. The heat pipe is a heat transfer device, which has three regions likely evaporator, adiabatic and condenser. Adiabatic region is also called as transport region. The evaporator section is attached to the heat source and the heat pipe filled with small quantity of working fluid. The working fluid evaporated to vapour in the evaporator region by using the heat availability and that vapour condensed in the condenser region. The condensed fluid return backs to the evaporator region with the help of capillary pressure created by the (wick structure) groove which is provided in the heat pipe. The process proceeds until there is a sufficient pressure, drives the condensate back to the evaporator region.

The startup behavior of conventional water heat pipe with stainless steel as a container material was tested to examine the increase the transport capacity and studied the effect of inclination angle [1]. Jank *et al* studied the transport behavior of copper – water axial grooved heat pipe [2].

Shung – Wen Kang *et al* [3] developed three layer structures radial grooved micro heat pipes with bulk micro-machining and eutectic bonding technique on silicon wafers. The experiments were conducted, to analyze the performance of silicon wafers with three varying wafer filler rates at different heat inputs. From the experimental result observed that the micro heat pipe with 70% fill rates proved the best performance as compared to other filler rates [3]. Balram Suman *et a*l [4] developed a transient model of triangular shape micro-grooved heat pipe. The combined equations of heat, mass and momentum transfer are determined to obtain the transient as well as steady state profiles of various parameters like substrate temperature, liquid pressure and liquid velocity. It was found that the time required 20 s to attain the steady state for the substrate temperature.

Muniappan *et al* [5] developed and tested a trapezoidal axial grooved wick cryogenic heat pipe using nitrogen as a working fluid. They reported that the thermal performance is improved 2.9 times more over solid copper rod at 100K. Liu Yi-Bing [6] developed micro – grooved plate heat pipes with three different shapes like rectangular, trapezoidal and triangular. He inferred that trapezoidal structure of the flat heat pipe shows best heat transfer performance next is rectangular structure followed by rectangular structure. K.N.Shukla [7] presented overview of heat pipes which includes development of loop hat pipes, micro loop heat pipes and micro and miniature heat pipes. The heat pipe mainly acts as a thermal protection system because of its light weight. Wick length enhances capillary fluid flow and working fluid such as nanofluids improve the heat transfer rates of the heat pipe. Hopkins *et al*. [8] investigated numerically and experimentally on a grooved wick structure flat plate heat pipe.

Yi Luo [9] fabricated rectangular shape copper and silicon micro heat pipes and inferred that copper micro grooves possessed a smaller contact angle and best capillary traction. Also it produced 17% higher thermal conductivity than the silicon – grooved micro heat pipes.

The concept of nanofluids was introduced by Choi [10] in the year 1995. Nanofluids are prepared by adding the nano sized metal particles in the base fluid like water, ethylene glycol. The nanofluids are new type of heat transfer and cooling medium because of its higher heat transport and thermal conductivity than the conventional fluids. Yang, and Liu (2008) carried out the thermal performance of a cylindrical miniature grooved heat pipe using aqueous CuO nanofluids under the steady operating pressure conditions and they reported that the thermal performance of the heat pipe had a remarkable increase by adding CuO nanoparticles into the base liquid [11].

The use of nanofluids in heat pipes has more and more attention because of the heat pipes are operated with the phase change of working fluid to transport the heat energy from one end to another end. The selection of working fluid is very important one to enhance the thermal performance of heat pipes. The enhanced heat transfer effects of nanofluids in the single phase and the phase changing heat transfer, researchers have used various nanofluids in heat pipes to enhance their thermal performance [12 & 13]

The performance characteristics of a cylindrical miniature grooved heat pipe using aqueous CuO nanofluid as the working fluid at steady and unsteady cooling conditions were studied and experiment results show that the nanofluid can apparently improve the thermal performance of the heat pipe for steady operation [14]. The total heat resistance and the maximum heat removal capacity of the heat pipe using nanofluids can maximally reduce by 50% and increase by 40% compared with water, respectively. For unsteady startup process, substituting the nanofluid for water as the working fluid, cannot only improve the thermal performance, but also reduce significantly the startup time.

