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Thermal Performance of Cylindrical Heat Pipe Using Nanofluid

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ABSTRACT

An experimental investigation is carried out to study the thermal performance of a cylindrical heat pipe operated with the mixture of nanoparticle and base fluid. The mixture of nanoparticle and base fluid is called as nanofluid. In this experimental investigation iron oxide nanoparticles and distilled water as base fluid are used. Iron oxide nanoparticles with average size of 40-50 nm are used. Three cylindrical heat pipe containing screen mesh were fabricated and tested with distilled water and iron oxide nanofluid with volume concentration of 1% and 2% as working fluids. Effects of volume concentration of nanofluid, heat pipe inclination, various heat input on the thermal efficiency of heat pipe are considered. The thermal efficiency of heat pipe with nanofluids is compared with the base fluid.

Keywords— Heat Pipe, nanofluid, thermal efficiency.

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INTRODUCTION

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by Gaugler in 1942. It was not, however, until its independent invention by Grover in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place. The heat pipe is a useful heat transfer device that can transport heat at high rates with a very small temperature difference by utilizing the phase change of working fluid. A heat pipe is a simple device with no moving parts that can transfer large quantities of heat over fairly large distances without requiring any power input. A heat pipe is basically a sealed slender tube containing a wick structure lined on inner surface and small amount of working fluid such as water at saturated state. It is composed of three sections: the evaporator section at one end, where heat is absorbed and the working fluid is vaporized; a condenser section at the other end where the vapor is condensed and heat is rejected; and adiabatic section in between where the vapor and liquid phases of the fluid flow in opposite directions through the core and the wick respectively to complete the cycle with no significant heat transfer between the fluid and the surrounding medium. The main regions of the standard heat pipe are shown in Fig.1. In the longitudinal direction (Fig. 1 a), the heat pipe is made up of an evaporator section, adiabatic section and a condenser section.

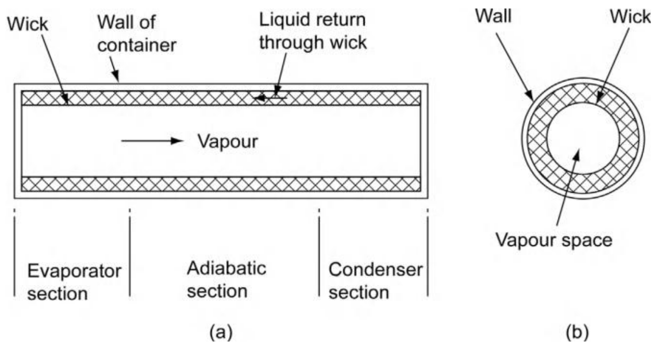


Fig.1. Main Region of Heat Pipe [23]

The cross-section of the heat pipe, Fig. 1b, consists of the container wall, the wick structure and the vapor space. The wick of a heat pipe provides the means for the return of the liquid to the evaporator. Therefore, the structure of the wick has a strong effect on the performance of a heat pipe, and the design and construction of the wick are the most critical aspects of the manufacturing process.[23]

All the types of heat pipe have a common problem of heat transfer limitation. These limitations determine the maximum heat transfer rate for a particular heat pipe under the normal working conditions. In heat pipe design, the capillary limit and boiling limits are important under the normal working conditions. The surface tension is an important key factor for capillary limit. The thermal properties of working fluids play a vital role in the development of energy-efficient heat pipe. Conventional heat transfer fluids such as water, methanol, and glycol have poor heat transfer properties than most solids. The surface tension of all the pure liquids is normally decreasing with increase in temperature, as the liquid moves along the interface towards the cooler condenser zone. To overcome these limitations of conventional working fluid, the thermo physical properties of the working fluid have to be improved. The heat transfer rate of heat pipe can be improved by adding additives to the working fluids to change the fluid transport properties and flow features. One of the methods for heat transfer enhancement is the application of nanofluid. Nanofluid is prepared by adding metals, metal oxides, carbon nanotubes or any other solid nanomaterial to a base fluid like water, ethylene glycol or engine oil. The term nanofluid was first used by Choi in 1995. When solid nanometre sized particles are suspended in working fluid, the enhancement of thermal conductivity can be significant. This enhancement can improve the efficiency of fluids used in heat transfer applications.

