Enhancement of Heat Pipe Thermal Performance using Nanofluids

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Abstract

The present research examines the heat pipe thermal performances utilizing various types of nanofluids. Heat pipes are two step heat transfer system with highly efficient thermal conductivity. Because of this high efficiency heat pipes are commonly used for the thermal control of electronic devices. This research focuses mainly on the effects of the various working fluids such as copper oxide, iron oxide, titanium oxide, graphene oxide nano fluids and De-Ionized water (DI water). A copper tube with an inner diameter of 19.1 mm and an outer diameter of 20 mm was used for an experimental setup. The most significant variables considered in this analysis are in the performance of heat pipe are the heat supply, angle of inclination and filling ratio of working fluid. Its heat inputs at the evaporator section are 30, 40, 50, 60 and 70 W. The angles of inclination with respect to horizontal direction are 0 °, 15 °, 30 °, 45 °, 60 °, 75 ° and 90°. Filling ratios used in this work are 20%, 40%, 60%, 80% and 100% of the evaporator volume. The experimental outcomes are measured in terms of their thermal performances and those are compared with all nanofluids.

Key Words: Heat Pipe, Nanofluids. Thermal Efficiency, Thermal Resistances

Introduction

Heat pipe is a heat exchanging device with the passive form because it does not require any power to transfer the heat. Also, the heat pipe operates on the principle of heat transfer from phase transition system. This comprises three parts, i.e., the segment of evaporator, condenser and adiabatic. These three sections are equally important and can have a major effect on the thermal performance of the heat pipe. There are several forms of heat transfer systems used to cool the equipment, but unlike the other tools that are found in modern days, the heat pipe is an one of the effective system. The heat pipe is favoured when significant amounts of heat are transferred without external sources. Heat pipe as a two-phase heat transfer system is commonly called as the superconductor and was used to cool the complicated electronic devices. It possesses a very high thermal conductance. The heat transfer fluids used generally such as water, mineral oil and ethylene glycol play a vital role in many industrial processes like power generation, chemical processes, heating or cooling processes and microelectronics. The heat pipes are extremely flexible to achieve and regulate the thermal gradient. This includes certain characteristics such as controlling ability, design and manufacturing simplicity, little end to end temperature drops. The major problems associated with the conventional working fluid are heat transfer limitations of the heat pipe and these problems overcome by using nanofluids.

The concept of nanofluid (nanoparticle suspension in base fluid) as a working fluid was first proposed due to its anomalous heat transfer characteristics by Choi in 1995 [1]. To be more specific, a new type of heat transfer and cooling working fluid was formed by adding nano-scale metal or metal oxide particles in the original liquid in a certain way and proportion. Owing to its stability and high thermal conductivity, the nanofluid shows promising prospects in heat transfer enhancement. At present, researches on the heat transfer of the nanofluid concentrate mainly on the forced convection in tube and pool boiling. Keblinski et al. [2] made an interesting review discussing the properties of nanofluids and future challenges. Senthilkumar et al. [3-4] (2010-11) experimentally investigated the thermal performance of heat pipe using aqueous solution of n-Butanol and n-Pentanol. The experimental results are compared with water and it shows the suitability of aqueous solution as a working fluid. Liu and co-workers [5] studied the steady heat transfer characteristics of cylindrical mesh wicked heat pipe using water-based CuO nanofluids with different nanoparticle concentrations under the three steady operating temperatures. It was found that the thermal performance of the heat pipe improved significantly when substituting nanofluids for deionized water as the working fluid. Both the heat transfer coefficients of the evaporator and the condenser and the maximum heat removal capacity apparently increase with the increase of the mass concentration when the mass concentration is less than 1.0 wt%. Then, they begin to decrease after the mass concentration is over 1.0 wt%. The mass concentration of 1.0 wt% corresponds to the best heat transfer coefficient (HTC) enhancement and the evaporating heat transfer coefficients can averagely increase by 2.5 times. Thermal efficiency of the heat pipe charged with nanofluid mixture of titanium nanoparticles and de-ionized water was 10.6% higher than that charged with de-ionized water [6-7] due to the higher heat capacity, thermal conductivity of the nanofluid and higher mixing fluctuation. Tsai *et al.* [8] have claimed that there is a reduction in thermal resistance at the evaporator and condenser sections by adding gold nanoparticles to the base fluid. They believed that the reduction in the condenser resistance is due to the increase in thermal conductivity of nanofluid and convective heat transfer coefficient of the fluid flow to the wall. However, the positive effect at the condenser resistance by nanofluids needs experimental verification. Wen and Ding [9] experimentally studied on the convective heat transfer of nanofluids in a copper tube. Zhou [10] experimentally investigated on the heat transfer characteristics of copper nanofluids with and without acoustic cavitation. Yang et al. [11] investigated the convective heat transfer coefficients of nanofluids under laminar flow in a horizontal tube heat exchanger. Kang et al. [12] experimentally investigated on the thermal performance of heat pipe with silver nano-fluid. Nguyen et al. [13] experimentally investigated on the behaviour and heat transfer enhancement of a particular nanofluid flowing inside a closed system for a cooling of the electronic components.

