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Experimental Study on the Thermal Performance of Grooved Heat Pipe using Nanofluids

*[1]S.Gajalakshmi, [2]R.Senthilkumar, [3]G.Sasikumar

[1]Department of Mechanical Engineering, CK College of Engineering & Technology, Cuddalore-607003, India
[2]Department of Mechanical Engineering, Annamalai University, Chidambaram – 608002, India
[3]Department of Power Engineering, GMR Institute of Technology, Rajam-532127, AP, India

Abstract : A heat pipe is a heat transfer device which is used to cool the heat transfer equipments by means of self-contained structure with a capillary action of grooved surface with a two phase flow working fluid. Nanofluid is employed as working medium for 600 mm grooved circular heat pipe. The nanofluids considered in this work are Copper oxide, Iron oxide, Titanium oxide and Graphene oxidewith DI water as base fluid. The average diameter of nanoparticles is 50 nm. The experiment was performed to measure and compare thermal resistance of De-Ionized water and nanofluid filled heat pipes. At the same charge volume the thermal resistance of heat pipe with nanofluid is greater as compared with DI water.
Keywords : Grooved heat pipe, Nano fluids, Thermal efficiency, Thermal resistance.

1. Introduction

The Heat pipe is a self-contained engineering structure which exhibits a thermal conductance greatly in excess of that which could be obtained by the use of a homogeneous piece of any known metal. This property is achieved within the containing envelope by the evaporation of a liquid, transport of the vapor to another part of the container, condensation of the vapor and return of the condensate to the evaporator through a wick of suitable capillary structure. The heat pipe principle is indeed applicable over a very wide range of sizes, shapes, temperatures and materials. The advantages of heat pipes are best realized when they are long and thin, that is, take the form of long cylinders or extended thin planar structures. Xiao-Dong Wang et al [2014] fabricated copper micro grooves using electroforming technique on the silicon wafer.Copper produces greater heat transfer capacity and capillary traction than silicon. He investigated that copper grooved micro heat pipes shows better results than silicon ones [1].

Yu-Tang Chen [2010] conducted experiment on a flat heat pipe of 3mm thickness and 200 cm length using silver nano fluid of 35 nm in size. The thermal performance of heat pipe filled with nano fluid shows better performance than DI Water [2].Prashant Shinde et al [2015] investigated experiment on straight heat pipe using Al_2O_3nano fluid. It was inferred that maximum performance was obtained at 45°inclination with 2 wt % concentration of nano fluid. The thermal resistance reduced by an amount of 16.68 % compared with 0° inclination for same working fluid [3].Mousa [2011] experimentally studied the characteristics of the nano fluid to know the performance of circular heat pipe.He also predicted the thermal resistance of pure water andAl_2O_3-

water based nanofluid and reported that thermal resistance decreases with increasing Al_2O_3-water based nanofluid compared to the pure water [4].

Walunj et al (2015) reviewed heat transfer enhancement in heat pipe using various nano fluids. They discussed about the effect of filling ratio, volume fraction of nanopractices with different base fluids and proved the potentials of nanofluids to improve thermal properties of working medium in heat pipe [5]. Nookaraju et al (2015) investigated evaporation, adiabatic and condensation phenomenon of thermosyphon,sintered copper wick and helical grooved heat pipes. The sintered copper wick structure found efficient than the others because of predominating capillarity property[6].RanaAshvini et al [2015] investigated experimentally the thermal performance oh heat pipe using silver nano fluid and it was inferred that thermal performance become enhanced by nano fluids. The experimental results shows that the heat transfer co-efficient increases 6.88% to 15.63% asheat input and inclination angle increases and also the thermal resistance decreases 6.85% to 17.7% as heat input and inclination angle increases[7].

Azeez et al [2015] investigated the performance of heat pipe with various wick geometry of 0.4mm, 0.6mm, 0.8mm and various shapes like sintered, V-Groove, screen groove wick. Copper is used as a heat pipe material and nickel-chromium alloy is used as a wick material and water, ethanol, aqueousethanol was used as the working fluids. It was inferred that water has the highest temperature gradient andhigh heat transfer coefficient among the other working fluids. Heattransfer rate increases significantly with increase in wick structure. Screen groove structured wick performance seems to be betterover other wick structures[8].Naphonet al [2008] studied experimentally the thermal efficiency of the heat pipe using titanium nano fluids of diameter 21 nm.The heat pipe container is copper which has dimensions of 15 mm OD and length 600 mm.The experimental result shows that the thermal efficiency was improved greatly by use of nanofluids [9].

