Experimental Study on Thermal Performance of Wicked Heat Pipe using Nanofluids

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ABSTRACT

This paper presents an experimental investigation on thermal performance evaluation of the heat pipe using Al_2O_3/water nanofluids as a working fluid. The heat pipe consists of a straight aluminum tube with outer diameter 18mm, thickness 3mm and length 475mm, with sintered porous wick made up of aluminum of 1mm thickness. The Al_2O_3 nanoparticles are uniformly suspended with the de- ionized water to prepare the Al_2O_3/water nanofluids. The present study analyzes about the effect of inclination angle and particle concentration of nanofluids on thermal performance of the heat pipe. The experimental results show that the inclination angle has a strong effect on the heat transfer performance of heat pipe using nanofluids. The inclination angle of 60^0 corresponds to the best thermal performance for sintered wick heat pipe using Al_2O_3/water nanofluids.

Keywords- Heat pipe, thermal performance, nanofluids, sintered wick.

Nomenclature

dx: Thickness (m)
dt: Temperature difference (^{0}C)
k: Thermal conductivity (W/m^{0}C)
R: Total thermal resistance (^{0}C/W)
A: Area (m^2)
D: Outer diameter (mm)
L: Length of heat pipe (mm)
t: Thickness (mm)
K: Overall thermal conductivity of heat pipe (W/m ^{0}C)
Q: Heat transfer rate (W)
T: Temperature (^{0}C)

m: Mass flow rate of working fluid (kg/s)
C_P: Specific heat of water (J/kg^{0}C)
r_1: Inner radius of heat pipe
r_2: Outer radius of heat pipe

Greek symbols
ω: Fluid concentration (wt.%)
η: Efficiency (%)
ρ: Density (kg/m^3)
Δ: Change/Difference

Subscripts
HP: Heat pipe
Out: Output
In: Input
l: Liquid(cooling water)
c: Condensation section
a: Adiabatic section
e: Evaporation section

1. INTRODUCTION

A heat pipe is a device with very high thermal conductance that can transport large quantities of heat with small temperature difference between its hot and cold ends. Heat pipes are widely used in aerospace applications, military devices, and temperature control systems and now in personal computers. The heat pipe was introduced by Gaugler (1942) and further improvements were made by Groover in 1964 [1]. Recent studies are focused on the changes in geometrical configuration and working parameters of heat pipe to enhance its thermal performance and characteristics, replacement of base fluid by better heat transfer fluid is the most effective technology to enhance the performance of heat pipe. A method was introduced by Argonne laboratory 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 fluid (called nanofluids) [2].

The thermal conductivity of different nanofluids was experimented in more than 30 organizations, reported on the INPBE (International Property Benchmark Exercise) [3]. The thermal conductivity ratio of alumina nanofluid was 1.039 ± 0.003 for 1% volume fraction and increased to 1.121± 0.004 for 3%. Transient hot wire method was used to measure the thermal conductivity of alumina nanofluid [4]. They reported an increase of 20% in thermal conductivity compared with the base fluid [5].

The wick structure is also important factor to enhance the thermal performance of heat pipe. The most commonly used wick structures for heat pipes are simple and homogeneous, such as grooves, wire mesh, sintered metal powders and fibers [6]. The wick structure is critical to the function of heat pipes because it provides the pumping force to the return the fluid to the evaporator. The secondary purpose of the wick is to distribute the fluid around the circumference of the tube to maximize the evaporator surface area. The thickness effective pore size and porosity of the wick determine the performance of the heat pipe. A smaller effective pore size generates a higher capillary pressure; however this can results in a higher pressure drop in the condensate return along the wick as a result of the porosity is reduced.