In the present study, grooved heat pipes are fabricated with copper as a container material. The working fluids used in this analysis are DI water and Iron oxide nanofluid. The experiments are conducted for various heat inputs (30, 40, 50, 60 and 70 W) and inclinations (0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o to horizontal). The filling ratio of the working fluid is 75%. The performances of the heat pipes are analyzed based on the thermal efficiency and thermal resistance.

EXPERIMENTAL SECTION

The grooved heat pipe is made up of copper material with evaporator length of 150 mm, condenser length 150 mm and adiabatic length 300 mm. The outer diameter of the heat pipe 9.5 mm and inner diameter of heat pipe 8.75 mm. Heat is supplied to the evaporator with the help of external heat source of capacity 250 W. The heat pipe is fully insulated using glass wool to reduce the heat loss from the surface of the heat pipe. The concentric tube condenser is used to remove the heat from the working fluid in condenser section. K-Type thermocouples are used to measure the surface temperature of the heat pipes as well as inlet and outlet temperature of cooling water which is used in the condenser with accuracy of temperature measurement is ± 0.1 °C. The nano particles used in the experiment were Iron oxide particles with a size of 50 nm immersed in DI water. The mixture was created using an ultrasonic homogenizer. Nanofluid concentration of 100 mg/lit was used in this study. Experiments were conducted DI water and nanofluid as working fluids for different orientation with different heat inputs. The microscopic structure of the grooved heat pipe as shown in figure 1.

The schematic diagram of the experimental setup is shown in the fig. 2. In this experiment, small amount of two different working fluids such as Iron oxide and DI water was used in two different grooved heat pipes of same dimensions. After filling the working fluid in the heat pipe, the input power is given to the evaporator section by using variac and the temperature distribution along the heat pipe was observed at regular interval of five minutes until steady state prevails. The heat pipe takes nearly 60 to 90 minutes to attain steady state. The input power is measured by wattmeter. After attain the steady-state condition had been reached, the temperature distribution was measured and recorded. The process was repeated for different heat inputs from 30 W to 70 W of 10 W regular intervals. The fill ratios used in this experiment was 75% of the evaporator volume for all two different working fluids. The experiments were repeated for various tilt angles (0°, 15°, 30°, 45°, 60°, 75° & 90°).