Liu et al [2006] studiedenhancement of thermal conductivity of copper nanofluid with water as base fluid by adopting the chemical reduction method.The thermal conductivity is the highest at the initial time and reduces considerably with respect to time. It was inferred that the lower concentration of copper nanofluid has the higher thermal conductivities than the other and water. The thermal conductivity enhances up to 23.8% when the concentration of copper nanoparticle is 0.001 (0.1 vol.%). Kim et al [2007]investigated the effect of the morphology of carbon nanotubes on the thermal conductivity of suspensions. Single walled nano tubes with small amount of surfactant showed that thegreater increase in effective thermal conductivity than functionalized single-walled nanotubes alone[11]. Kang et al [2009] conducted experimentsto study the temperature distribution and compare the results of nanofluids with DI water. They found that the surface temperature of nanofluid as the working mediums in the heat pipes less than the DI water filled heat pipes for all heat loads [12].

Lodhi et al [2013] presented the enhancement of the thermal performance of a copper heat pipe with an outer diameter 18 mm, thickness 1mm and length of 475 mmusing copper oxide and water nanofluids. The concentrations of copper nanofluid considered in this analysis were1g/lit, 5g/lit and 10g/lit by volume.They discussed that nanoparticles have important effect in the enhancement of thermal performance with increase of fluid concentrations.From the experimental results at a input power of 80 W, the thermal conductivity and heat transfer rate for CuO/Water nanofluid heat pipe are 50.46% and 1.75% respectively, which are better than that ofpipes using pure water as the working fluid [13].Aoki et al [2011] developed ultra thin heat pipe for the application of thinner and lighter electronic equipments. In this they focused on optimizing vapor and liquid flow pressure drop in the heat pipe. Heat pipe of thickness 1 mm produces maximum heat transfer rate of 22.1W [14].Han et al [2011] fabricated and tested a specially designed grooved heat pipe with hybrid nano fluids like Ag-H_2O and Al_2O_3-H_2O as working fluids.From the results it has been observed that hybrid nano fluids shows higher overall resistance with higher value of concentrations [15].Nilas [2011] proposed the inspection system of heat pipe cooling for electronicdevices.In this Acousticemission sensor is provided on theheat pipe to measure the degree of vibration of the system.This model helps to improving the quality assurance operation of heat pipe cooling inspection system in any industries [16].

SenthilKumar et al [2011] improved the thermal performance of heat pipe using copper nano fluid with aqueous solution of n-Butanol. They discussed the effect of heat pipe inclination,effect of working fluid, heat input and thermal resistance.The results showed that enhancement of performance is by adding little amount of long chain alcohol produces better performance than the conventional working fluid and nano fluid [17].Mozumder et al [2010] studied experimentally the performance of heat pipe of size 5 mm in diameter and

150 mm long with a thermal capacity of 10 W.The working fluids used in this study are water,methanol and acetone.It was observed that working fluid fill ratio as a percentage of evaporator volume is identified to have minimum effect of performance of heat pipe with respect to temperature difference when water and methanol used as a working fluids [18].