The experimental as well as numerical work considering with or without sintered wick was carried out by many researchers in literature. The some important research work related to the heat pipe having wicking structure is summarized given in Table-1 as below:

Table 1: Summary of some important Literature Review

Author	Working fluid	Type of Heat pipe	Conclusions
Charoensawan et al. (2003) [7]	Water, Ethanol & R-123	Pulsating Heat Pipes (PHPs)	There are at least three thermo mechanical boundary conditions which are to be satisfied for the structure to behave as a true pulsating device.
Mangal singh lodhi et al.(2013) [8]	DI water & copper nanofluids	Flat heat pipe	The thermal efficiency of the heat pipe increase with increasing nanoparticles concentration in the base fluid. .
Zhen- hualiu et al. (2010) [9]	CuO Nanofluid	Miniature Grooved heat pipe	The inclination angle affects the heat transfer characteristics of the heat pipe using water. The maximum value of heat transfer obtained at 75^0 orientation of heat pipe.
Senthikumar et al.(2011) [10]	DI water & copper nanofluids	Flat heat pipe	The use of nanoparticles and tilt angle enhances the operating range and thermal performance of heat pipe when compared with that of the heat pipe with DI water.
Ping Yang Wang et al. (2012) [11]	CuO	Miniature mesh heat pipe	The inclination angle has great effects on heat transfer. When the inclination angle is equal to 45^0, the average evaporation HTC and condensation HTC increase by about 22% and 5% compared with those of the horizontal pipe, respectively.
Suchana akter Jaha et al.	Water and Ethnol	Closed loop pulsating heat	The best performance is obtained at 75^0 orientations of heat pipe. In all circumstances water provided to better

(2013) [12]		pipe	performing than ethnol in the experiment.
G. kumaresan et al. (2014) [13]	(CuO/DI)	Flat heat pipe and mesh & sinterd wick	The heat transport capacity of sintered wick heat pipe is 14.3% more compared with mesh wick heat pipe under the same operating conditions.
M. Nazarimanesh (2015) [14]	Water	Flat heat pipe	The best concentration is 50ppm and with the maximum entrance power of 40W, the cool source temperature standing at 40^0C at an angle of 30^0, the maximum decline pertaining to thermal resistance in proportion to the base fluid reaches 40% in comparison with other conditions.

In the present study, capillary wick is made of sintered powder which adheres to the inner walls of the heat pipe. This acts to transport the fluid through capillary action. Choosing a sintered structure as the heat pipe wick will provide high power handling, low temperature gradients and high capillary forces for antigravity applications.

2.DESCRIPTION OF EXPERIMENTAL SETUP AND WORKING FLUID

2.1. Preparation of nanofluid

The Al_2O_3/water nanofluid used in this study contains commercial nanoparticles of purity of 98.0%. The nanoparticles are in the size range of 30-50nm. The nanofluid is prepared by mixing 1gm of Al_2O_3 nanoparticles with 100 ml distilled water. Mixing of nanoparticles with distilled water is carried out by direct synthesis method. Al_2O_3/water nanofluids were statically placed for two weeks to confirm suspension performance. The specification of Al_2O_3 nanoparticles are shown in Table-2 as below:

Table 2: The specification of Al_2O_3 nanoparticles

The specification of Al_2O_3 nanoparticles	**Values**
Colour and appearance	Grey Power
Purity (%)	98.0
Particle size (nm)	30-50
Density (kg/m^3)	3000
Specific heat (J/kg^{0}C)	451
Thermal Conductivity (W/m ^{0}C)	12

2.2. Experimental setup details

The complete experimental set up with major components of heat pipe is shown in Fig. 1. The heat pipe in this study was made up of straight aluminum tube with an outer diameter of 18mm, thickness 3mm and length 475mm. It is mainly divided into three sections namely evaporator, adiabatic and condensation sections having length of 125mm, 200mm and 150mm respectively. The technical specifications of the heat pipe are given in Table-3 as follows:

Table 3: Technical specification of heat pipe

Major Components	**Dimensions**	**Material**
Heat pipe (straight circular tube)	Total length (L) = 475 mm Outer diameter (D) = 18 mm Thickness (t)= 3mm	Aluminum
Insulating material	Thickness (t) = 10 mm	Glass wool
Cooling jacket (mild steel pipe)	Length = 150 mm	Mild steel
Sintered wick	Thickness (t) = 1mm Porosity (ε) = 0.65	Aluminum