Perkins tube was the ancestor of the heat pipe that established by the Perkins family from the middle of nineteenth to twentieth century. The Perkins tubes are wickless gravity assisted heat pipes which transport the heat by means of latent heat of evaporation of working medium Reay and Kew and the idea of heat pipe contemplated by Gaugler [14]. The device has closed tube in which vapourization takes place as result of heat absorbed by the liquid in the evaporator. When the vapour moves along the length of the tube it condenses in the condenser section and releases its latent heat. The liquid moves back to evaporator as result of capillary pressure are evolved in the wick or owing to gravity.

Ashvini *et al.* [15] investigated experimentally the heat transfer enhancement of heat pipe of 6 mm outer diameter, 300 mm long and 0.5 mm wall thickness using de-ionized water and silver/water nanofluid as a working fluid. Based on the experimental results nanofluid filled heat pipe shows the efficient performance than the DI water filled heat pipe. Shinde Et al. [16] investigated on the straight heat pipe using Al_2O_3 nano fluid as a working fluid. They inferred that maximum performance was obtained at 45° inclination with 2 wt % concentration of nano fluid. The thermal resistance reduced by the amount of 16.68 % compared with 0° inclination for same working fluid at an angle of inclination 45°. Nookaraju *et al.* [17] experimentally studied the behaviour of sintered copper wick heat pipe with different orientations. It was observed that after 250 W of input power the efficiency of heat pipe decreases because the working fluid meets the burn out temperature. The efficiency of sintered copper heat pipe is 74.28 % at the input power between 100-300 W. Due to the strong capillary action of sintered copper heat pipe the variations in thermal efficiency with angle of orientations were less. Manimaran *et al.* [18] **(2013)** experimentally investigated the performance of copper heat pipe with two layers of screen mesh wick using three different working fluids like DI water, CuO nanofluid and TiO_2 nano fluid at various filling ratios. They reported that 75 % filling ratio shows predominant results for all working fluids. The heat pipe with CuO produces lower thermal resistance and higher overall thermal coefficient than other two fluids. Klinbun [19] considered the effect of filling ratio on the thermal performance of heat pipe made of copper with 5.4 mm inner diameter and 6.0 mm outer diameter and the wick structure made up of copper powder sintering. In this study, the filling ratios of working fluids were 35 %, 45 %, 55 % and 65 %. As a result, 65 % filling ratio can transfer 50 W of heat load and 0.013°C/W of thermal resistance.

Experimental Analysis:

The body of the heat pipe is made of copper, 600 mm long, 19.1 mm inner diameter and 20 mm outer d iameter. The capillary action was enhanced with two layers of stainless-steel mesh wick. The evaporator, adiabatic and condenser sections are 150 mm, 300 mm and 150 mm long respectively. The heat pipe surface temperature distribution in the adiabatic zone is measured by T-type thermocouple. The thermocouples are located at the equal distance in the adiabatic section. The material for T-type thermocouple is copper – constantan with an uncertainty of ±1ºC.

The heat pipe's adiabatic section is totally enclosed with glass wool. The amount of heat lost on the condenser surface and evaporator are negligible. The input of electric power is supplied by a cylindrical electric heater with a proper electric insulation to the evaporator portion and the heater is supplied by 230V of AC supply with a variable and ±1W uncertainty power transducer. The Condenser and evaporator are about 150mm wide. Six more thermocouples are located over the evaporator and condenser section (each three) in order to calculate the average temperatures.

At the end of the heat pipe the water jacket was used to extract the heat out from the heat pipe. The heat pipe will transfer the heat through the internal construction.
The cooling water thus circulates first through the condenser shell, until the heat is transferred to the evaporator. The cooling water flow rate is monitored by using a rotameter on the inlet line to the jacket with an uncertainty of ±1% and a steady flow rate of 0.08 kg / min.

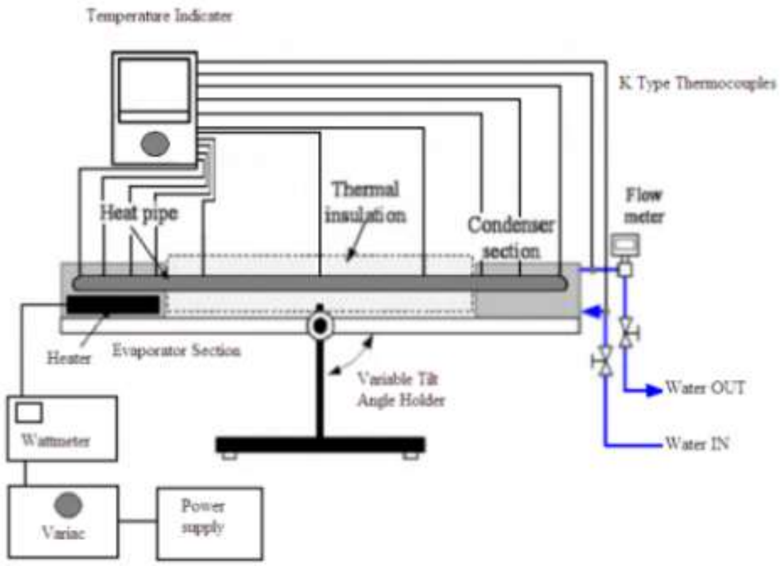

Fig. 1 Schematic diagram of Experimental setup

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The steady state is described as a situation in which the temperature change takes 10 minutes to 0.1 ° C. Then the power is raised to the next stage and the heat pipe is evaluated for thermal performance. At a stable value of 30ºC, the condenser inlet temperature is retained for cooling medium. For different heat inputs (30, 40, 50, 60 and 70 W) and different pipe inclinations (0º, 15º, 30º, 45º, 60º, 75º and 90º) to the horizontal location, experimental procedure are repeated and observations are reported. The vacuum pressure in the inner side of the heat pipe is monitored by vacuum gauge (Borden type), which is attached in the condenser end of the heat pipe.

