International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.1, 2015

RESEARCH ARTICLE

ISSN: 2321-7758

HEAT TRANSFER ENHANCEMENT OF HEAT PIPE USING TiO_2 NANOFLUID

A. VICTOR RICHARDSON[1]*, M. GANESH KARTHIKEYAN[2], C KANNAN[3], T. RAJAJAYASINGH[4]
[1]M.E Thermal Engineering, TRP Engineering College (SRM Group).
[2]Assistant Professor, TRP Engineering College (SRM Group).
[3]Assistant Professor, TRP Engineering College (SRM Group).
[4] Assistant Professor, TRP Engineering College (SRM Group).

Article Received: 18/02/2015
Article Revised on:24/02/2015
Article Accepted on:28/02/2015

A. VICTOR RICHARDSON

ABSTRACT

Heat pipe is a heat transfer device which transports large quantities of heat with minimum temperature gradient without any additional power between the two temperature limits. In this work to study the thermal efficiency enhancement of the heat pipe using titanium oxide nanofluid as the working fluid, and using two different heat pipes typically copper and stainless steel tube heat pipe. The titanium oxide nanoparticles are uniformly suspended with the demineralized water using ultrasonic homogenizer to prepare the titanium oxide nanofluid. The working fluid is filled with two heat pipe and the heat input is added. The study discusses about the effect of heat pipe inclination, type of working fluid and heat input on the thermal efficiency and thermal resistance. The experimental results are evaluated in terms of its performance and are compared with two heat pipes which one gives the better performance for heat transfer applications.

Keywords- Heat pipe, Heat transfer, Heat input, Angle of inclination, Thermal efficiency, Thermal resistance, Titanium oxide Nanofluid.

INTRODUCTION

Heat transfer 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.

A. HEAT PIPE AND ITS LIMITATIONS

Heat pipe is a heat transfer device which transports large quantities of heat with minimum temperature gradient. It consists of three different sections namelyevaporator, adiabaticsection and condenser section.Figure.1 shows the schematic arrangement of a heat pipe.

These three parts have equal importance and can significantly affect the performance of a heat pipe. The heat input is added to the evaporator section of the container, the working fluid present in the wicking structure which is kept in the container is heated until it vaporizes. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance.

The high temperature and corresponding high pressure in the evaporator section cause the vapour to flow to the cooler condenser section, where the vapour condenses and releases its latent heat of vaporization. The capillary forces existing in the wicking structure then pump the liquid back to the evaporator. The evaporator and condenser sections of a heat pipe function independently, needing only common liquid and vapour streams.

A novel idea is to suspend ultrafine solid particles in the fluid for improving the heat transfer properties of a fluid. Many types of particle, such as metallic, non-metallic and polymeric, can be added into fluids to form slurries. However, the usual slurries, with suspended particles in the order of millimeters or even micrometers may cause severe problems. The abrasive action of the particles causes the clogging of flow channels, erosion of pipelines and their momentum transfers into an increase in pressure drop in practical applications. Furthermore, they often suffer from instability and rheological problems. In particular, the particles tend to settle rapidly. Hence, even though the slurries give better thermal properties they are unable to act as coolants in practical applications.

There is an urgent need for new and innovative coolants with improved performance. The novel concept of nanofluids are the heat transfer fluids containing suspensions of nanoparticles has been proposed as a means of meeting these challenges. The term nano fluid is used to indicate a newly introduced special class of heat transfer fluids that contain nanoparticles less than 100 nm of metallic or non-metallic substances uniformly and stably suspended in a conventional heat transfer liquid.