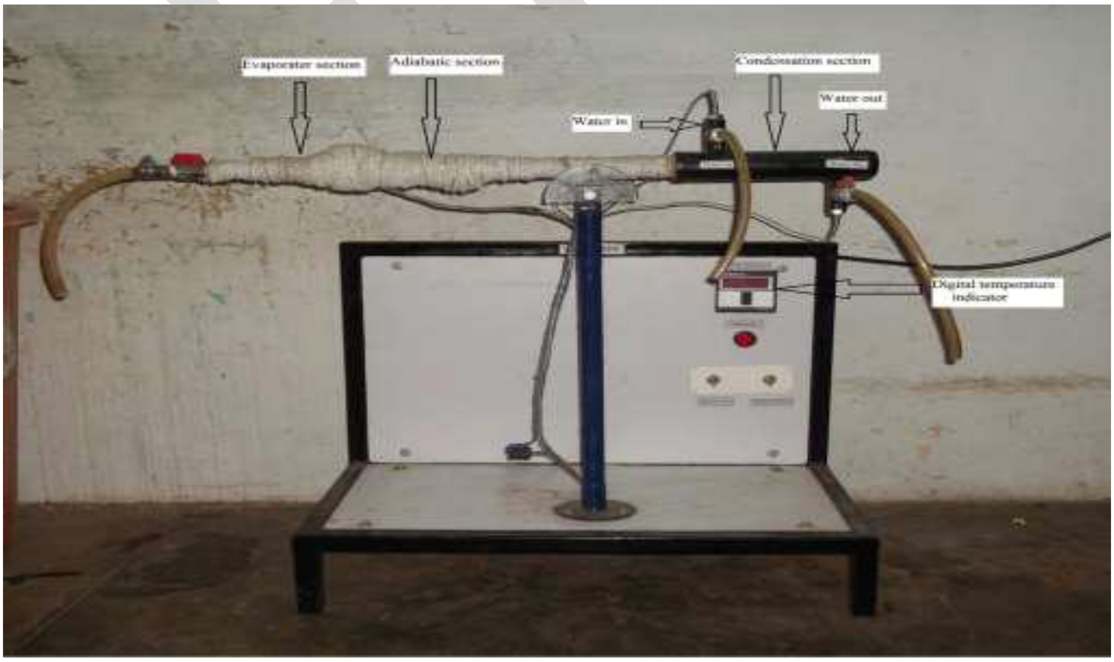

Figure 1: Experimental setup of heat pipe

The different three sections i.e. (Evaporator, Adiabatic and Condenser section) along with the positions of thermocouples are shown in Fig. 2.