2. Experimental Methodology

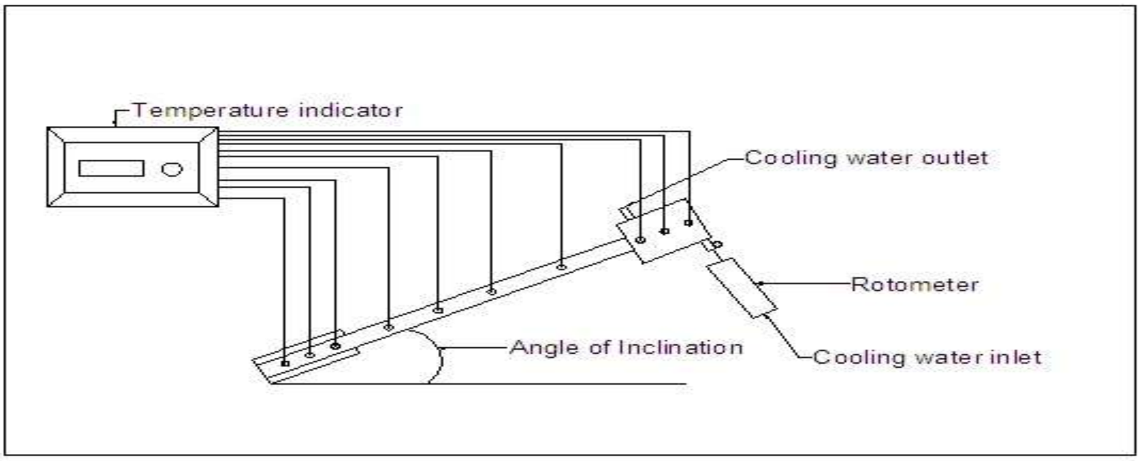

Figure 1.Experimental Setup

The grooved heat pipe is made up of copper with a length of 600 mm, outside and inside diameters are 9.5 mm and 8.75 mm respectively.The heat pipe is charged 75 % of evaporator volume. The five identical grooved heat pipes are fabricated as per dimensions to conduct the experimental analysis. One heat pipe is filled with copper nanofluid, second one with iron oxide, third with titanium oxide and fourth with graphene and last with DI water as the working fluids.

The distance between evaporator and condenser is 300 mm and evaporator and condenser lengths are 150 mm. The heat pipe surfaces are insulated by glass wool.The electric power input is applied grooved heat pipe by means of cylindrical heater which attached at the evaporator section. Three thermocouples each are attached at the evaporator and condenser region to measure the surface temperature and four more are attached at the adiabatic region.To remove heat from the condenser section cooling water is used at the end of the condenser of the pipe. The inlet and outlet temperature of the cooling mediums are measured by using T-type thermocouples (copper –constantan). The input power is applied at the evaporator section and it was gradually raised to the desired levels.The surface temperatures at the evaporator section, the adiabatic section, the condense section are recorded at regular interval of time (every five minutes) until it reaches the steady state condition. At the same time the inlet and outlet temperature of the cooling water also measured.After attains steady state the heat pipe is allowed to cool for next experimental purpose. The experimental procedure is repeated for different heat inputs (30,40,50, 60 & 70 W) and different angle of inclination of pipe (0°,15°,30°,45°,60°,75°& 90°) with respect to horizontal position for all five grooved heat pipes.

3. Results and Discussion

3.1 Effect of Tilt Angle on Thermal Efficiency

The heat transfer through the grooved heat pipe (Q_{out}) was determined by applying an energy balance at the condenser water jacket given by

$$Q_{out} = mCp\,(T_{wo}-T_{wi}) \qquad (3.1)$$

The efficiency of the heat pipe is calculated as

$$\eta = \frac{Q\ out}{Q\ in} \times 100 \qquad (3.2)$$

Figure 2 to 6shows the variation of heat pipe thermal efficiency with heat pipe tilt angle for nanofluids and DI water. It can be seen from the all figures that the heat pipe efficiency increases with increasing tilt angleup to 45° and then decreases for further increase in tilt angle. This is due to the gravitational force acting on the working fluid in the heat pipe has a significant effect when the fluid moving between the evaporator section and the condenser section. The thermal efficiency of the grooved heat pipe increases with increase in the heat input at the evaporator section. It is owing to the increase in the evaporation of working fluid at the higher heat inputs. Therefore, the grooved heat pipe thermal efficiency tends to increase as the heat flux increases.At lower heat inputs the thermal efficiency is low because of poor evaporation of working fluid. The thermal efficiency of the grooved heat pipe filled with graphene oxide is higher for all heat inputs and inclinations. The graphene oxide has the good heat transport properties than the other nanofluids and the base fluid (DI water).