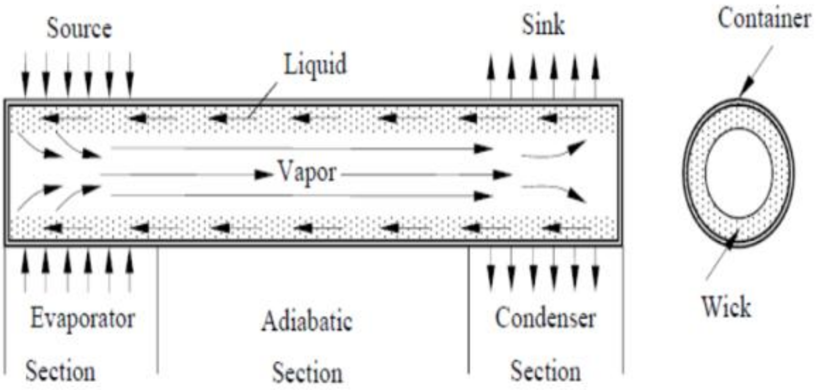

Fig.1 Heat Pipe

Nanofluids can be considered to be the next generation heat transfer fluids because they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids. The thermo physical and transport properties of the conventional fluids are improved by adding the nanoparticles in base fluid. The effective thermal conductivity of nanofluids increases with increase in temperature. In convective heat transfer in nanofluids, the heat transfer coefficient depends not only on the thermal conductivity but also on other properties, such as the specific heat, density, and dynamic viscosity of a nanofluid. At low volume fractions, the density and specific heat of nanofluids looks to be very similar to those characterizing the base fluid.

B. HEAT PIPE PARAMETERS

When the applied heat flux in the evaporator leads to boiling, vapor bubbles are produced in the evaporator which may partially block the liquid flow coming from the condenser. This causes dry out condition in the evaporator, known as boiling limit. As the vapor passes in the counter flow direction to the liquid, high shear forces are developed. This entrains the liquid and resulting in insufficient liquid flow to the wick structure, known as entrainment limit. Operation of heat pipe at low temperatures creates low vapor pressure which may be insufficient to support the increased vapor flow. This condition is called viscous limit. Choking of heat pipe may occur due to low vapor densities and this is called the sonic limit of heat pipe.

Ideally, the applied heat flux in the evaporator should be equal to heat rejection from the condenser,which is controlled by convection and radiation to the surroundings and this is called condenser limit.

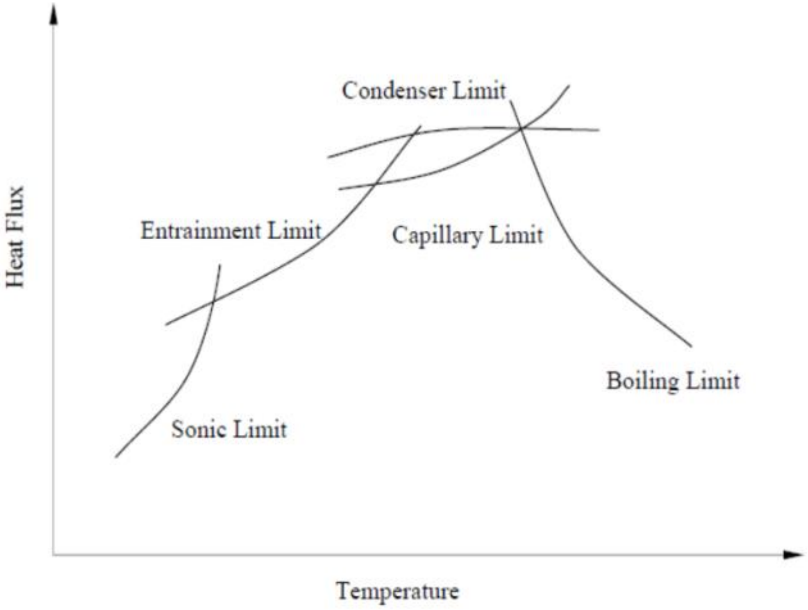

Fig .2 Heat Pipe Operating Limits

As with any other system, the performance and operation of a heat pipe is limited by various parameters. Physical phenomena that might limit heat transport in heat pipes include capillary forces, choked flow, interfacial shear and incipient boiling. The heat transfer limitations depend on the size and shape of the pipe, working fluid, wick parameters, and operating temperature. The lowest limit among these constraints defines the maximum heat transport limitation of a heat pipe at a given temperature.

C. HEAT PIPE WICK MATERIAL

The main functions of the wick are to generate capillary pressure and to distribute the liquid around the evaporator area. If the heat pipe has to return the liquid over a distance against the gravity field there is big requirement of the wick. Therefor there are many different forms of wick depending of the heat pipe and its location to be able to use.