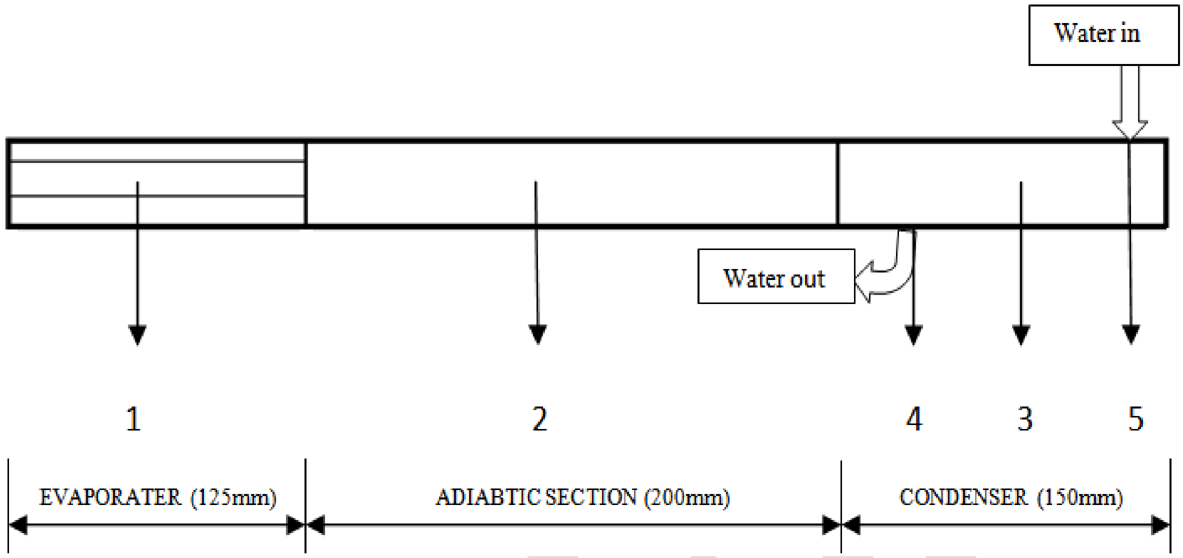

Figure 2: Locations of thermocouples

The experimental setup consist a resistance heater, digital temperature indicator and cooling jacket of mild steel pipe. The digital temperature indicator is used to record the thermocouple (J-type) readings at different positions of the heat pipe. The accuracy of temperature measurements was ±0.50 ^{0}C. The three thermocouples were attached on the heat pipe wall, i.e. two at both the evaporation and condenser section, and one at the adiabatic section. The thermocouples are welded over the surface of the heat pipe. The entire heat pipe is insulated by using glass wool powder to avoid heat loss from the system. A cooling jacket, which consists of inlet and outlet ports for cooling water, is fabricated using mild steel pipe. The temperature of cooling water at the inlet and outlet are measured using J-type thermocouples.

The locations of thermocouple on wall of heat pipe are given in Table 4 as below:

Table 4: Location of thermocouples used in heat pipe

Thermocouple Number	**Thermocouple location**	**Distance from Evaporator end cap (mm)**
1	Evaporator section	50
2	Adiabatic section	150
3	Condenser section	350
4	Cooling jacket inlet	320
5		360

2.3. Experimental Procedure

The heat pipe was charged with 20ml of nanofluid of different concentrations as 0.10 wt. %, 0.50 wt. % and 1.0 wt. % respectively. An AC power supply is source of power for the cylindrical resistance heater, used for heating the resistance heater which is mounted over the evaporator section. The heating power of resistance heater is kept constant as 200W with an accuracy of ± 0.5W. The cooling jacket in the condensation section contained cooling water inside a mild steel pipe. This allowed the water tank to provide cooling water at a temperature of 35±0.5 ^{0}C. Experimental procedure is repeated for different concentrations and different inclinations of pipe (0^0, 15^0,30^0,45^0,60^0,75^0 and 90^0) to the horizontal and observations are recorded. The flow rate of cooling water is measured when the heat pipe attains steady state conditions. It is adjusted to get the temperature difference of 3-40 ^{0}C. The test of heat pipe performance was with varying parameters such as fluid concentrations (ω) and input temperature (T). The overall thermal Conductivity of the heat pipe was then calculated using Eq. (2) to evaluate its thermal performance.

3. MATHEMATICAL FORMULATION

The rate of heat conduction in one dimensional direction in hollow cylinder under a steady state condition can be described by Fourier's law which is expressed as

$$\boldsymbol{Q = 2\pi k L \frac{\Delta T}{\ln(r2/r1)}} \tag{1}$$

The overall thermal conductivity of heat pipe is calculated by the formulas:

$$\boldsymbol{k_{HP} = \frac{Q}{A_s \Delta T}} \tag{2}$$

The overall thermal resistance (R_{th}) is a measure of thermal performance of heat pipe, which is defined as:

$$\boldsymbol{R_{th} = \frac{\Delta T}{Q_{in}}} \tag{3}$$

Where $\Delta T = T_e - T_c$

The efficiency of heat pipe can be expressed as a ratio of the output heat by condensation to the inlet heat by evaporation, i.e.

$$\boldsymbol{\eta_{HP} = \frac{Q_{out}}{Q_{in}}} \tag{4}$$

4. RESULTS AND DISCUSSIONS

4.1 Effect of inclination angle on thermal performance of heat pipe

The effect of inclination angle on thermal performance in terms of overall thermal conductivity, thermal resistance and thermal efficiency of heat pipe is shown in Fig. 3, 4 and 5 respectively.