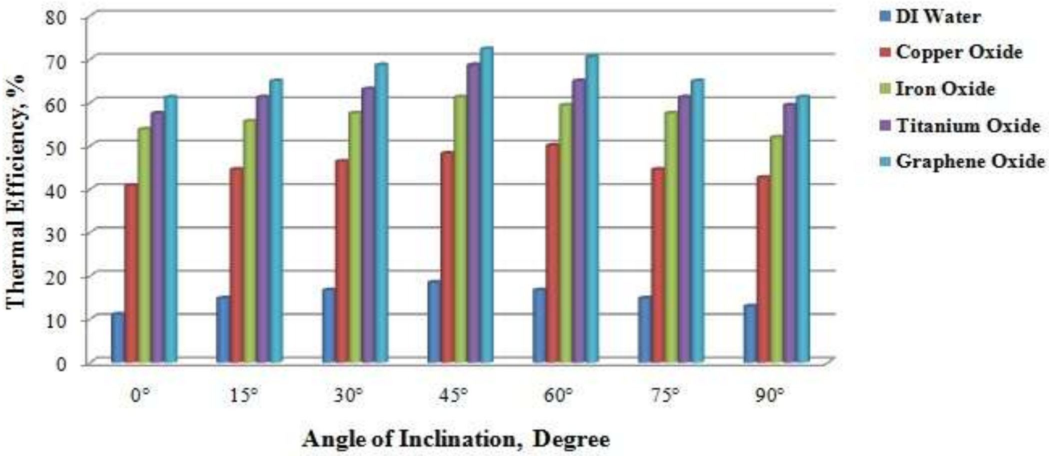

Figure2.Variations of heat pipe efficiency with nano fluids for 30 Wheat input

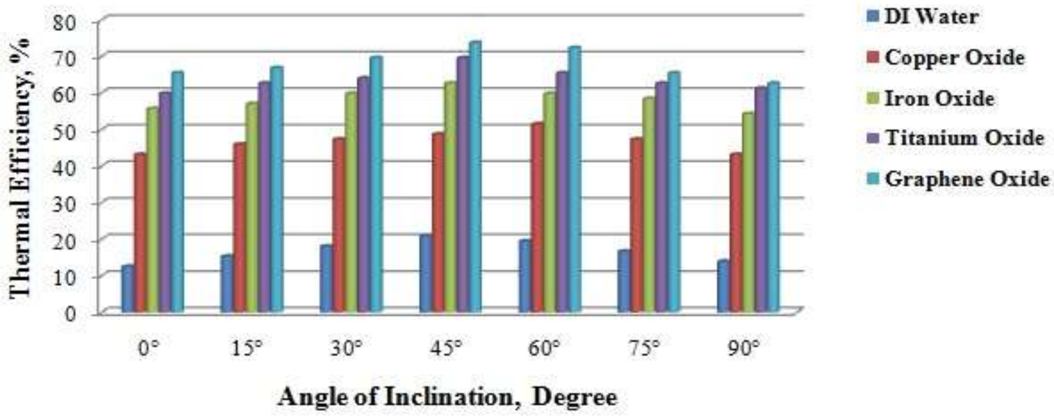

Figure 3.Variations of heat pipe efficiency with nano fluids for 40 W heat input

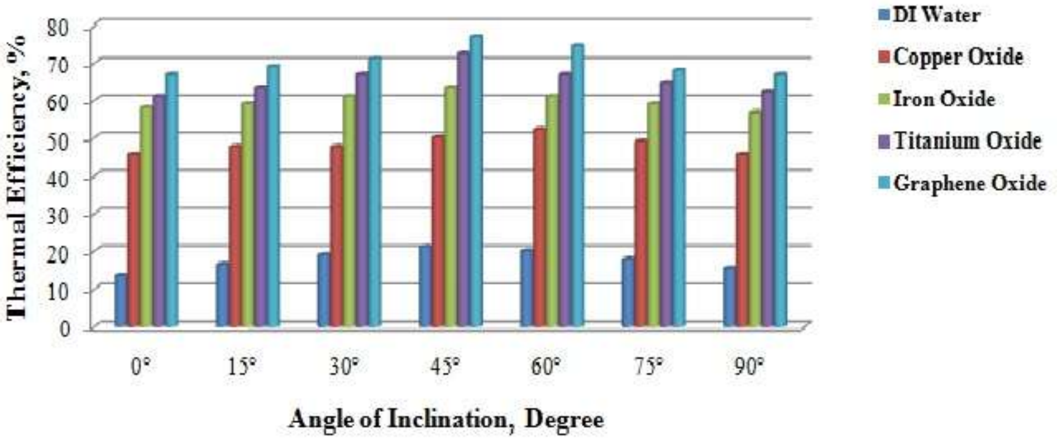

Figure 4.Variations of heat pipe efficiency with nano fluids for 50W heat input

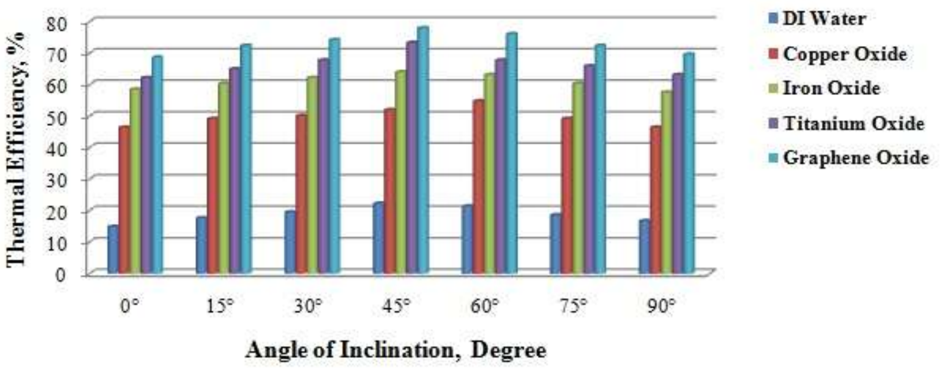

Figure 5.Variations of heat pipe efficiency with nano fluids for 60 W heat input

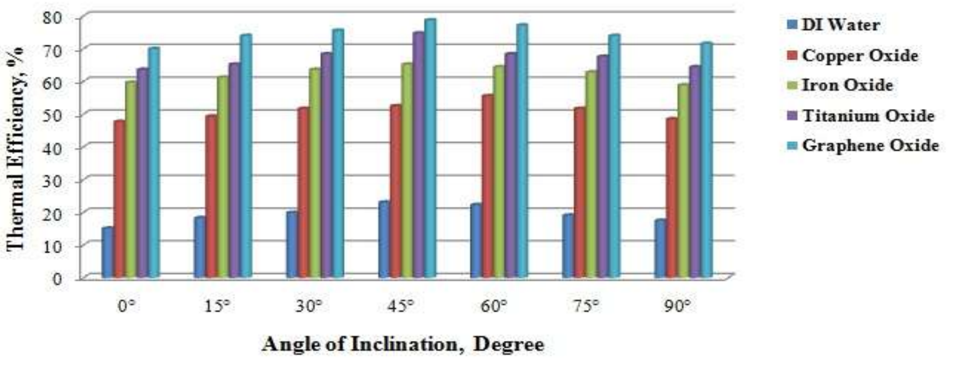

Figure 6.Variations of heat pipe efficiency with nano fluids for 70 W heat input

3.2 Effect of Tilt Angle on Thermal Resistance

The figures 7 to 13 shows the thermal resistance of grooved heat pipe filled with various nano fluids and DI water.The thermal resistance of grooved heat pipe is defined as the ratio of the temperature difference between the evaporator section and condenser section to the heat input at the evaporator region.The value of thermal resistance decreases with increase in value of heat input at the evaporator section.When the heat load is high, the vapour formation is higher than the lower heat inputs. So the thermal resistance is low at the higher heat loads. Similarly when the heat load is low thermal resistance is high owing to presence of liquid film in the condenser side inner wall gives the resistance to flow of heat between the liquid and the vapour of the working fluid. The thermal resistance of the nanofluid filled heat pipes are lower than the DI water because of the suspended nanoparticles tend to breaks the vapour bubble during the time of vapourbubble formation. Therefore, it is expected that the size of vapour bubbles are much smaller for fluid with suspended nanoparticles than that without nanoparticles.The thermal resistance of the graphene filled heat pipe is lower than the other nanofluid and the DI water at all heat loads and inclinations of the grooved heat pipe. The value is nearly half of the DI water filled grooved heat pipes.