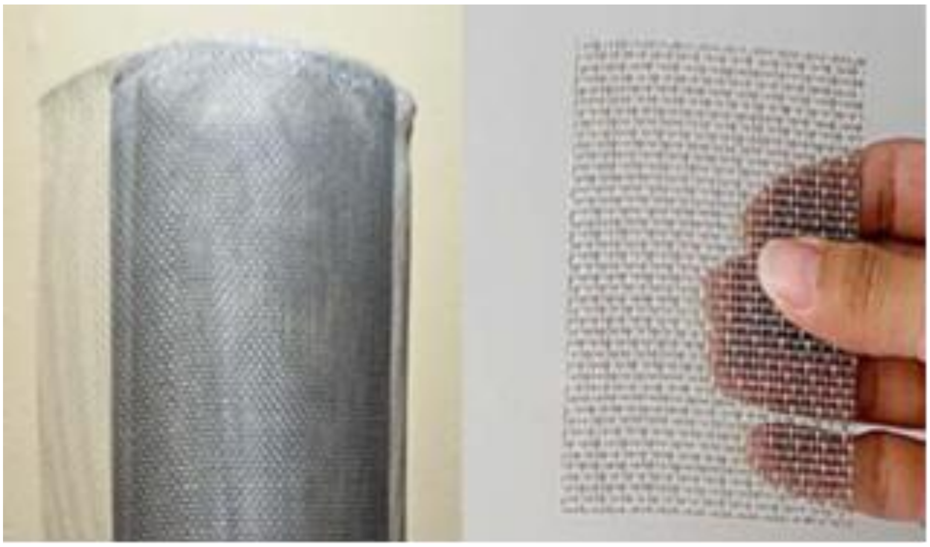

Fig .3 Screen mesh wick used in the heat pipe

The desired material properties and structural characteristics of heat pipe wick structures are,

- High thermal conductivity.
- High wick porosity.
- Small capillary radius.
- High wick permeability.

I. HEAT PIPE WORKING FLUID SELECTION

In heat transfer applications, conventional fluids like water, oil, refrigerant, etc. are used in heat exchangers, IC engines, refrigerators and air conditioners. Heat transfer capability mainly depends and limited by the thermal conductivity of the working fluid. A method was introduced by Argonne laboratory in 1996 to raise the thermal conductivity of the conventional fluids. In this method nano–sized metallic and non–metallic particles having high thermal conductivity are dispersed in the base fluids called Nanofluids.

Thermal conductivity of a fluid can be improved by adding nanoparticles and thus preparation of nanofluid is important. Nanofluid preparation involves two methods: single step and two step method. The single step method is a process that combining the preparation of nanoparticles with the synthesis of nanofluids. Physical vapor deposition, liquid chemical method and chemical reduction method are some of the methods available to prepare the nanofluid by single step method.

The fluid which is prepared by this method gives better stability and reduced agglomeration (collection of tiny particles to form a bulk mass that will settle more rapidly). But the single step method can be used only for low vapor pressure fluids. This method does not have a lengthy preparation process.

In the two step method, initially nano–scale sized metals, metal oxides, fiber particles and carbon nanotubes (CNT/NCT) are prepared. The dry powder is produced by various processes like chemical vapor condensation, mechanical alloying, etc. Thereafter, it is dispersed in the base fluids. The agglomeration is high in this method, because of its prolonged stages in the preparation.

A. NANOFLUID PROPERTIES

Thermal conductivity is the primary property that influences the heat transport capacity of nanofluids. Several methods are available to estimate the thermal conductivity of nanofluids. Among them, Transient Hot Wire (THW) method is widely used by many researchers.

Viscosity and temperature of any liquid is always interrelated with inverse proportionality. For the nanofluids also, the viscosity primarily depends on the temperature and the influence of particle volume fraction is also significant. If the viscosity is measured using capillary viscometer, the radius of capillary tube becomes an important parameter at higher volume fractions.

Nanofluid is a mixture of solid particles and a base fluid. Nanoparticles tend to aggregate with the time due to its high surface activity. The settling down of the particles creates obstruction to the flow velocity and clogging may occur particularly in micro channel flows. Sedimentation method is a simple and widely used one to find the stability of nanofluids.