I. LITERATURE REVIEW

Extensive work has been completed on thermal performance of cylindrical heat pipe using nanofluid. Since 1990s, researchers began to apply nano-material technology to heat transfer field and have achieved many meaningful results on heat transfer enhancement. In 1995, Choi firstly proposed the concept of “nanofluid”, which is a fluids with some kinds of nanometre-sized particles suspended into a base liquid. Some examples of applied nanoparticles are pure metals (Au, Ag, Cu, Fe), metal oxides (CuO, SiO_2, Al_2O_3, TiO_2, Fe_3O_4), carbides (SiC, TiC), Nitrides (AlN, SiN) and different types of carbon. This literature review summarizes the findings from different researchers.Shung-Wen Kang et. al. [2] investigated the thermal performance of a heat pipe filled with the silver nanofluid. The type of heat pipe used for this experiment is micro-grooved circular heat pipe. The length and outer diameter of heat pipe used in this experiment is 200mm and 6mm respectively. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nanoparticles. The tested nanoparticle concentrations ranged from 1 mg/l to 100 mg/l. The result shows that with greater silver nanoparticles dispersed in working fluid, the increase in heat pipe wall temperature was smaller than that for a pure water filled heat pipe under various heat loads.

Paisarn Naphon et. al. [4] experimentally investigated the effect of titanium nanofluid on the thermal efficiency of heat pipe. The heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15, 600 mm, respectively. In this study the heat pipe with de-ionic water, alcohol and nanofluid are tested. The titanium nanoparticles with diameter of 21 nm are used in this study. The mixtures of alcohol and nanoparticles are prepared using an ultrasonic homogenizer. From the results we can say that for heat pipe with 0.10% nanoparticles volume concentration, the thermal efficiency is 10.60% higher than that with the base working fluid.Maryam Shafahi et. al. [6] investigated the thermal performance of cylindrical heat pipes using nanofluid as the working fluid. Three most common nanoparticles are used namely Al_2O_3, CuO, TiO_2.A substantial change in the heat pipe thermal resistance, temperature distribution, and maximum capillary heat transfer of the heat pipe is observed when using a nanofluid. The results show that the thermal performance of a heat pipe is improved and temperature gradient along the heat pipe and thermal resistance across the heat pipe are reduced when nanofluids are utilized as the working fluid. The results also show that the thermal resistance decreases as the concentration increases or particle diameter decreases.

K. N. Shukla et. al. [7] studied the thermal performance of cylindrical heat pipe using nanofluids. In this study a cylindrical copper heat pipe with 19.5 mm outer diameter and 400 mm length was filled with three different working fluids and tested for different heat inputs in the range of 100-200W. Results show that, at the copper weight percentage of 0.1 the maximum efficiency variation of 14% was obtained and the silver weight percentage of 0.008 in a silver nanofluid, the efficiency increases up to 8% compared with the one filled with pure water. Furthermore, it was found that an increase in the metal fraction in copper–water nanofluids lead to enhancement in thermal efficiency of the heat pipe.

Gabriela Huminic et. al. [8] studied the heat transfer characteristics of a two-phase closed thermosyphon using nanofluid. In this study effect of operating temperature, effect of thermosyphon concentration levels on the heat transfer characteristics of thermosyphon is considered. Thermosyphon is fabricated from copper with outer diameter 15mm and length 2000mm.The iron oxide nanoparticles with mean diameter of 4–5 nm were obtained by the laser pyrolysis technique and the mixtures of water and nanoparticles are prepared using an ultrasonic homogenizer. Outcome of this experimentation is that the heat transfer rate increases in the case of thermosyphon with iron oxide nanoparticles as the inclination angle increases. The thermal resistance of thermosyphon decreases with the increase of the inclination angle.

R. Senthilkumar et al [11] did the experimental analysis of cylindrical heat pipe using copper nanofluid with an aqueous solution of n-Hexanol. The experiment is carried out for various heat inputs and inclination angle of heat pipe. The heat pipe is made up of copper with a length of 600mm and outside diameter of 20mm. The heat pipe charged with 40ml of working fluid which approximately corresponds to the amount required to fill the evaporator. From experimental results, it is found that the thermal efficiency of copper nanofluid with an aqueous solution of n-Hexnol is higher than the base fluid DI water and copper nanofluid and thermal resistance also reduces to three fourth of base fluid.

