Experimental Investigation of Thermal Performance of Horizontal Heat Pipe having Sintered Wick using Nanofluid

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Abstract— This paper presents the experimental investigation of the thermal performance of heat pipe charged with Al_2O_3 nano particles. Al_2O_3/water nanofluid served as the working fluid with three concentrations by volume as 1g/l, 5g/l and 10g/l in heat pipe. This heat pipe consists of a straight aluminum tube with outer diameter 18mm, thickness 3mm and length 475mm. This heat pipe also consist a sintered porous wick made up of aluminum of 1mm thickness. This paper presents a detailed discussion on the effect of various performing parameters by different temperature inputs as well as fluid concentrations as mentioned above. The nanoparticles have observed considerable effect on the enhancement of thermal performance of heat pipe by increasing fluid concentration as well as different temperature inputs.

Key words: Heat Pipe, Thermal Performance, Al_2O_3 Nanoparticles, Sintered Wick

NOMENCLATURE

dx: Thickness(m)
dt: Temperature difference(^oC)
k: Thermal conductivity(W/mK)
R_{HP}: Total thermal resistance (^oC/W)
A_s: Surface area (m^2)
V_{HP}: Total volume of heat pipe (m^3)
D: Outer diameter (mm)
T: Thickness (mm)
K_{HP}: Overall Thermal conductivity of heat pipe (W/mK)
L: Length of heat pipe(mm)
Q_{in}: Heat transfer rate (Heating Power in W)
Q_{out}: Heat outlet by condensation (W)
T_{in}: Inlet temperature of cooling water (^oC)
T_{out}: Outlet temperature of cooling water (^oC)
m_1: Mass flow rate of working fluid (Kg/s)
V_1: Volume of working fluid (m^3)
C_p: Specific heat of water (J/KgK)
ΔT: Temperature difference (K)
r_1: Inner radius of heat pipe
r_2 :Outer radius of heat pipe
T_e: Evaporator temperature
T_c: Condenser temperature

Subscripts:

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

Greek symbols:

ώ: Fluid concentration(g/l)
η : Efficiency(%)
ρ : Density(Kg/m^3)
Δ: Change/Difference

Acronyms:

TPCT: Two-Phase Closed Thermosyphon
PHP: Pulsating Heat Pipes
OHP: Oscillating Heat Pipes
HP: Heat pipe
Fig: Figure

I. INTRODUCTION

The heat pipe was first invented in 1942 by Rechard S. Gauler a General Motor Engineer. Heat pipes are efficient heat transfer devices with small temperature drops along the length of the heat pipe. The heat transport capacity of the heat pipe is controlled by the thermo-physical properties of working fluids.[6]

Heat pipes, which are well regarded as “super thermal conductors” and often the primary components of a heat transfer system, have been widely used in thermal devices and components for their efficient cooling and thermal management. The applications of heat pipes can be seen in many industrial areas such as the electrical and electronic, aerospace, telecommunications, food industries, etc. Over the past decades, much attention has been paid to the improvements of heat pipes including the appearance, design and optimisation, miniaturisation and weight reduction, and towards achieving higher heat flux. According to the report for NASA, reducing one pound of weight on a spacecraft can help save $10,000 US dollars in launch costs. Also, in terms of a telecommunication satellite, more than a hundred heat pipes are often required. In addition, for current electronic device design, such as CPUs, graphic cards etc., it is necessary to minimise the size and accommodate much more heat generation than in previous products, so that current cooling devices must absorb more heat energy and be similarly more compact. Based on these requirements, “lightweight” and “high performance” becomes the key goals for current heat pipe design, especially for applications in the aerospace and electronic industries.[11]

The common types of heat pipes primarily include as: Two-Phase Closed Thermosyphon (TPCT) heat pipes, Pulsating Heat Pipes (PHPs) and Oscillating Heat Pipes (OHPs).[10]

Heat pipes are used extensively in various applications, for achieving high rates of heat transfer utilizing evaporation and condensation processes. Heat pipes have been used in spacecrafts, computers, solar systems, heat and ventilating air conditioning systems and many other applications. Heat pipes have been used in various applications, including Air-Conditioning Systems, the cooling of Electronic components, Thermal storage, and Solar Heating systems.[10]