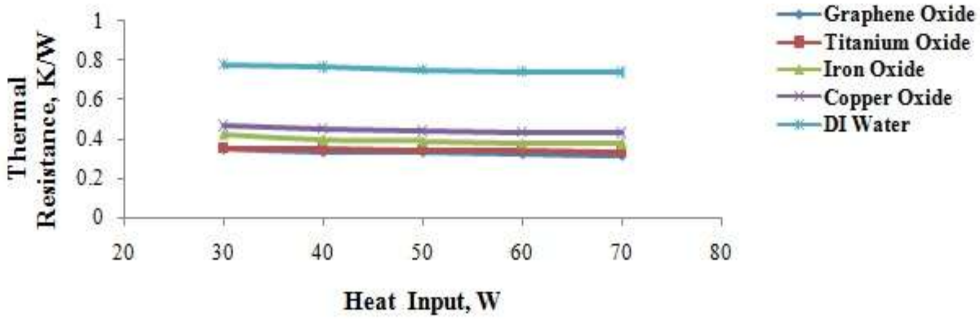

Figure 7.Effect of 0° tilt angle on thermal resistance

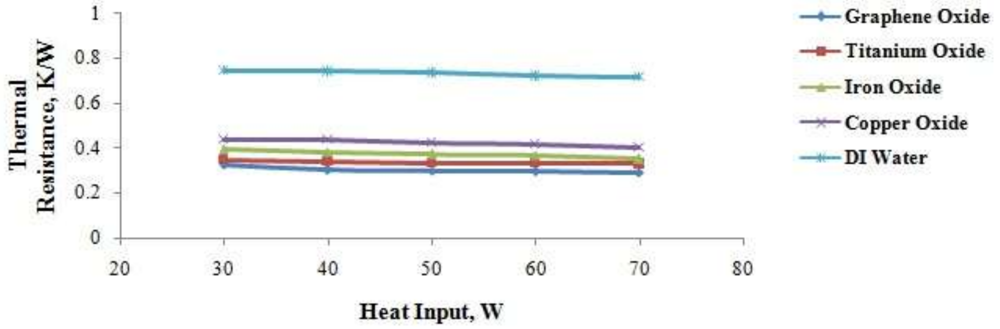

Figure 8. Effect of 15° tilt angle on thermal resistance

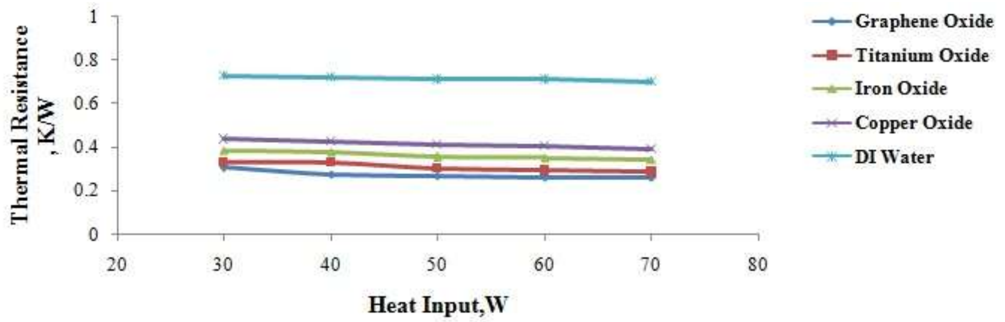

Figure 9.Effect of 30° tilt angle on thermal resistance

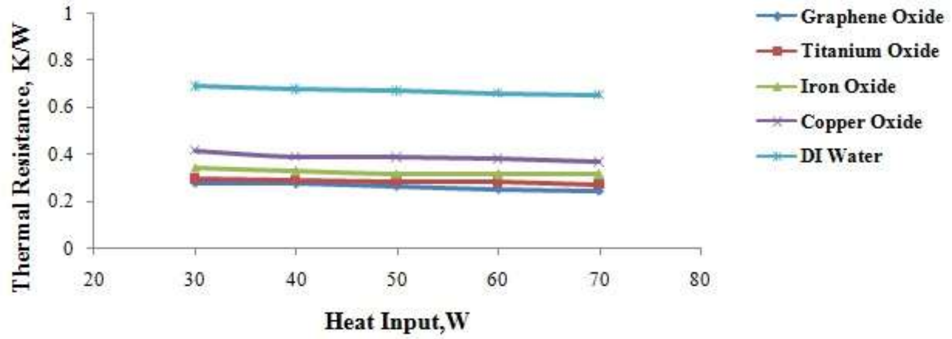

Figure 10. Effect of 45° Tilt angle on Thermal Resistance

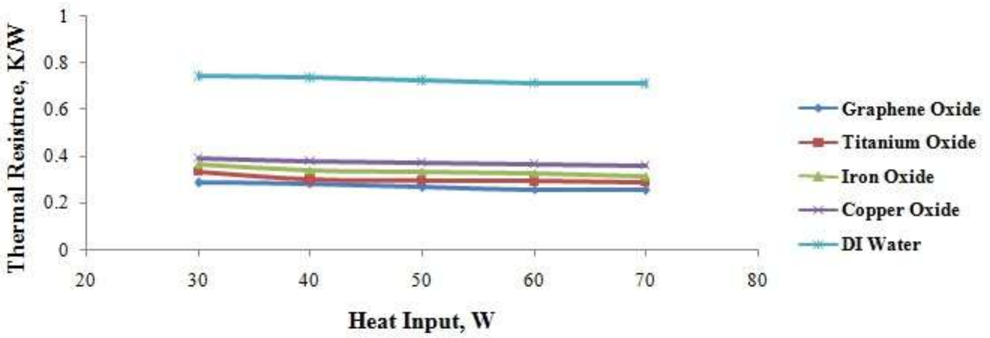

Figure 11. Effect of 60° Tilt angle on Thermal Resistance

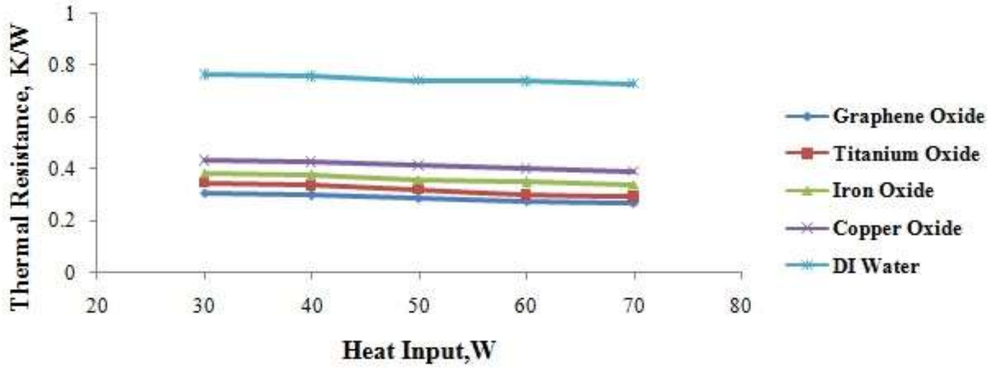

Figure 12. Effect of 75° Tilt angle on Thermal Resistance

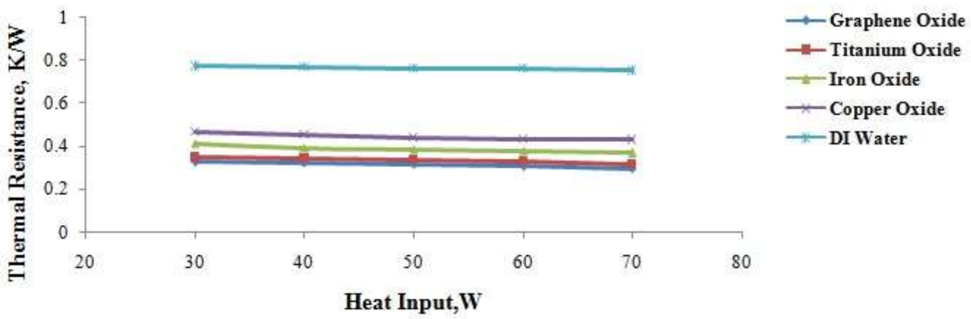

Figure 13.Effect of 90° Tilt angle on Thermal Resistance

4. Conclusion

The goal of this work is show the benefits of the grooved heat pipes using nanofluids. The experiments are conducted for various heat inputs and inclinations of the grooved heat pipes using Copper oxide, Iron oxide, Titanium oxide and Graphene oxide. The results are compared with the base fluid i.e. DI water. Based on the experimental analysis the thermal performances of the heat pipe filled with nanofluids gives the better performance than the base working fluids. The nanofluids have the superior potential for heat transfer than the base fluids.

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