R.Manimaran et al. [18] compared the thermal performance of heat pipe using CuO and TiO2 nanofluids. For better capillary action two layers of screen mesh wick is used in the heat pipe which is made up of copper. The outer diameter, inner diameter and length are 22mm, 20.8mm and 600mm respectively. The results show that the CuO nanofluid shows better heat transfer effect than TiO2 nanofluid, the reason for enhancement is higher thermal conductivity of copper oxide nanofluid than titanium oxide nanofluid. When heat pipe operated at 75% fill ratio CuO nanofluid shows lowest thermal resistance and percentage decrease was about 38.8% and 62% when compared with TiO2 nanofluid and DI water respectively. The overall heat transfer coefficient is found to be higher for CuO nanofluid when compared with TiO2 nanofluid and DI water.

Lazarus et al. [20] studied the operational limitations of heat pipes with silver-water nanofluids. The heat pipe is made up of copper with a length of 180mm and outer diameter of 10mm respectively. The tested nanoparticles concentration ranged from 0.003 vol. %to 0.009 vol. % with particle diameter of <100 nm. The nanofluid as working fluid enhances the effective thermal conductivity of heat pipe by 40%, 58%, and 70%, respectively, for volume concentrations of 0.003%, 0.006%, and 0.009%.

Yi- Hsuan Hung et al. [21] have studied the evaluation of the thermal performance of heat pipe using alumina nanofluid. The heat pipe in this study is a straight copper tube with an outer diameter of 9.52mm and different lengths of 0.3m, 0.45m and 0.6m. Experimental results show that at a heating power of 40W, the optimal thermal performance of Al2O3/water nanofluid heat pipes measuring 0.3m, 0.45m & 0.6m was 22.7%, 56.3% and 35.1% respectively better than that of pipes using distilled water as the working fluid.

S.M. Peyghambarzadeh et al. [22] investigated thermal performance of different working fluids in a dual diameter circular heat pipe. This heat pipe is made up of copper with two diameters; smaller in adiabatic & condenser section and larger in evaporator section. Three different liquids including water, methanol, and ethanol are separately filled within the heat pipe. Result shows that higher heat transfer coefficients are obtained for water and ethanol in comparison with methanol. The inclination angle has a great effect on the heat pipe thermal resistance using water as the working fluid.

From above mentioned literature, it is observed that all the researchers have stated that the various nanofluid concentration, various inclination angle, various heat input are the key parameters which affects the cylindrical heat pipe performance. The different nanofluids used are Al_2O_3, Cuo, SiO_2, TiO_2, ZnO. In the present work iron oxide nanoparticles with 1%, 2% volume concentration are dispersed in distilled water and used as the working fluid in the heat pipe. The heat pipe is tested for different heat loads, different inclination angle. The effect of heat load, volume concentration and inclination angle on thermal performance of cylindrical heat pipe are experimentally investigated and presented.

II. EXPERIMENTATION

1. Experimental Set Up:-

The experimental set up is as shown in fig. which consists of heat pipe, ammeter, voltmeter, temperature indicator, dimmerstat.

Fig 2 Experimental Set Up

Experimental set consists of a 25.4 mm outer diameter heat pipe with a length of 600mm and wall thickness of 1mm. The wick consists of screen mesh. The heat pipe is charged with working fluid which corresponds to the amount required to fill the evaporator. To measure the wall temperature distribution in the adiabatic section, three thermocouples are placed. The thermocouples are also located in evaporator and in condenser section. Two thermocouples are placed at the inlet and outlet of the condenser jacket. The heat input is applied at the evaporator section by using cylindrical heater of 200w. Water cooled condenser is used to at the condenser end to remove the heat from the heat pipe. The length of the condenser is of 150mm. The cooling water is circulated first through the condenser jacket, before the heat is supplied to the evaporator because a sudden rise in wall temperature occurs which could damage the heat pipe if the heat is not released at the condenser properly.