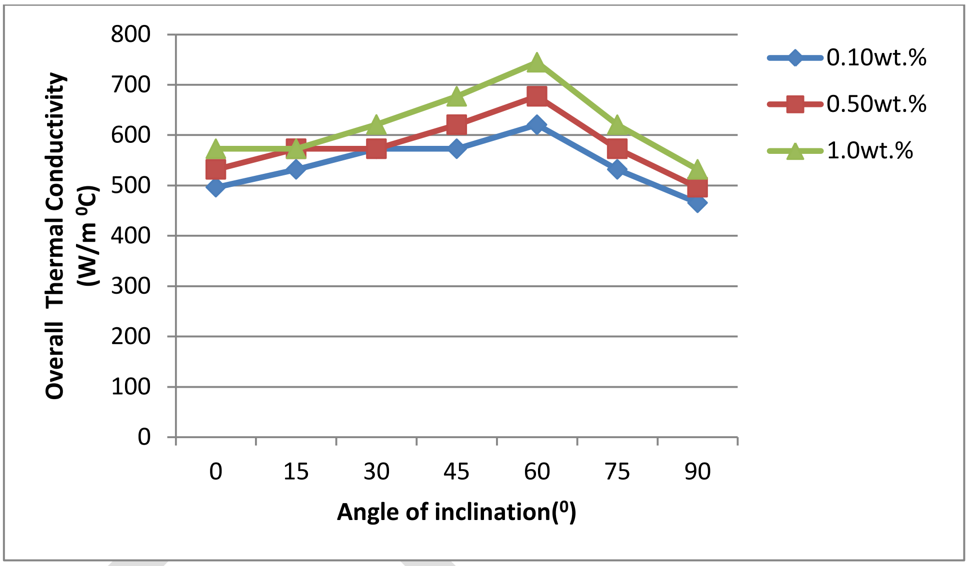

Figure 3: Effect of inclination angle on overall thermal conductivity

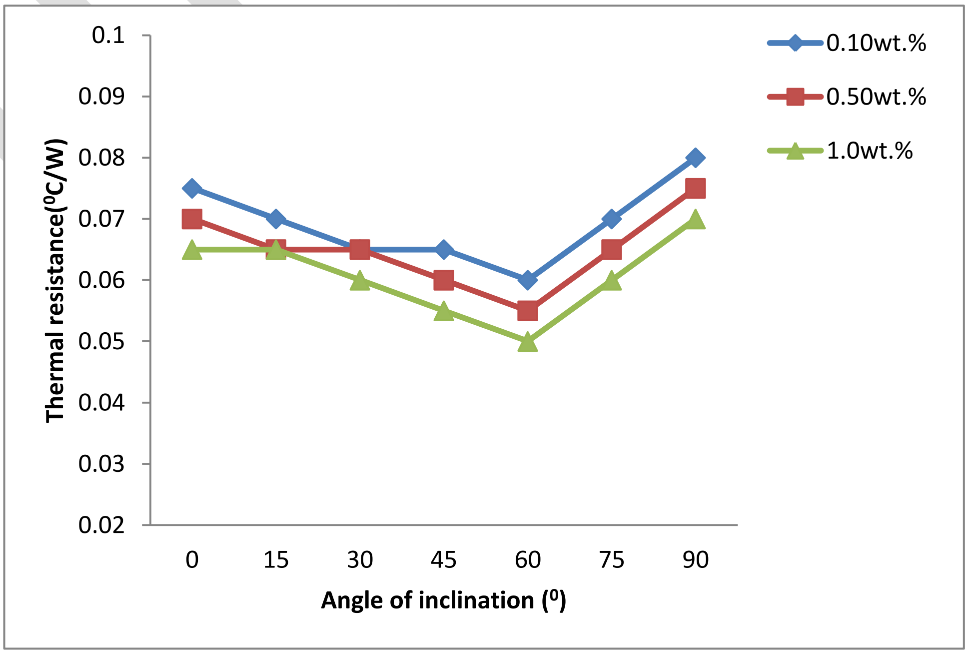

Figure 4: Effect of inclination angle on thermal resistance

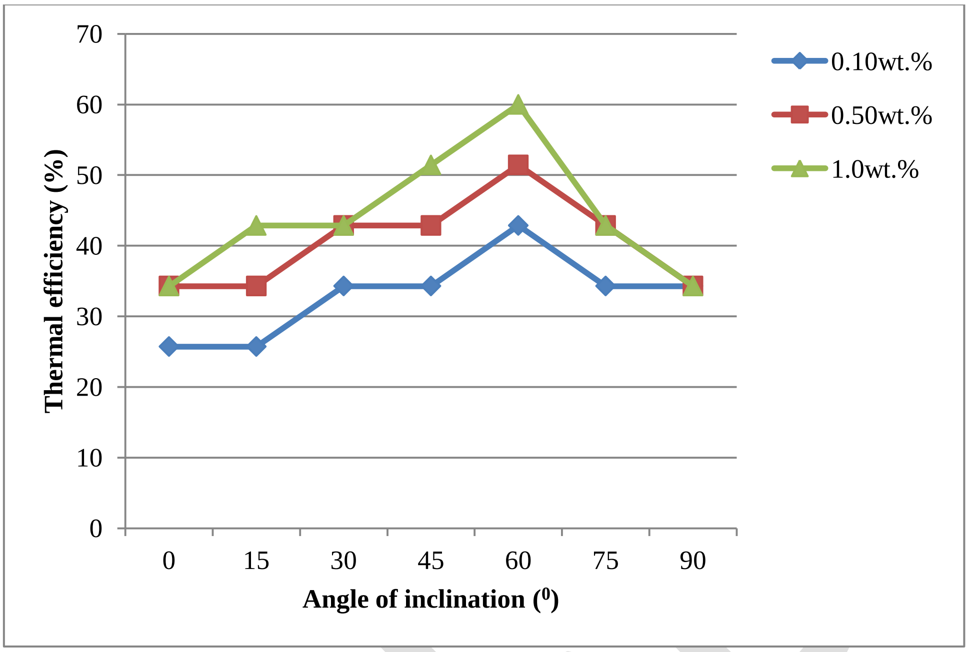

Figure 5: Effect of inclination angle on thermal efficiency

The thermal conductivity of heat pipe gradually increases with increasing the orientation i.e. inclination angle up to 60^0 as shown in Fig. 3. Orientation of heat pipe also significantly enhances the thermal conductivity. The impact of gravitational force in sintered wick heat pipe more so thermal conductivity increases up to 60^0.

The thermal resistance of heat pipe decreases with increasing nanofluid concentration and tilt angle up to 60^0 and after it increases as show in Fig. 4. At supply heat input the thermal resistance of heat pipe high because of the relatively solid liquid film that resides in the evaporator section. When the heat pipe orientation and concentration of nanofluid increases, these thermal resistances condense quickly to their minimum value.

The thermal efficiency of heat pipe increasing as inclination angle increases up to 60^0 and after it decreases as shown in Fig. 5. From the above results it is observed that, as the evaporator section is moving towards the ground the heat transporting ability of heat pipe is increasing up to $60\ ^0$ and from then onwards it goes on decreasing.

4.2. Effect of particle concentration on wall temperature of heat pipe

The effect of particle concentration on wall temperature of heat pipe at three different positions or inclination angle 0^0, 45^0 and 90^0 are shown in Fig. 6, 7 and 8 respectively.