B. NANOFLUID SELECTION PERAMETERS

Selection of working fluid is directly linked to the properties of the fluid. The properties are going to both affect the ability to transfer heat and the comparability with the case and wick material. Below are some things to consider when choosing the working fluid

- Compatibility with wick and wall materials.
- Good thermal stability.
- Wettability of wick and wall materials.
- Vapor pressures not too high or low over the operating temperature range.
- High latent heat.
- High thermal conductivity.
- Low liquid and vapor viscosities.
- High surface tension.

EXPERIMENTAL SETUP

The experimental setup used in this study as shown in fig.4 and the thermocouple locations are shown in figure. The specifications of the at pipes are givenin table1.

Container material	Copper, stainless steel
Wick material	Stainless steel screen mesh
Total length of pipe	1000 mm
Evaporator length	300 mm
Adiabatic length	400 mm
Condenser length	300 mm
Outer diameter of the pipe	22 mm
Inner diameter of the pipe	20 mm

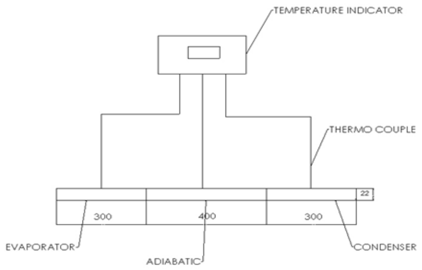

Fig. 4 Heat Pipe Apparatus

The heat pipe body is made up of copper and stainless steel, with a length of 1000 mm, outside and inside diameter of 22 mm and 20 mm respectively. The wick consists of two wraps of a stainless steel wrapped screen mesh with a wire diameter of 0.183 mm and 2365 strands per meter. The heat pipe is charged with 100 ml of working fluid, which approximately corresponds to the amount required to fill the evaporator. The evaporator section of heat pipe is heated by circumferentialelectricheaterwhichisattachedintheevaporatorsection.

The distance between the evaporator and the condenser is normally called as the adiabatic section with a length of 400 mm. The wall temperature distribution of the heat pipe in adiabatic zone is measured using three evenly spaced copper constantan (T-type) thermocouples with an uncertainty of ±0.1^{0}C, at an equal distance from the evaporator. The amount of heat loss from the evaporator and condenser surface is negligible.

The electrical power input is applied at the evaporator section using cylindrical electric heater attached to it with proper electrical insulation and the heater is energized with 230V AC supply using a variac and measured using a power transducer with an uncertainty of ±1 W. The evaporator and condenser have a length of 300 mm.

The heat pipe has the ability to transfer the heat through the internal structure. As a result, a sudden rise in wall temperature occurs which could damage the heat pipe if the heat is not released at the condenser properly. To measure the temperature of the condenser, equally spaced thermocouples are distributed along the length of the heat pipe. **Table 1**.Specifications of heat pipe

II. EXPERIMENTAL ANALYSIS

The experiments are conducted using twoidenticalheatpipeswhicharemanufacturedaspermentioneddimensions.Oneofthe heat pipes is copper pipe filled with titanium oxide nanofluid and another one with stainless steel pipe filled with titanium oxide nanofluid.

The power input to the heat pipe is gradually raisedtothedesiredpowerlevel.Thesurfacetemperaturesoftheheatpipearemeasuredat egulartimeintervalsuntiltheheatpipereachesthesteadystatecondition.Simultaneously the evaporator wall temperatures, condenser wall temperatures are measured.

Fig 5. Heat Pipe Experimental Setup

Once the steady state is reached, the input power is turned off. The heat pipes make it ready for further experimental purpose. The steady stateisdefinedasthevariationintemperaturelessthan± 0.1^{O}Cfor10min.Then the power is increased to the next level and the heat pipe is tested for its performance.

Experimental procedure is repeated for different heat inputs (20,40,60,80 and 100W) and different inclinations of pipe(0^{O},30^{O} and 60^{O}) to the horizontal and observations are recorded. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow.