2. Experimental Procedure:-

The experiments are conducted using three identical heat pipes which are manufactures as per required dimensions. One heat pipe is filled with distilled water, second is filled with 1% volume fraction of iron oxide nanofluid, and third is filled with 2% volume fraction of iron oxide nanofluid. The heat input to the heat pipe is gradually raised to the required power, initially upto 40W. Surface temperatures measured along the heat pipe at regular interval of time until the heat pipe reaches the steady state condition. Water inlet and water outlet temperatures in the condenser section also measured. Once the steady state is reached the power supply is turned off and cooling water allowed to flow through the condenser to cool the heat pipe. After that heat input is raised to 60w, 80w, 100w respectively. The observations were noted down for different angle of inclinations which ranges from 0° to 90° with 15° interval.

III. RESULTS AND DISCUSSIONS

1. Effect of Thermal Resistance:-

Fig. 3-9 shows the comparison of thermal resistance of heat pipe with distilled water, 1% iron oxide nanofluid, 2% iron oxide nanofluid.

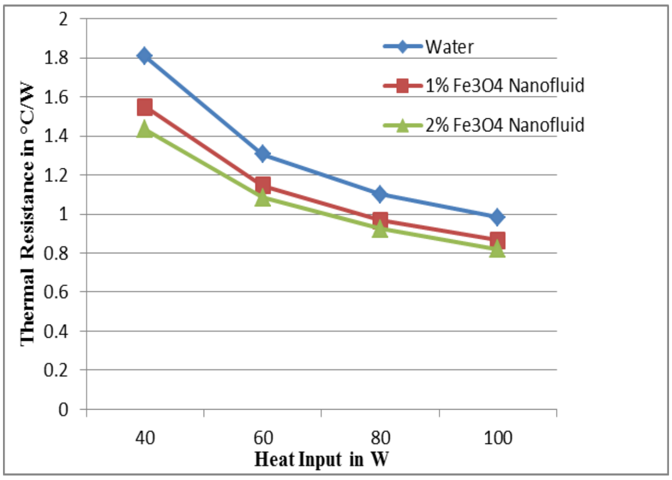


Fig. 3 Thermal Resistance vs Heat Input at 0° inclination

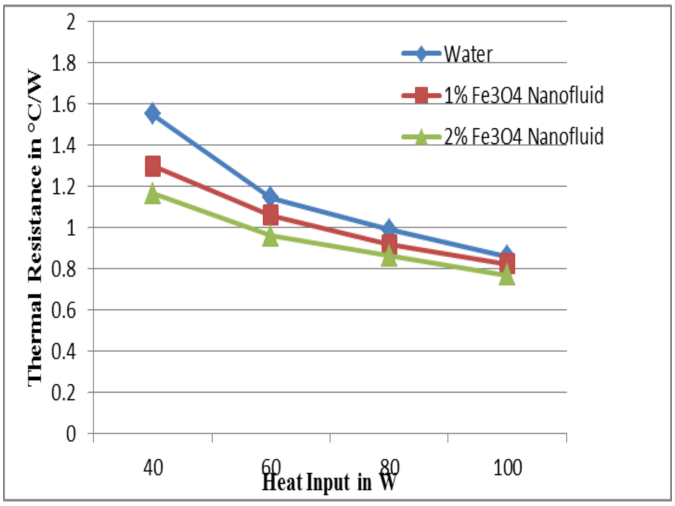


Fig. 4 Thermal Resistance vs Heat Input at 15° inclination

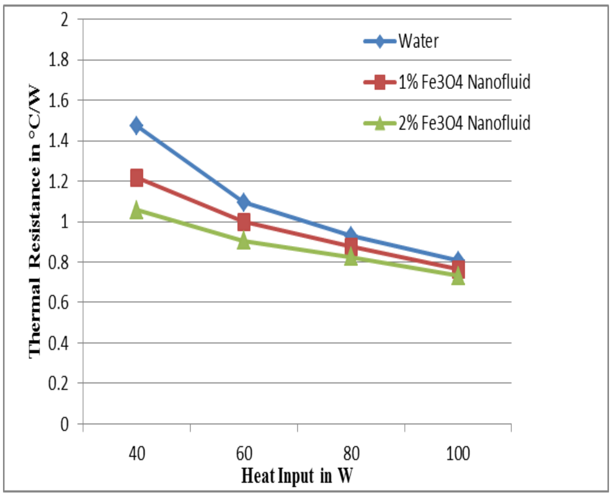


Fig. 5 Thermal Resistance vs Heat Input at 30° inclination

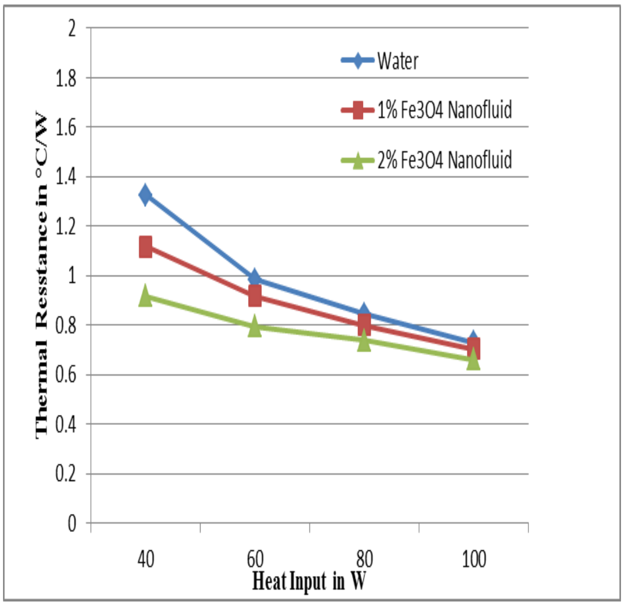


Fig. 6 Thermal Resistance vs Heat Input at 45° inclination

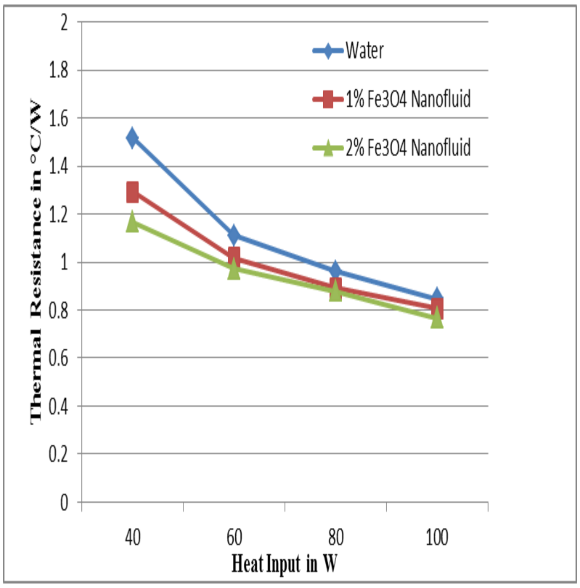


Fig. 7 Thermal Resistance vs Heat Input at 60° inclination

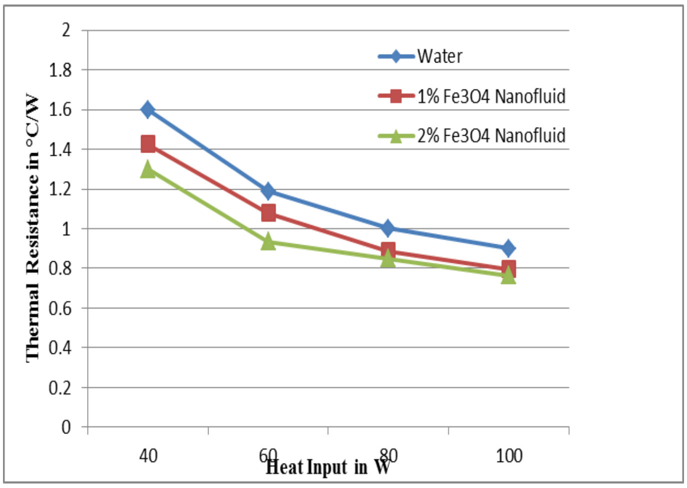


Fig. 8 Thermal Resistance vs Heat Input at 75° inclination

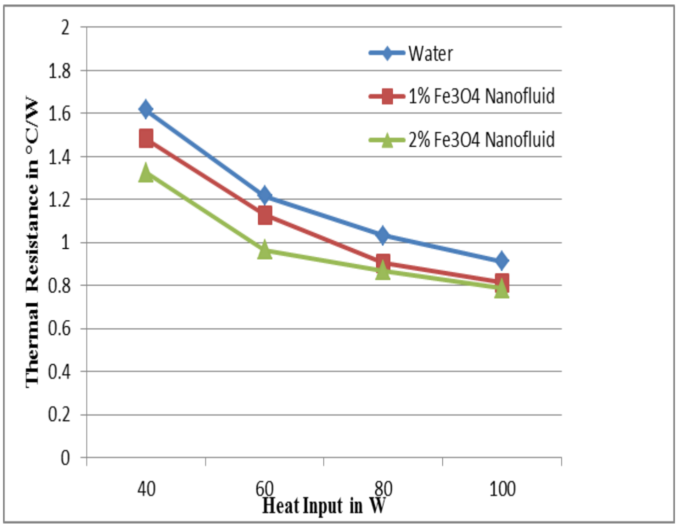


Fig. 9 Thermal Resistance vs Heat Input at 90° inclination

The thermal resistance Rth of the heat pipe is defined as the ratio of temperature difference of evaporator and condenser to heat supplied. Mathematically thermal resistance is defined as follows:-