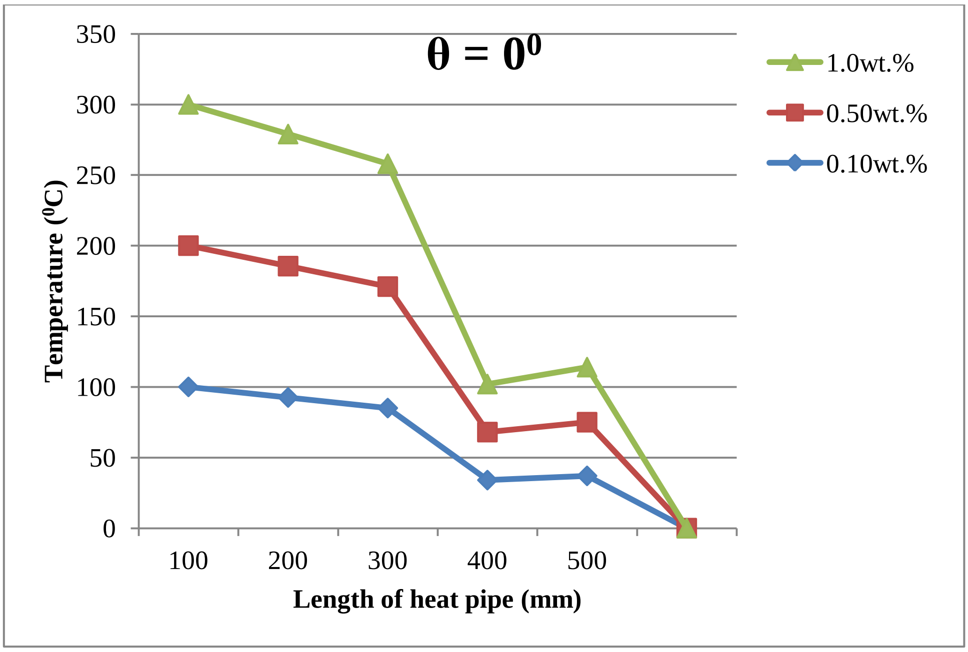

Figure 6: Axial variation of wall temperature of horizontal heat pipe ($\theta=0^0$)

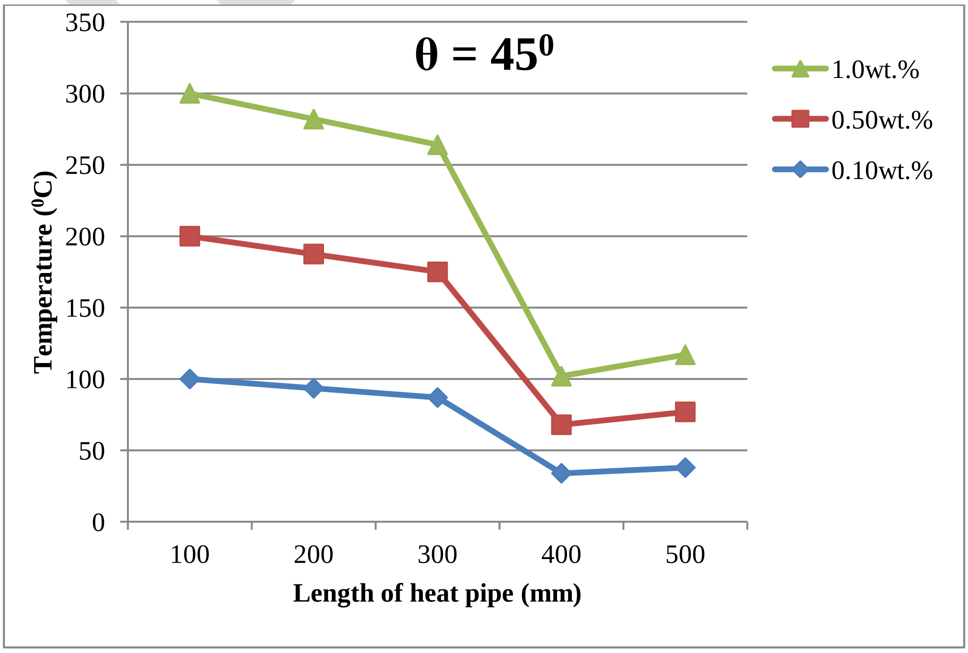

Figure 7: Axial variation of wall temperature of inclined heat pipe ($\theta=45^0$)