HEAT PIPE PERFORMANCE RESULTS

A. EFFECTS OF ANGLE OF INCLINATION AND HEAT INPUT ON THERMAL RESISTANCE

Figure shows the thermal resistance of heat pipe with titanium oxide nanofluid. The thermal resistance(R) of the heat pipe is calculated using,

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

Where T_e and T_C are temperature values at the evaporator and condenser sections respectively and Q is the heat supplied to the heat pipe. From the figures (6-8),it is clear that the thermal resistance of heat pipe decreases for both the heat pipes with increasing values of angle of inclination andt he heat input.

At low heat input, the thermal resistances of both the heat pipes are high because of the relatively solid liquid film that resides in the evaporator section. When the heat load increases, these thermal resistances condense quickly to their minimum value. The thermal resistance of the copper heat pipe is always less than the stainless steel heat pipe.

The heat transfer enhancement of a heat pipe using nanofluids is not only due to the thermophysical properties of nanofluids but also due to the formation of thin porous coating layer produced by the nano particles in the evaporation region. The coating layer formed by the nanoparticles improves the surface wettability by reducing the contact angle and increasing the surface roughness, which inturn increases the critical heat flux and it significantly reduces the thermal resistance of the heat pipe using nanofluids.

B. EFFECTS OF ANGLE OF INCLINATION AND HEAT INPUT ON THERMAL EFFICIENCY

Thethermalefficiencyoftheheatpipeiscalculatedbythe ratioofcoolingcapacityrateof condenserfluidatthecondensersectionandthesuppliedpowerattheevaporatorsection. Fig (9-11) shows the variation of thermal efficiency of the heat pipe with respect to the various angles of heatpipe inclination. From all the figures, it is clear that the thermal efficiency of heatpipe increases with increasingvaluesoftheangleofinclinationupto60^{O}using titanium oxide nanofluid with respect to the horizontal position of the heatpipe. It is due to the fact that, the temperature of the working medium increases and hence more amount of heat can be removed in the condenser section. It is not only due to the capillary action of wick but the gravitational force also has a considerable cause on the flow of working fluid between the evaporator section and the condenser section.

The heat pipe thermal efficiency increases with using titanium oxide nanofluid in two different heat pipes.Fromthisanalysis,itisfoundthatthethermalefficiencyoftheheatpipeenhancesby using copper tube heat pipe instead of stainless steel heat pipe.