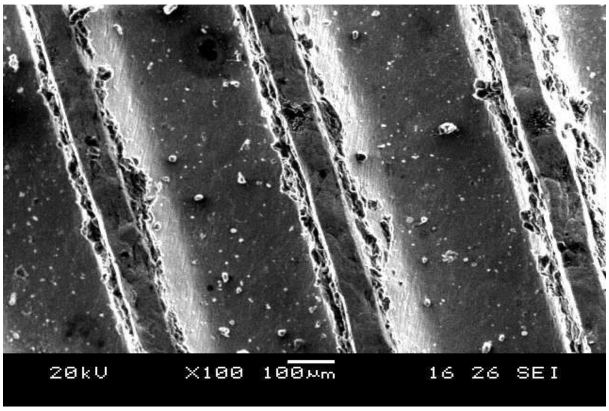

Figure 1. Microscopic structure of grooved heat pipe

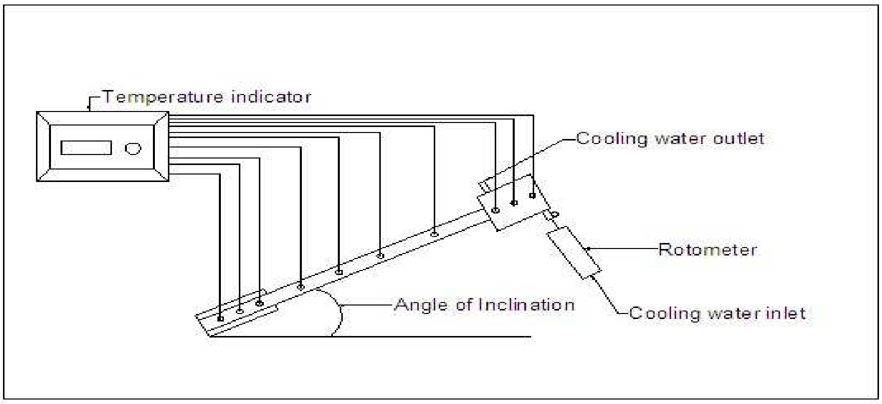

Figure 2 Experimental setup

RESULTS AND DISCUSSION

Variations of Efficiency with Heat Input:

The thermal efficiency of the heat pipe is defined as the ratio of heat carrying capacity of the cooling medium in the condenser section to the to the heat supplied in the evaporator section.

$$\text{Thermal efficiency} = \frac{mC_p(T_{co}-T_{ci})}{Q_{in}} \qquad (1)$$

Where m is the flow rate of cooling water in the condenser in kg/s, C_p is the specific heat of water in J/kg K, Q_{in} is the heat supplied at the evaporator in W, T_{ci} and T_{co} are the temperature of the cooling water in the condenser jacket at inlet and exit respectively in K.

Figures 3 & 4 shows the variations of thermal efficiency with heat input and angle of inclinations for two different working fluids in the heat pipe. It was observed that the input power in the evaporator increases, the temperature difference between the evaporator section and condenser sections of the heat pipe increases and thermal efficiency of the grooved heat pipe also increases. It is owing to the fact that the heat generated in the surface of the heat pipe is larger, the higher rate of heat input in the evaporator section and the working medium which is in the form of vapour moves strongly into the condenser section. As a result the efficiency of the grooved heat pipe increases with the excessive heat in the cooling water absorbed in the condenser. The rise in ambient temperature affects the heat transport rate at higher heat loads. These graphs were used to compare the thermal characteristics of grooved heat pipe using two fluids like DI water and Fe_2O_3 . The efficiency of grooved heat pipe with working fluid Fe_2O_3 gives three times greater than the base fluid (DI water). The tilt angle of 45° gives satisfactory results for both working fluids.

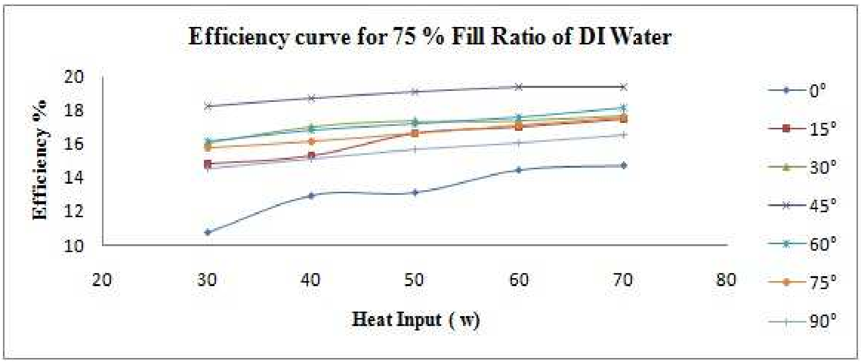

Figure 3 Variations of Efficiency with varying heat inputs for DI Water

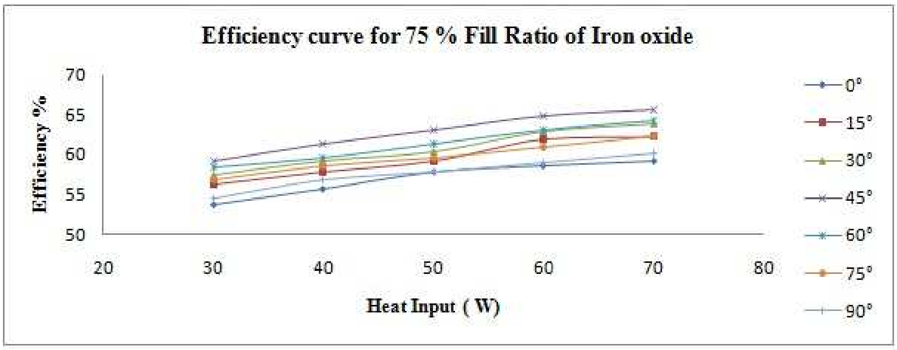

Figure 4 Variations of Efficiency with varying heat inputs for Fe_2O_3

Variations of Thermal Resistance with Heat Input:

The thermal resistance (TR) of the heat pipe is defined as

$$\text{Thermal resistance} = \frac{T_e - T_c}{Q_{in}} \qquad (2)$$

Where T_e and T_c are the average surface temperatures of the heat pipe at the evaporator and the condenser section. Qin is the heat energy supplied in the evaporator section in W.

Figures 5 & 6 show the variations of thermal resistances that occur at different tilt angles for the two different working fluids at different heat inputs. The value of thermal resistance is higher at lower loads than the higher heat loads. Since the evaporation rate at lower heat load is less, therefore the evaporator section has solid liquid film which occupies bottom of the evaporator section. At higher loads the evaporation rate is high and the solid film also removed. So that the value of thermal resistance is gets reduced. These graphs were used to compare the thermal resistance of grooved heat pipe using two fluids like DI Water and Fe_2O_3. The thermal resistance of grooved heat pipe with working fluid Fe_2O_3 gives 1.75 times lower than other fluid. The tilt angle of 45° gives satisfactory results for both working fluids.

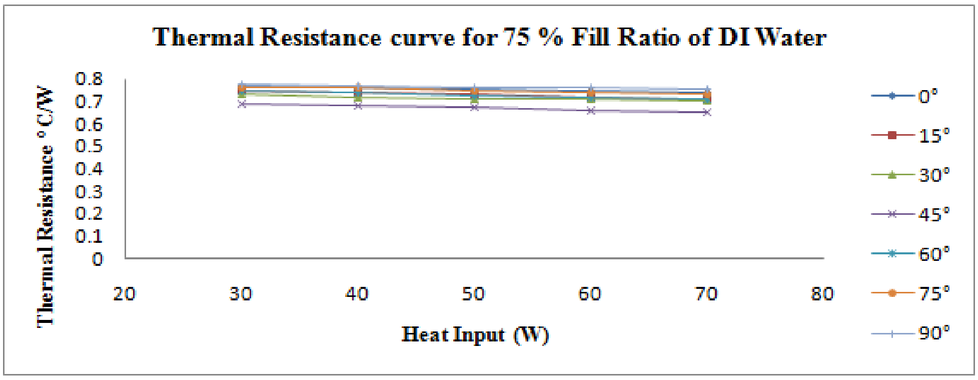

Figure 5 Variations of thermal resistance with varying heat inputs for DI water

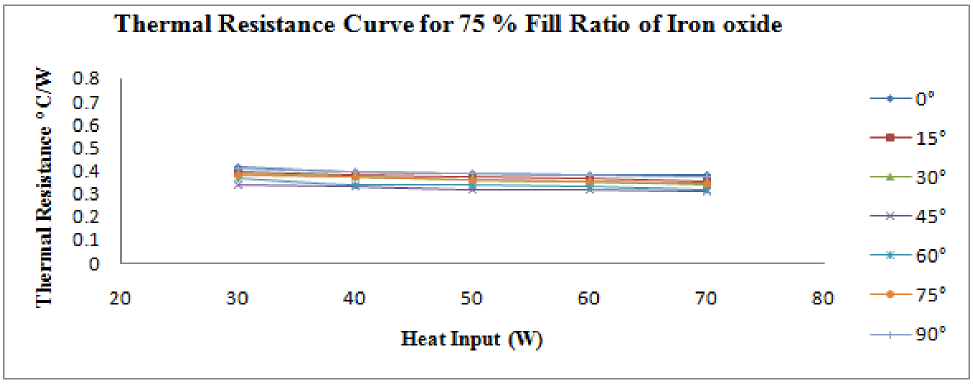

Figure 6 Variations of thermal resistance with varying heat inputs for Fe_2O_3

Comparison of efficiency with varying tilt angle

Figure 7-12 shows the comparative performance of heat pipe for two different fluids and tilt angle varying from 15° to 90° with regular interval of 15 °. It can be seen that the efficiency heat pipe with Fe_2O_3 always produces better results than other fluid for all tilt angles. The tilt angle of 45° gives best results for both working fluids.