$$Rth = \frac{(Te - Tc)}{Qe}$$

Where Te and Tc are the average temperatures at the evaporator and condenser section respectively and Qe is the heat supplied to the heat pipe. From all the figures it is clear the thermal resistance of heat pipe decreases for all three working fluid with increase in angle of inclination and the heat input. From fig. 6 thermal resistance is low at 45° for all the three working fluid. From all the figures we can say that as the concentration of nanofluid increases the thermal resistance of heat pipe decreases. At higher inclination i.e. above 60° the thermal resistance is increased. It can be seen that increasing the nanoparticle concentration decreases the heat pipe thermal resistance.

2. Effect of inclination of heat pipe on thermal efficiency:

Fig. 10- 13 shows the variation of heat pipe efficiency for distilled water, 1% iron oxide nanofluid, 2% iron oxide nanofluid.

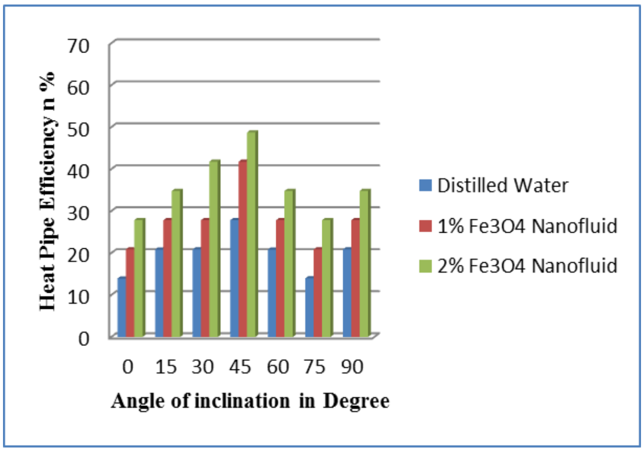
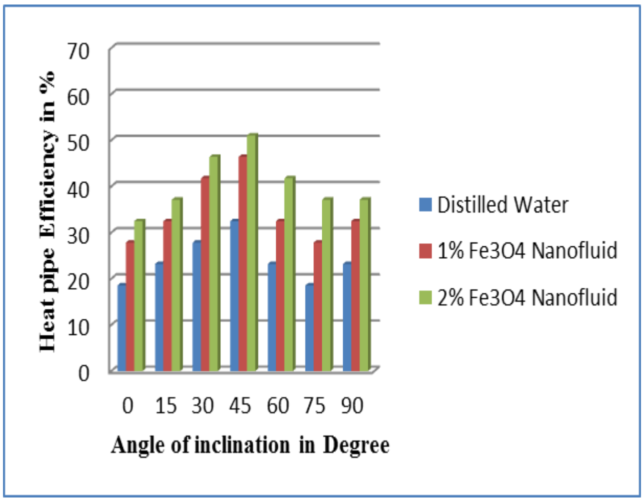