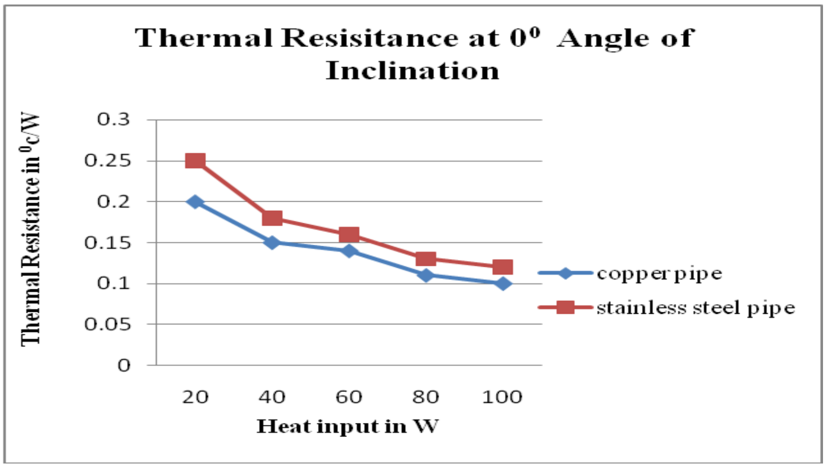

Fig 6. Thermal Resistance at 0^0 Angle of Inclination

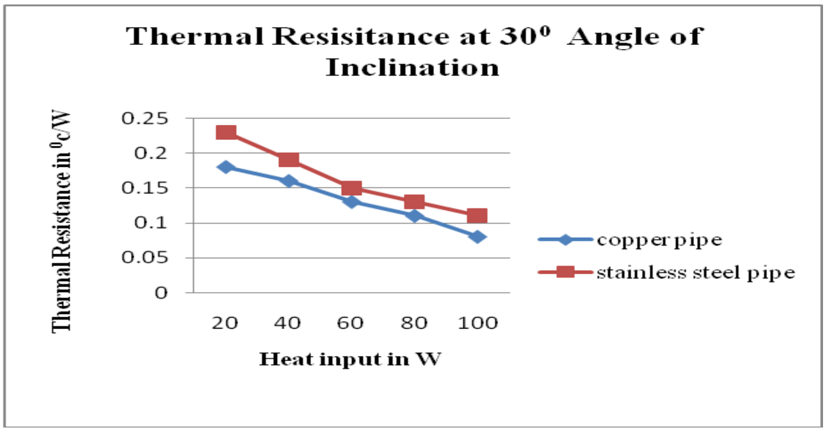

Fig 7. Thermal Resistance at 30^0 Angle of Inclination

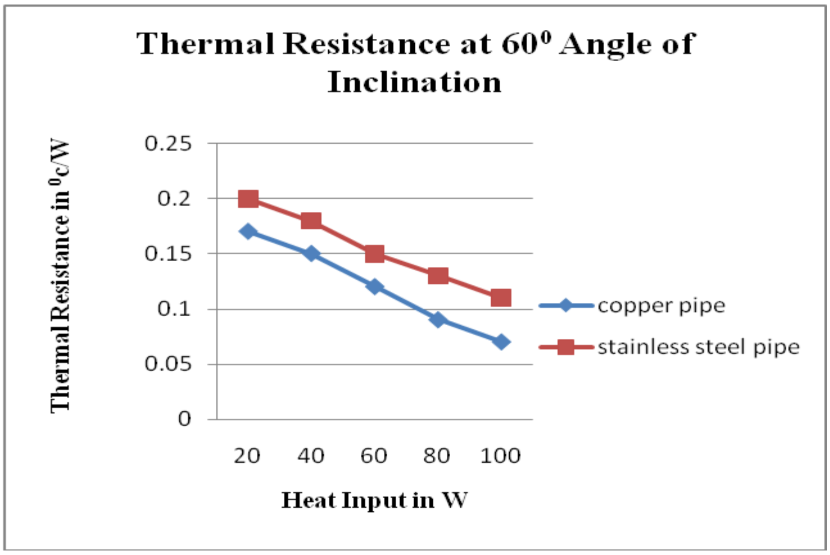

Fig 8. Thermal Resistance at 60^0 Angle of Inclination

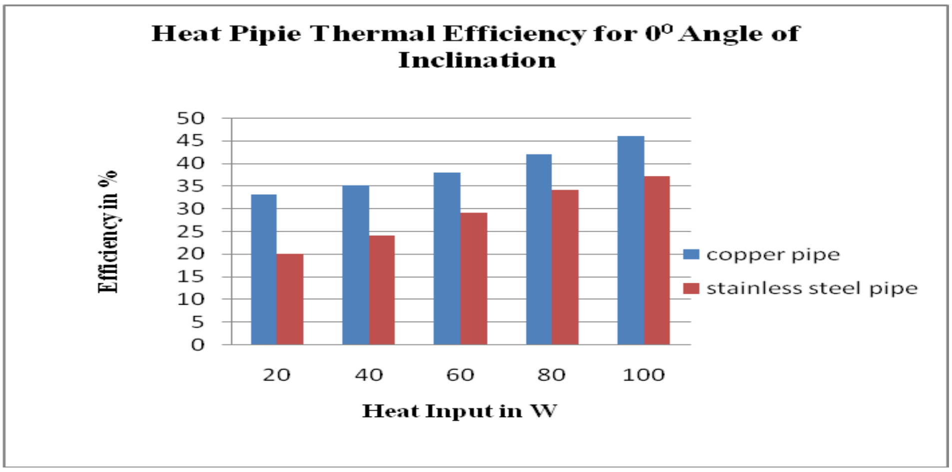

Fig 9. Heat Pipe Thermal Efficiency for 0^0 Angle of Inclination

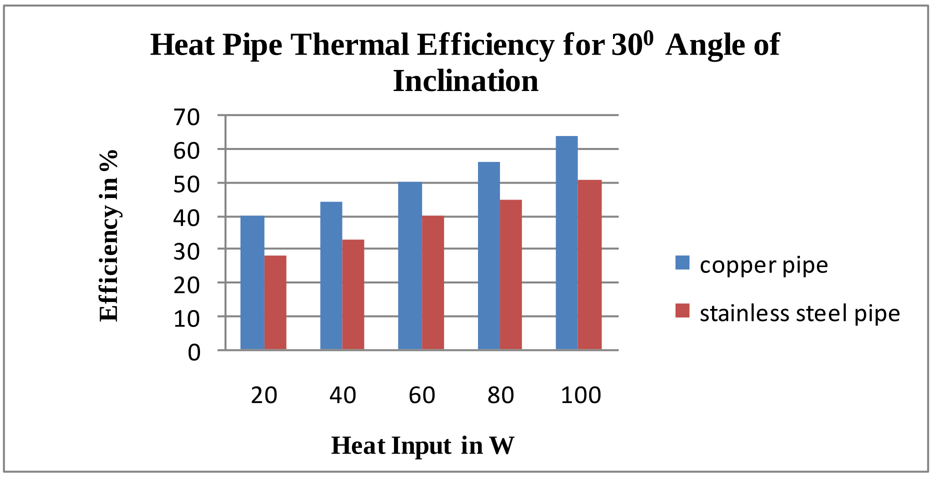

Fig 10. Heat Pipe Thermal Efficiency for 30^0 Angle of Inclination

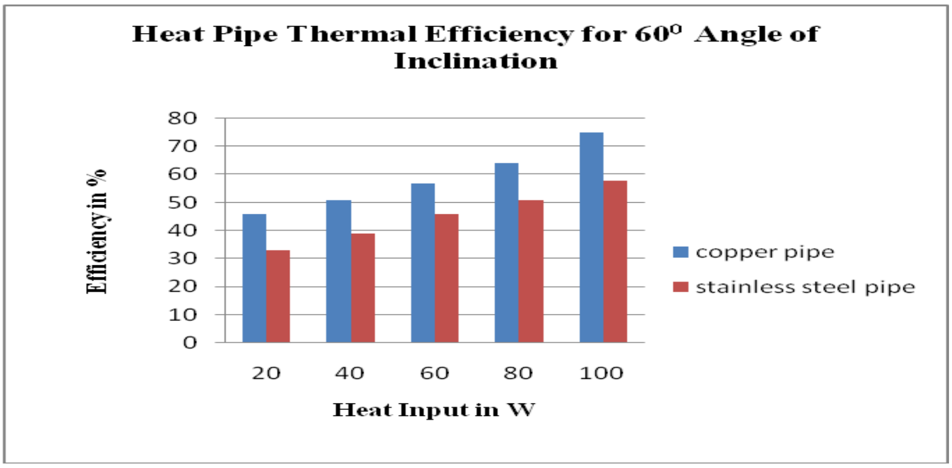

Fig 11. Heat Pipe Thermal Efficiency for 60^0 Angle of Inclination

III. CONCLUSION

The thermal performance enhancement of the heat pipe is predicted under different operating conditions like working fluid, power input and angle of inclination of the heat pipe.

It was shown that titanium oxide nanofluidis the best working fluid as compare to the basefluid, regarding higher temperature and high heat transfer coefficient in the evaporator section. The thermal resistance of the evaporator section washig her than that of the condenser section.

The power input at 100 watts gives the better efficiency than the lower power input. The inclination angle gave agreat effecton heatpipe thermal efficiency and thermal resistance. Ideal working position of the heat pipe was horizontal position. The experiment was conducted that the heat pipe is able to operate at different angle of inclinations. From the experimental results heat pipes are operated on maximum performance and maximum mass flow transfer in the angle of inclination of 60^0 positions. And using two different heat pipe materials, like copper and stainless steel heat pipe the copper heat pipe has the better efficiency than the stainless steel pipe.

From the experimental study, it is found that the thermal efficiency of copper heat pipe is higherthan the stainless steel pipe, and the thermal resistance is also considerably less than the stainless steel heat pipe.

IV. ACKNOWLEDGEMENTS

The research has been supported generously by TRP Engineering College, Trichy, Tamilnadu. The authors express their sincere appreciation for all of the support provided.

REFERENCES

[1]. R. Manimaran, K. Palaniradja, N. Alagumurthi, 2012, “Effect of filling ratio on thermal characteristics of wire mesh heat pipe using copper oxide nanofluid,” Frontiers in Heat Pipes Journal (2012).