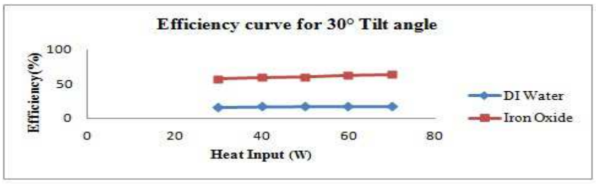

Figure 7. Comparison of Efficiency for two working fluids with 30° tilt angle

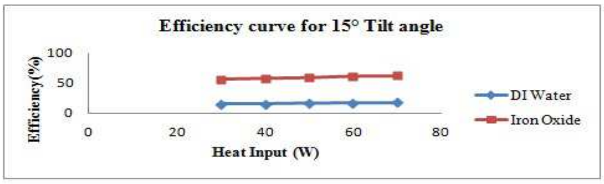

Figure 8. Comparison of Efficiency for two working fluids with 15° tilt angle

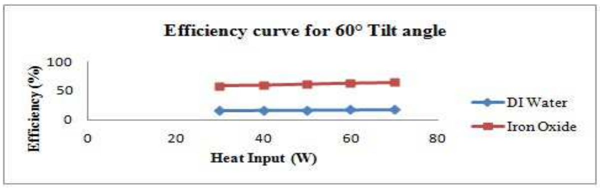

Figure 9. Comparison of Efficiency for tw working fluids with 60° tilt angle

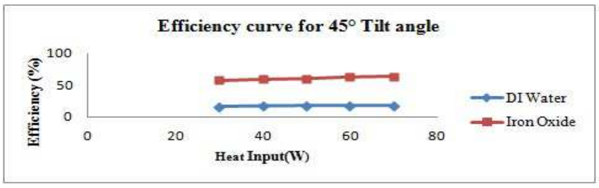

Figure 10. Comparison of Efficiency for two working fluids with 45° tilt angle

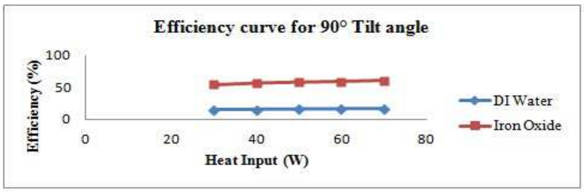

Figure 11. Comparison of Efficiency for two working fluids with 90° tilt angle

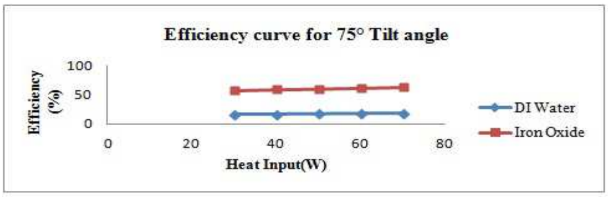

Figure 12. Comparison of Efficiency for two working fluids with 75° tilt angle

Comparison of thermal resistance with varying tilt angle

Figure 7-12 shows the comparative performance of heat pipe for two different fluids and tilt angle varying from 15° to 90° with regular interval of 15 °. It can be seen that the thermal resistance of heat pipe with Fe_2O_3 always produces better results than other fluid for all tilt angles. Heat pipe with DI Water shows the maximum values for all heat inputs and tilt angles. The tilt angle of 45° gives satisfactory results for both working fluids.