Table 1. Heat Pipe Specifications

Specification	Dimensions
Outside diameter, m	0.021
Inside diameter, m	0.0191
Evaporator length, m	0.150
Condenser length, m	0.150
Adiabatic length, m	0.300
Total length, m	0.600
Working Fluid	DI Water, Copper oxide, Ion oxide, Titanium Oxide and Graphene Oxide
Wick mesh size,	80 per Sq. inch
No. of layers of wick	2

Result and Discussion

Thermal Efficiency:

The thermal efficiency of the heat pipe can be determined from the ratio of the water cooling power at the condenser segment to the energy supplied at the evaporator segment [4]. Fig. 2-6 shows the variations of heat pipe thermal efficiency for DI water, copper oxide, Iron oxide, Titanium oxide and Graphene oxide nanofluids with various tilt angles of the heat pipe for 30 W, 40 W, 50 W, 60 W and 70 W heat inputs respectively. Thermal Efficiency of heat pipe is given by

$$Thermal\ Efficiency = \frac{mC_p\,(T_{co} - T_{ci})}{Q_{in}}$$

Where m – mass flow rate of coolant in kg/s, C_p – Specific heat of cooling water in J/kg.K, T_{co} – Coolant outlet temperature in the condenser section in K, T_{ci} - Coolant inlet temperature in the condenser section in K and Q_{in} – Heat supplied at the evaporator section.