[2]. M.G. Mousa, 2011, “Effect of nanofluid concentration on the performance of circular heat pipe,” Ain Shams Engineering Journal (2011) 2, 63–69

[3]. A. Brusly Solomon, B. C. Pillai and Mohammed Ibrahim, “Thermal performance of cylindrical heat pipe using nanofluids”.

[4]. Yimin Xuan, Qiang Li, 1999, “Heat transfer enhancement of nanofluids” International Journal of Heat and Fluid Flow 21(2000), 58-64.

[5]. G. Kumaresan, S. Venkatachalapathy, “Heat transfer enhancement studies of heat pipes using nanofluids”.

[6]. Alexander Oron and Philip Rosenau, 1994, “On a nonlinear thermocapillary effect in thin liquid layers,” Journal of Fluid Mechanics., 273(1), 361-374.

[7]. Choi, S.U.S. 1995, “Enhancing thermal conductivity of fluids with nanoparticles, developments and applications of non-Newtonian flows,” FED-vol.231/MD-vol. 66, 99–105.

[8]. Choi S. U. S, Eastman J.A, Li S and Yu W, Thompson J, 2001,“Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-based Containing Copper Nanoparticles,” Applied Physics Letters, vol.78(6), 718-720.

[9]. Das S.K., Putra N, Thiesen P and Roetzel W, 2003, “Temperature dependence of thermal conductivity enhancement for nanofluids,” ASME Trans. Journal of Heat Transfer 125(8), 567–574.

[10]. Das S.K, Putra N and Roetze W, 2003, “Pool boiling characteristics of nano-fluids,” International Journal of Heat Mass Transfer, 46 (5) , 851–862.

[11]. Kim H.D, Kim J and Kim, 2007, M.H “Experimental studies on CHF characteristics of nano-fluids at pool boiling,” International Journal of Multiphase. Flow, 33(7), 691–706.

[12]. Li C.H, Wang B. X and Peng X.F, 2003,” Experimental investigations on boiling of nano-particle suspensions,” Boiling Heat Transfer Conference, Jamaica, USA.

[13]. Nengli Zhang, 2001, “Innovative heat pipe systems using a new working fluid,” International Communications .of Heat & Mass Transfer, 28(8), 1025-1033.

[14]. Paisarn Naphon, Pichai Assadamongkol and Teerapong Borirak, 2008, “Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency,” International Communications of Heat and Mass Transfer 35 (10), 1316–1319

[15]. 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.

[16]. 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.

[17]. Tu J.P, Dinh N and Theofanous T, 2004, " An experimental study of nanofluid boiling heat transfer", Proc. of 6th International Symposium on Heat Transfer, Beijing, China.

[18]. Vassallo P, Kumar R and D'Amico S, 2004, "Pool boiling heat transfer experiments in silica–water nanofluids," International Journal of Heat and Mass Transfer, 47(2), 407–411.

[19]. Vochten R, and Petre G, 1973, "Study of the Heat of Reversible Adsorption at the Air-Solution Interface, II. Experimental Determination of the Heat of Reversible Adsorption of Some Alcohols," Journal of Colloid and Interface Science, 42(2), 320-327.

[20]. Wang X and Mujumdar A S, 2007 "Heat transfer characteristics of nanofluids: A review," International Journal of Thermal Science, 46(1), 1–19.

[21]. Xuan Y and Roetzel W, 2000, "Conceptions for heat transfer correlation of nanofluids," International Journal of Heat and Mass Transfer, 43 (19), 3701.-3707.

[22]. Xuan Y and Li Q, 2003, "Investigation on Convective Heat Transfer and Flow Features of Nanofluids," Journal of Heat Transfer, 125(1), 151-155.

[23]. Gaugler, R.S.: Heat transfer devices, U.S. Patent 2,350,348 1944.

[24]. Trefethen, L.: On the surface tension pumping of liquids or a possible role of the candlewick in space exploration, GE Tech. Int. Ser. No G15-D114, General Electric Co., NY 1962.

[25]. Grover, G. M., Cotter, T.P. Erikson, G.F.: Structures of very high thermal conductivity, J. Appl. Phys. 1964.