Fig. 10 Heat Pipe Efficiency vs Angle of inclination at 40 w



Fig, 11 Heat Pipe Efficiency vs Angle of inclination at 60 w

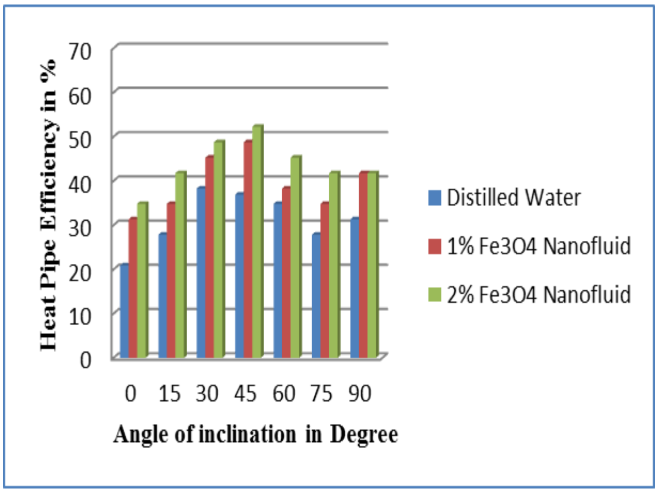


Fig. 12 Heat Pipe Efficiency vs Angle of inclination at 80 w

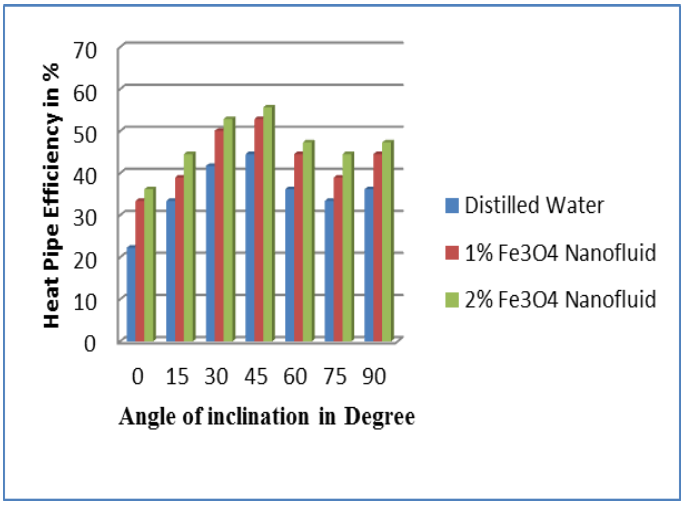


Fig 13 Heat Pipe Efficiency vs Angle of inclination at 100 w

All the figures show the heat pipe efficiency changes for different heat input (40W, 60W, 80W, 100W) and for different inclination. Heat pipe efficiency is defined as the ratio output power to input power

$$\eta_{th} = \frac{Qc}{Qe}$$

Where Qc is heat carried out by water

Qe is the heat supplies by the evaporator.

From figure it is clear that with increasing tilt angle the heat pipe efficiency also get increased. This is due to gravitational force which has a significant effect on the flow of working fluid. When the angle increases 45° the heat pipe efficiency decreases. Nanofluid concentration also has the effect on thermal efficiency. As the concentration increases the heat pipe efficiency increases for all the angles.

IV. CONCLUSION

In this work three heat pipe with screen mesh are experimentally investigated using distilled water, 1% iron oxide nanofluid, 2% iron oxide nanofluid. Thermal efficiency is calculated for 1% and 2% iron oxide nanofluid and it is compared with the heat pipe filled with distilled water. Similarly thermal resistance also calculated and it is compared with base fluid. Form experimental results, it is found that thermal efficiency of iron oxide nanofluid is higher than that of base fluid. Similarly thermal resistance also get decreased for nanofluid which helps to enhance the performance of heat pipe. For 45° angle of inclination the rise in heat pipe efficiency is nearly 30% when nanofluid is used as a working fluid. From observed result we can conclude that the nanoparticles present in the base fluid can significantly enhance the heat transfer, reduce the thermal resistance and increases the thermal efficiency.

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