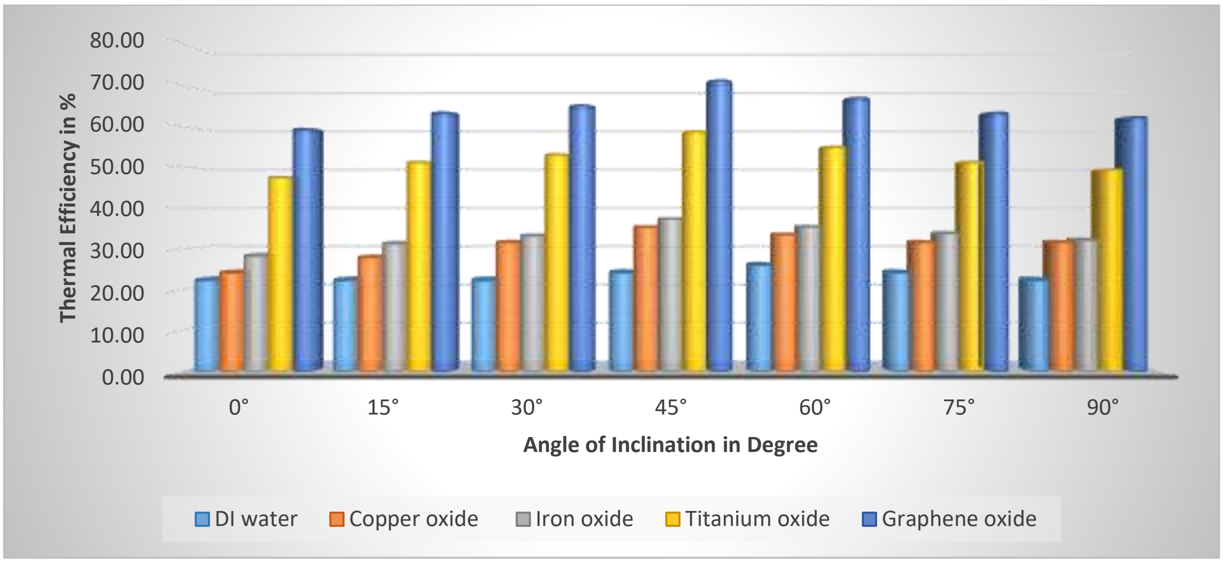

Fig. 2 Variations of heat pipe efficiency for 30 W heat input

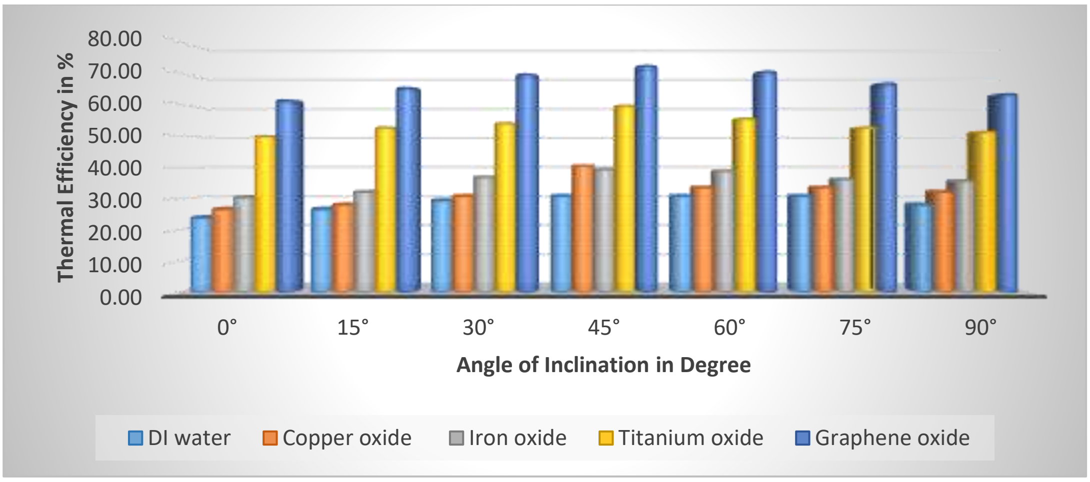

Fig. 3 Variations of heat pipe efficiency for 40 W heat input

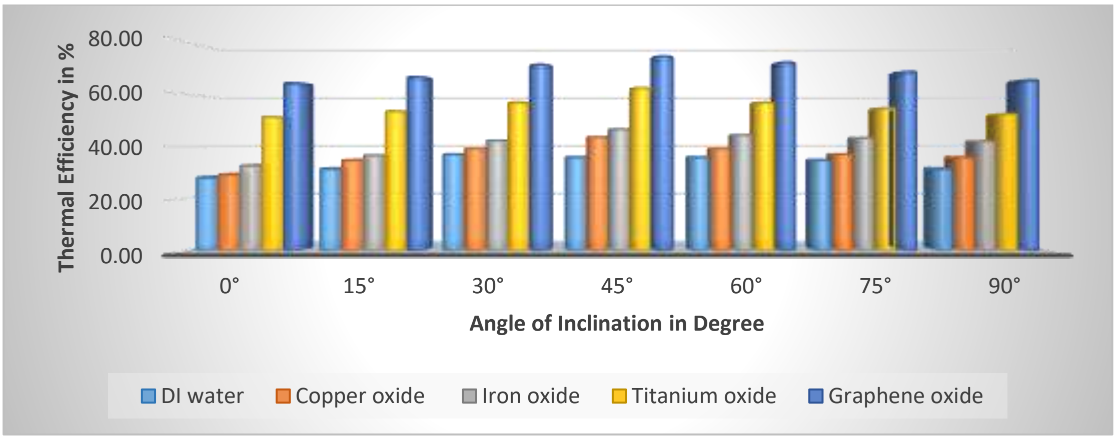

Fig. 4 Variations of heat pipe efficiency for 50 W heat input

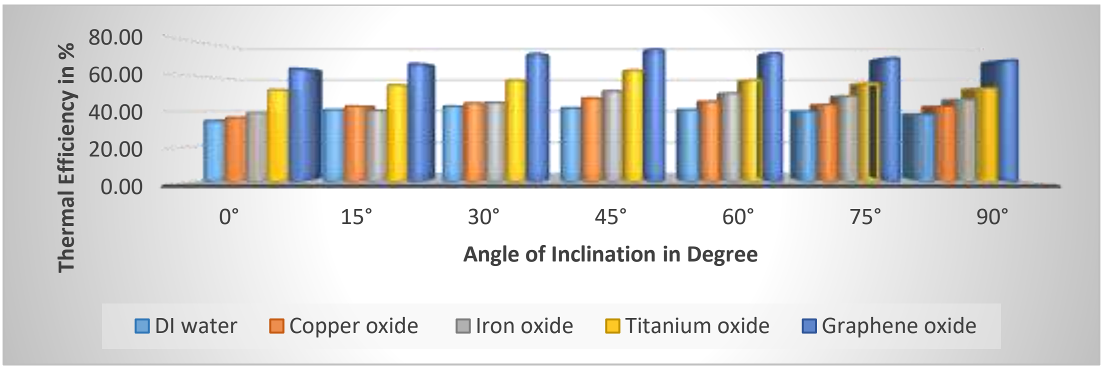

Fig. 5 Variations of heat pipe efficiency for 60 W heat input

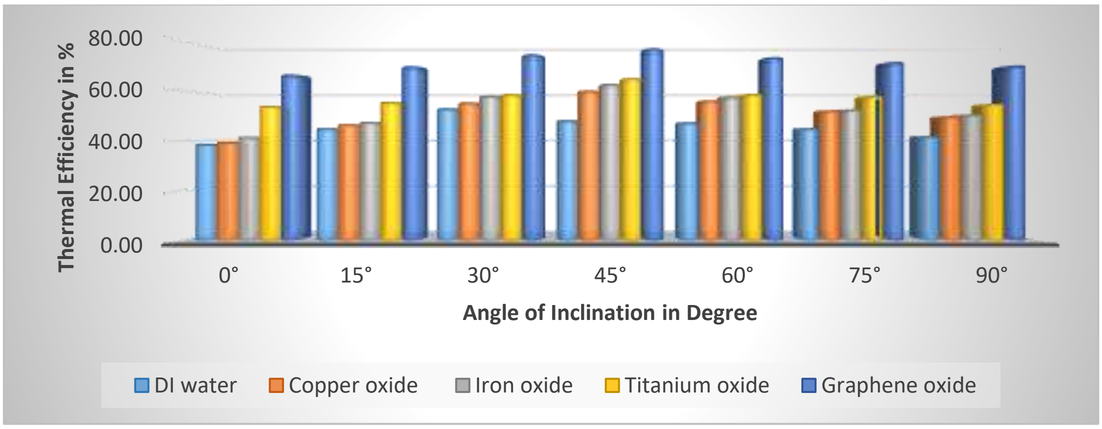

Fig. 6 Variations of heat pipe efficiency for 70 W heat input

It has been observed from all the figures that heat pipe efficiency increases with rising the angle of inclination values. The reason behind reduction of efficiency is due to working fluid on which gravitational force has great influence in the heat pipes, when the fluid is in motion between the evaporator and the condenser section. The increase in thermal efficiency of the heat pipe is due to addition of heat input at the evaporator section. At the higher heat inputs, the rate of evaporation of the working fluid increases linearly. Therefore, the heat pipe thermal efficiency increases as result of heat flux rise. In the evaporator section, the lack of vapourization of working fluid reduces the thermal efficiency at lower heat inputs. Thermal efficiency of the heat pipe filled with the nanofluids always higher than the base working fluids like water, ethylene glycol etc. The nanofluid filled heat pipe has the higher efficiency because the suspended particles in the nanofluid transfer the more amount of heat than the liquids. From the all the nanofluids the graphene oxide nanofluid has the better than the others, because the graphene oxide has the good oxidation properties.

Thermal Resistance:

Fig. 7-13 shows the comparative study of thermal resistance of heat pipe filled with DI water, copper oxide, Iron oxide, Titanium oxide and Graphene oxide nanofluids. The thermal resistance (R) of the heat pipe is defined as

$$\mathbf{R} = \frac{Te-Tc}{Qin} \,°\mathrm{C/W}$$

Where T_e and T_c are average temperature values in the evaporator and condenser parts and Q_{in} is the heat supplied to the heat pipe respectively. It is clear that the thermal resistance of the heat pipe decreases for all five operating fluids with increased inclination angle and heat input values. However, the thermal resistance of heat pipes for both the base fluid and nanofluids is relatively high at low heat loads owing to the fact that the evaporator portion includes a reasonably large liquid layer. At the other side, as the heat load is raised, these thermal resistances condense rapidly to its minimal value.