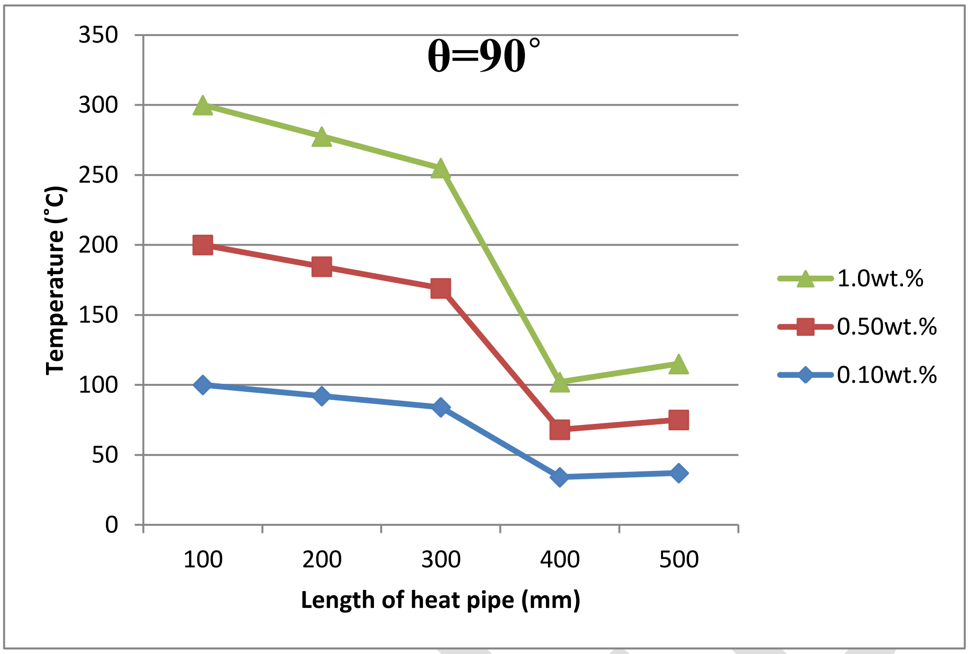

Figure 8: Axial variation of wall temperature of vertical heat pipe ($\theta=90^0$)

The above figures show that the wall temperature of heat pipe decreases with increasing nanoparticles concentration as well as axial length of heat pipe. The reason behind the decrement in wall temperature of heat pipe is that the thermal conductivity of nanofluids increases by increasing in the nanoparticles concentration.

It is observed that the tilt angle has a strong influence on the wall temperature distribution of sintered wick heat pipe. The wall temperature gradually reduces with the increasing tilt angle. Interestingly the maximum reduction in temperature for heat pipe occurs at different orientations viz. 45^0 with 1.0 wt.% .The variations in the temperature distribution is mainly due to the gravitational effect. The effect of gravity is more on sintered wick structure and it is observed that the sintered wick has good capillary action.

5. CONCLUSIONS

The following are the main results of this experimental investigation:

- The overall thermal conductivity of the heat pipe increases with increasing nanoparticles concentration in the base fluid. The maximum value of overall thermal conductivity is obtained at 60^0 is 744.60 W/m ºC with 1.0 wt. % nanofluid which is 20% higher than that of fluid concentration at 0.10 wt. %.

- The thermal resistance decreases with increasing nanoparticles concentration in the base fluid. The minimum thermal resistance is obtained at 60^0 is 0.05 ºC/W with 1.0 wt. % nanofluid which is 16.66% lower than that of fluid concentration at 0.10 wt. %.
- The thermal efficiency of the heat pipe increases with increasing nanoparticles concentration in the base fluid. The maximum value of thermal efficiency is obtained at 60^0 is 59.99% with 1.0 wt. % nanofluid which is 40% higher than that of fluid concentration at 0.10 wt. %.
- The wall temperature of heat pipe decreases with increasing heat pipe length. The wall temperature of heat pipe is enhanced by alteration of different concentration of nanoparticles in the working fluid.

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