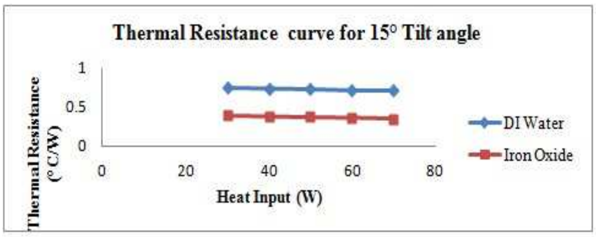

Figure 13. Comparison of Resistance of two working fluids with 15° tilt angle

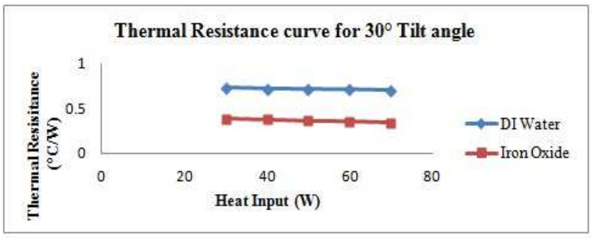

Figure 14. Comparison of Resistance of two working fluids with 30 ° tilt angle

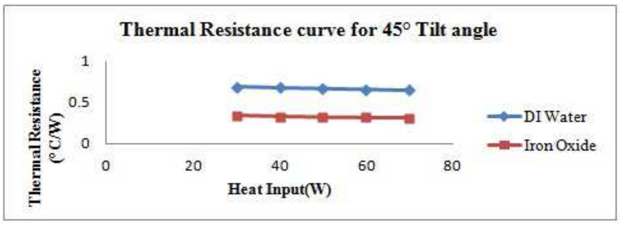

Figure 15. Comparison of Resistance of two working fluids with 45° tilt angle

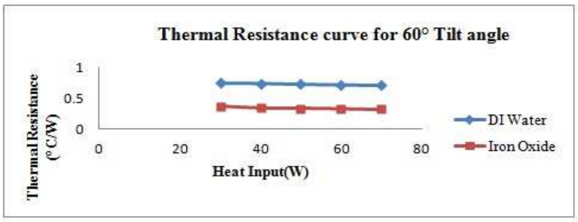

Figure 16.Comparison of Resistance of two working fluids with 60° tilt angle

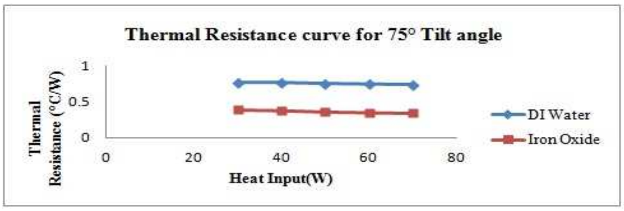

Figure 13. Comparison of Resistance of two working fluids with 75 ° tilt angle

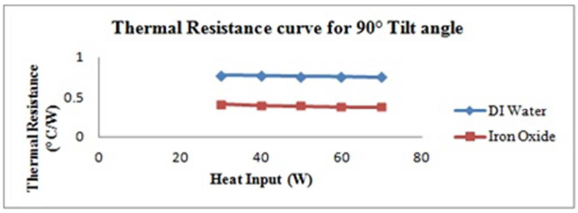

Figure 14. Comparison of Resistance of two working fluids with 90° tilt angle

CONCLUSION

In this study, thermal efficiency and thermal resistance were presented for two different working fluids with different heat inputs and tilt angles. From the experimental results the following conclusions were made.

- From the experimental results, with Fe_2O_3as the working fluid produces better efficiency and thermal resistance than DI Water.
- It was concluded that 45 ° tilt angle shows better performance in both DI Water and Fe_2O_3 grooved Heat pipe.
- Thermal efficiency of the heat pipe with iron oxide nanofluid is three times higher than the base fluid,
- Thermal resistance of the heat pipe with iron oxide nanofluid is nearly 1.75 times less the base fluid,
- Temperature of the adiabatic surface is almost constant.

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