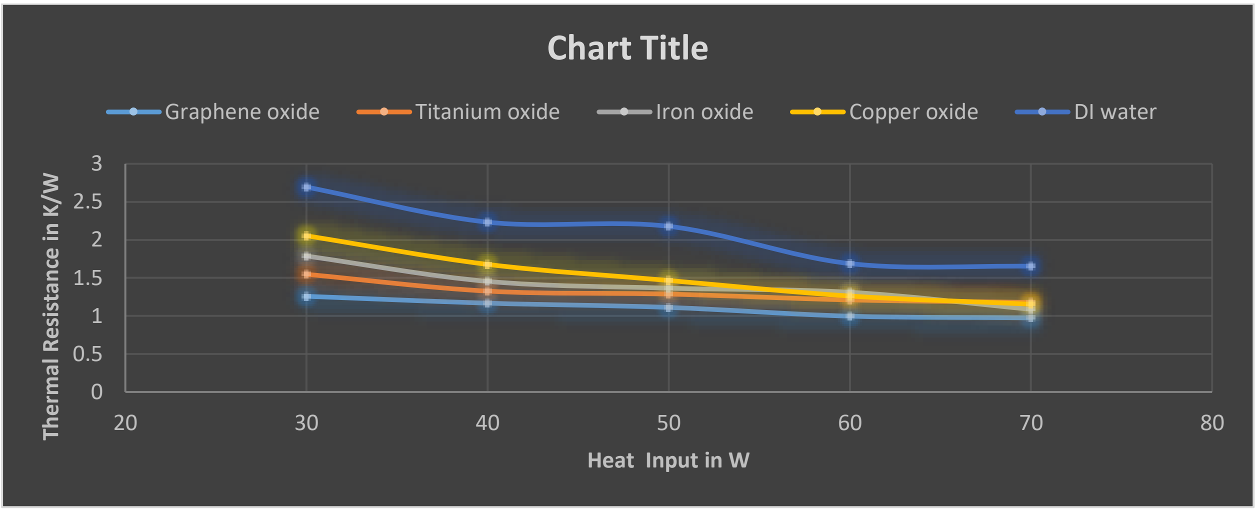

Fig. 7 Thermal resistance of heat pipe for 0° inclination

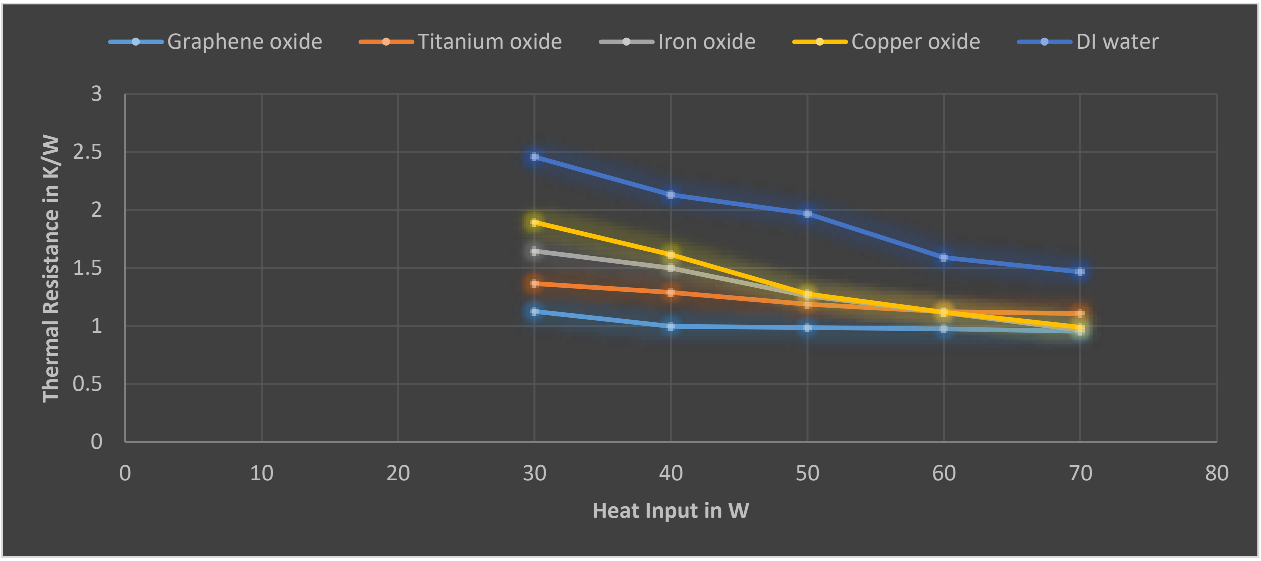

Fig. 8 Thermal resistance of heat pipe for 15° inclination

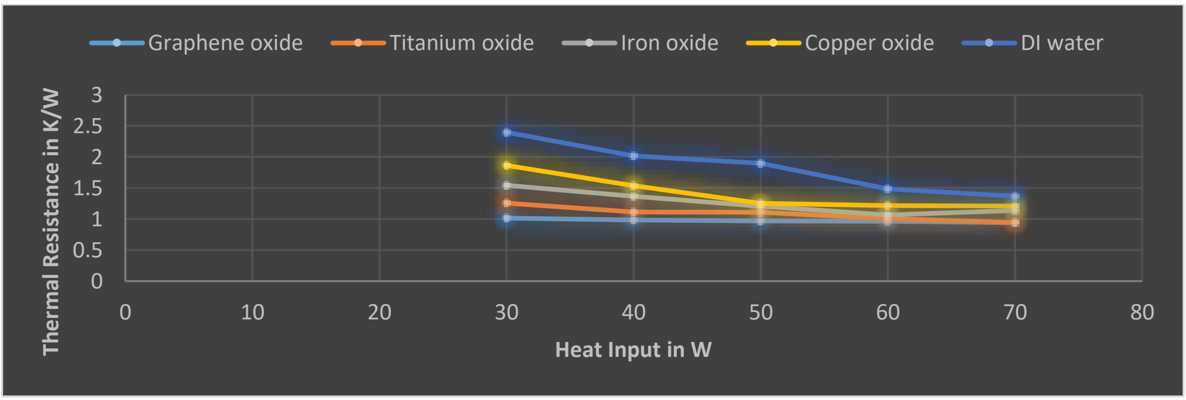

Fig. 9 Thermal resistance of heat pipe for 30º inclination

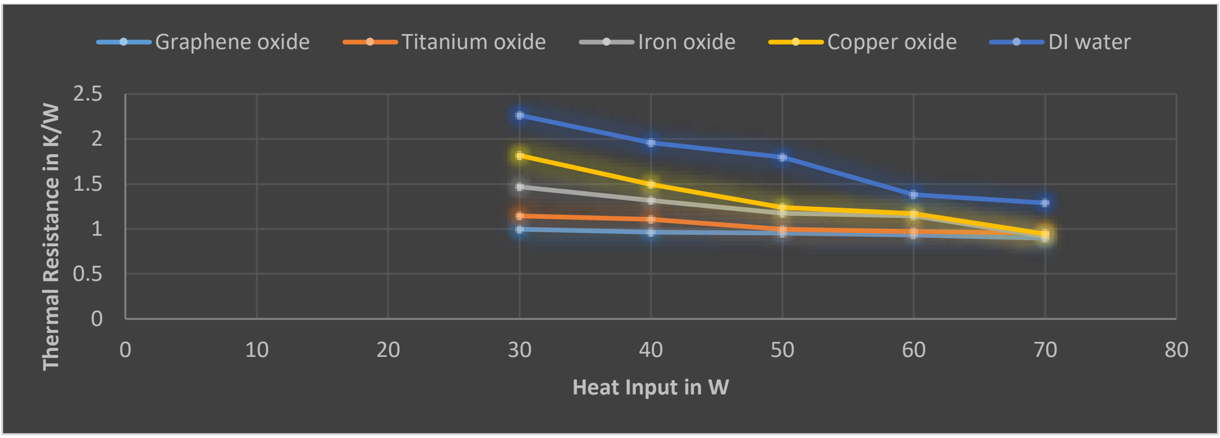

Fig. 10 Thermal resistance of heat pipe for 45º inclination

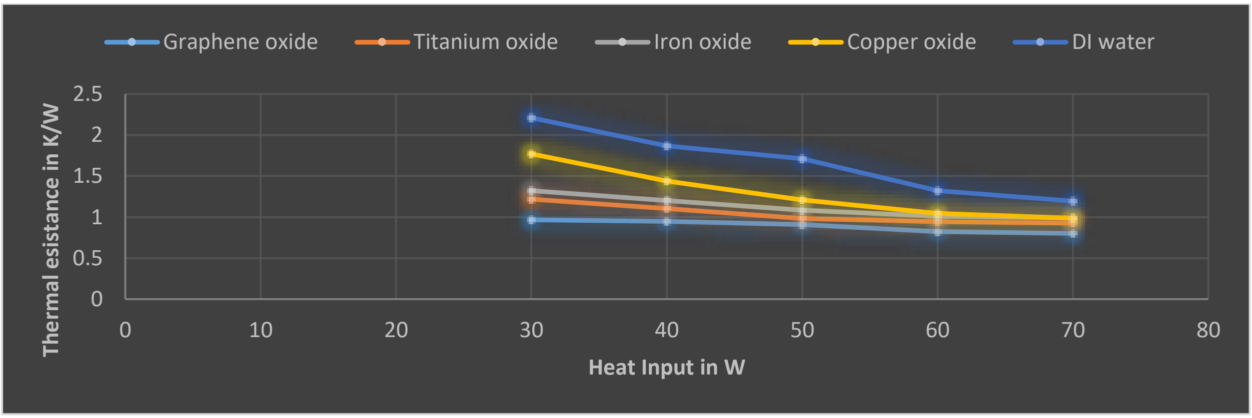

Fig. 11 Thermal resistance of heat pipe for 60º inclination

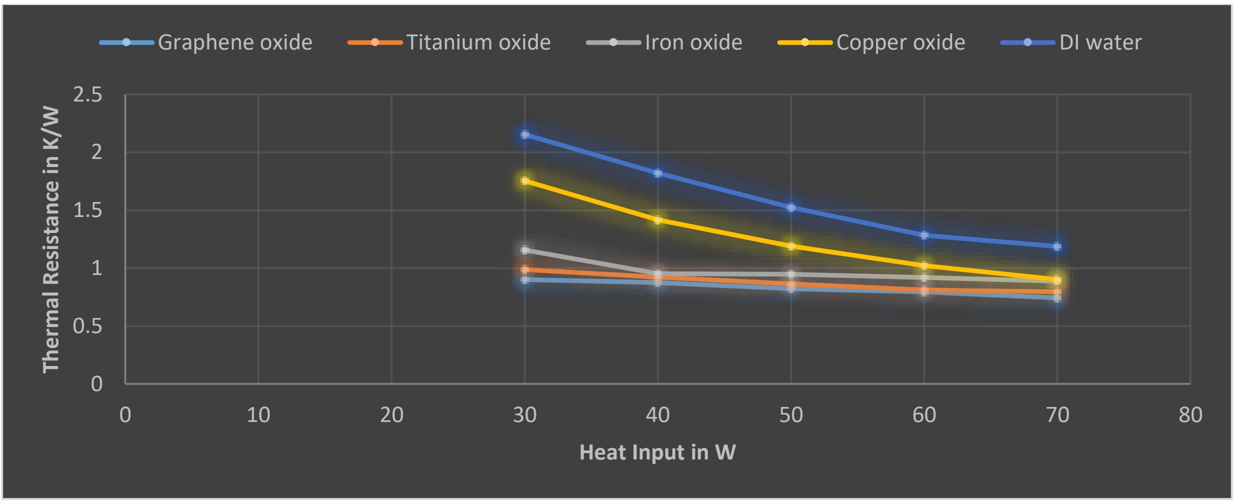

Fig. 12 Thermal resistance of heat pipe for 75º inclination

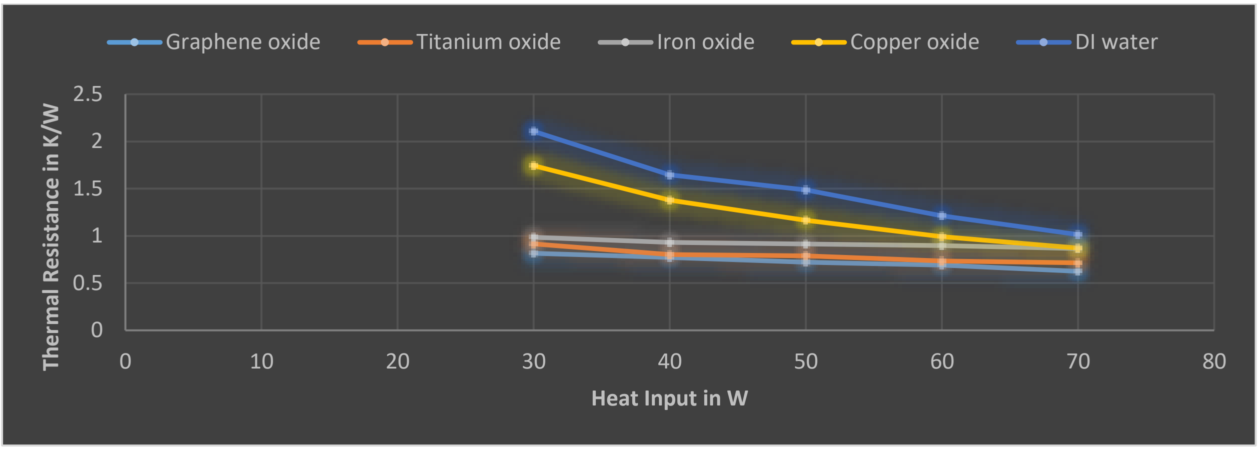

Fig. 13 Thermal resistance of heat pipe for 90° inclination

When the heat load added to the evaporator section from lower to higher value, the generation of vapour bubble is less at lower value while more on higher value. During higher heat load the thermal resistance becomes less compared to lower heat input. On the contrary to above, when the heat load is low, the 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 which increases the thermal resistance.

Conclusion:

The heat pipe efficiency increased directly proportional to inclination angle up to 45° and declines further addition of tilt angle. The reason behind reduction of efficiency is due to working fluid on which gravitational force has great influence in the heat pipes when the fluid is in motion between the evaporator and the condenser section. By comparing the heat pipes performance, the nanofluids shows better thermal performance than the base fluid DI water. Because of increasing effectual liquid conductance in heat pipe, the nanoparticles can level the transverse temperature gradient of the fluid. The thermal efficiency of the heat pipe filled with graphene oxide filled heat pipe nearly 40% higher than the base fluid.A lso similar trend obtained in thermal resistance. As a result, the better thermal performances of the nanofluid have shown its potential as alternate for DI water in the heat pipe.

References:

[1] S.U.S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, ASME FED 231 (1995) 99– 105.
[2] P. Keblinski, J.A. Eastman, D.G. Cahill, Nanofluids for thermal transport, Mater. Today 8 (2005) 36–44.
[3] Senthilkumar. R, Vaidyanathan S and Sivaraman B, 2010,"Study of heat pipe performance using an aqueous solution of n-Butanol," *Indian Journal of Science and Technology* Vol. 3(6), 702-706
[4] Senthilkumar. R, Vaidyanathan S and Sivaraman B, 2011, "Performance Investigation of Heat Pipe Using Aqueous Solution of n- Pentanol with Different Inclinations", *Journal of Mechanical Science and Technology,* 25(4), 923-929.
[5] Z.H. Liu, Y.Y. Li, R. Bao, Application of aqueous nanofluids in a horizontal mesh heat pipe, Energy Convers. Manage. 52 (2011) 292–300.
[6] P. Naphon, D. Thongkum, P. Assadamongkol, Heat pipe efficiency enhancement with Refrigerant nanoparticles mixtures, Energy Convers. Manage. 50 (2009) 772e776.
[7] P. Anthon, P. Assadamongkol, T. Borirak, Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency, Int. Commun. Heat Mass Transfer 35 (2008) 1316e1319.
[8] C.Y. Tsai, H.T. Chien, P.P. Ding, B. Chan, T.Y. Luh, P.H. Chen, Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance, Mater. Lett. 58 (2004) 1461e1465.
[9] D. Wen, Y. Ding, Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, International Journal of Heat and Mass Transfer 47 (2004) 5181–5188.
[10] D.W. Zhou, Heat transfer enhancement of copper nanofluid with acoustic cavitation, International Journal of Heat and Mass Transfer 47 (2004) 3109–3117.
[11] Y. Yang, Z.G. Zhang, E.A. Grulke,W.B. Anderson, G.Wu, Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow, International Journal of Heat and Mass Transfer 48 (2005) 1107–1116.

[12] S.W. Kang,W.C.Wei, S.H. Tsai, S.Y. Yang, Experimental investigation of silver nanofluid On heat pipe thermal performance, Applied Thermal Engineering 26 (2006) 2377–2382.
[13] C.T. Nguyen, G. Roy, C. Gauthier, N. Galanis, Heat transfer enhancement using Al_2O_3-water nanofluid for an electronic liquid cooling system, Applied Thermal Engineering 27 (2007) 1501–1506.
[14] Heat Pipe Background 1800s – A. M. Perkins and J. Perkins developed Perkins tube 1944 – R. S. Gaugler introduced the use of a wicking structure 1964 – G. M. Grover published research and coined the “Heat Pipe”.
[15] RanaAshvini , R.Dhiman, V.D. and Patel,J.J., Experimental Investigation of Heat Transfer Enhancement of Heat Pipe using Silver/Water Nano fluid, University Journal of Research, 2015,1,1-15
[16] Shinde, P., Shinde,V., Talape, R. and Korade, D.N., Experimentation of Heat pipe used in Nano fluids, International Journal of Recent Research in Civil and Mechanical Engineering, 2015,2, 135 – 139.
[17] ChNookaraju, B., KurmaRao, P. S. V., & Sarada, S. N. (2015). Thermal Analysis of Gravity Effected *Sintered Wick Heat Pipe. Materials Today*
[18] Manimaran, R., Palaniradja, K., Alagumurthi, N., & Hussain, J. (2013). Experimental comparative study of heat pipe performance using CuO and TiO2nanofluids. International Journal of Energy Research, 38(5), 573–580
[19] Jirapol Klinbun* - Influence of Filling Ratios on the Thermal Performance of Flat Heat Pipes- Thammasat International Journal of Science and Technology - Vol.19, No.4, October-December 2014