In recent times, there has been an urgent need in many industrial fields for a new cooling medium with significantly improved heat transfer performance compared to those currently available and it is also well known that fluids typically have lower thermal conductivity compared to crystalline solids. Therefore, fluids containing suspended solid particles can be reasonably expected to have higher thermal conductivities than pure fluids. The idea of using nanofluids, defined as liquids with nanometer-sized particle suspensions, was first introduced by Choi in 1995. It has been shown that when solid nanometer-sized particles are suspended in fluid, the enhancement of thermal conductivity can be significant. This enhancement can improve the efficiency of fluids used in heat transfer applications.[5]

The wick is very important component in the heat pipe. That is why every researcher concentrates on the design of wick structure. There are many types of wicks are used in this field, some of them are axial grooved wick, mesh wick, and wire bonded wick, two layer composite wick, and sintered wick. In most of the research work screen mesh wick is used by the researchers. At the same structural porosity, the more and smaller pores produce more contact interfaces between working fluid and solid structures, thus promoting the length and total area of thin film simultaneously. The sintered powder structures provide many small pores, which characteristic is related to powder parameters and sintering processes. Because these small pores exist, the mechanism of thin-film evaporation occurs obviously in sintered powder structures. The characteristics of higher fluid pumping effect and lower conductive thermal resistance also indicate that sintered powder structures are suitable to be used as the wick structure of heat pipes.

S. no.	Reference	Study type	Heat pipe type	Working fluid	Type of wick	Conclusion
1	Khandekar et al[1]	Experimental	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.
2	Yan-Jun Chen et al. [2]	Experimental	Flat heat pipe	Water, Ethanol, Nanofluid	-	The heat pipe using wire diameter of 1 mm has the best Heat transfer performance.
3	Shen-Chun Wu et al . [3]	Experimental	Loop heat pipe	Ammonia	Double layer wick	At thickness ratio of 0.28, performance increased with ratio and outer biporous layer increase; beyond 0.57, the performance decreased due to too much monoporous wicks.
4	Rosari Saleh et al[5]	Experimental	Loop heat pipe	ZnO based nanofluid	Screen-mesh wick	Temperature distribution and thermal resistance decrease as the concentration and the crystallite size of the nanoparticle increased.
5	AB Soloman et al. [6]	Experimental	Loop heat pipe	CuO nanofluid	Nanoparticle coated wick	The total resistance of heat pipe operated with coated wick is lower than that of conventional one and it decreases with increasing heat input.
6	Hajian et al. [7]	Experimental	Loop heat pipe	Ag/DI water nanofluids	Screen-mesh wick	Response time of the heat pipe with Ag/DI water nanofluids decreased up to 30% and 20% respectively, compared to a heat pipe with DI water.
7	G. Kumaresan et al[8]	Experimental	Loop heat pipe	CuO nanofluids	Copper sintered wick	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.
8	Liu et al[4]	Experimental	Loop Heat Pipe	CuO nanofluids	Screen-mesh wick	The thermal efficiency of heat pipe increases with increasing nanoparticle concentration in base fluid.
9	Jiayin Xu et al[9]	Experimental	Loop Heat Pipe	Nanofluids	Double layer wick	The loop heat pipe with Cu3Ni2 wick has low evaporation temperature during the operation.

Table 1: Summary of some important Literature Review

II. EXPERIMENTAL SETUP DETAILS

A. 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 nanoparticle with this size range is chosen for performance comparison with the heat pipe operated with nanofluid prepared using the same size particles.

The nanofluid is prepared by mixing 1gm of Al nanoparticles with 1 L distilled water. Mixing of nanoparticles with distilled water is carried out by direct synthesis method. The Al_2O_3/water nanofluid produced direct synthesis method was then adopted as the experimental sample. Al_2O_3/water nanofluids were statically placed for two weeks to conform suspension performance.

S.No.	Properties of Al_2O_3 nanoparticles	Values
1	Colour and appearance	Grey Power
2	Particle size(nm)	30-50
3	Thermal Conductivity(W/mK)	12
4	Purity (%)	98.0%
5	Density(Kg/m3)	3000
6	Specific Heat(J/KgK)	451

Table 2: The thermo-physical properties of Al_2O_3 nanoparticles are shown below:

B. Setup Details:

The heat pipe in this study was made up of straight aluminium 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 this heat pipe are as follows:

S. No.	Component	Dimensions	Material
1	Heat Pipe (straight aluminium tube)	Length(L)= 475mm Outer dia(D)= 18mm Thickness= 3mm	Aluminium
	Evaporator	L_e=125mm	
	Adiabatic	L_a=200mm	
	Condenser	L_c=150mm	
	Total surface area of pipe	A_s	
	Total volume of pipe	V_{HP}	
2	Insulating material	Thickness=10mm	Glass wool
3	Cooling jacket (mild steel pipe)	Length=150mm	Mild steel
4	Sintered wick	Thickness=3mm	Aluminium
5	Porosity of sintered wick	P=65%	

Table 3: Technical specifications of heat pipe:

The experimental setup consist a Resistance heater. The temperatures on the heat pipe were measured using a Digital temperature indicator with three thermocouples (J-type) at different points. The accuracy of temperature measurements was ±0.50°C. The Digital temperature indicator is used to record the thermocouple readings at different positions of the heat pipe. In total 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.

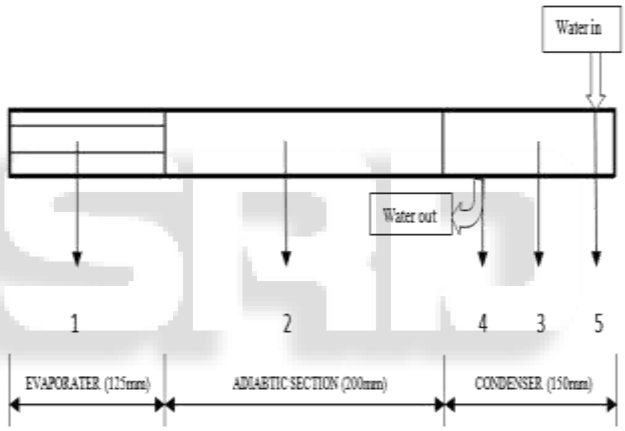

Fig. 1: Block diagram of heat pipe

Fig. 2: Setup of heat pipe

Thermocouple Number	Heat Pipe 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	Cooling jacket outlet	360

Table 4: Location of thermocouples used in heat pipe:

The heat pipe was charged with 20ml of nanofluid of different concentrations as 1g/l, 5g/l and 10g/l 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. 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 3-4^{0}C. The test of heat pipe performance was with varying parameters such as fluid concentrations (ώ) and input temperature (T). The overall thermal Conductivity of the heat pipe was then calculated using Eq. (2) to evaluate its thermal performance.

The accuracy of the power supply is ±0.5W. The accuracy of the steel ruler is ±1.0 mm. The accuracy of the thermocouples is ±0.50C.

C. Mathematical Formulas used for Calculations:

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:

$$Q=2\pi KL\frac{\Delta T}{\ln(r2/r1)} \quad (1)$$

The overall thermal conductivity of heat pipe is calculated by the formula

$$K_{HP}=\frac{Q}{Rth} \quad (2)$$

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

$$R_{HP}=\frac{\Delta T}{Qout}, \quad (3)$$

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.

$$\eta_{HP}=\frac{Qout}{Qin} \quad (4)$$

III. RESULTS OF EXPERIMENTAL INVESTIGATION

A. Effect of input temperature on the heat transfer rate of heat pipe:

The heat transferred by the heat pipe is calculated using heat balance equation, that is

$$Q=\dot{m}C_P(T_{OUT}-T_{IN}) \quad \text{Where } \dot{m}=\rho V_1 \quad (5)$$

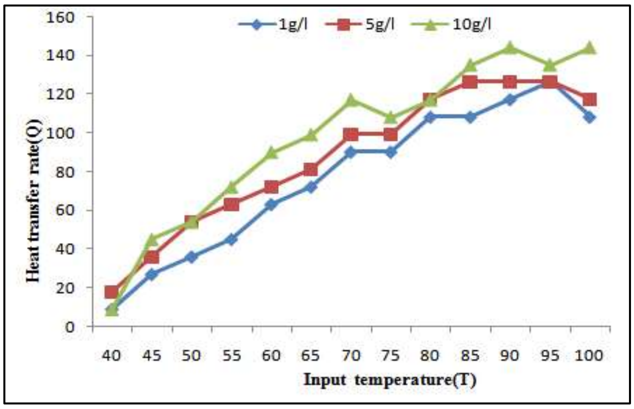

Fig 3: Effect of fluid concentration on heat transfer rate of heat pipe

B. Variation of Condenser Temperature with respect to Evaporator Temperature:

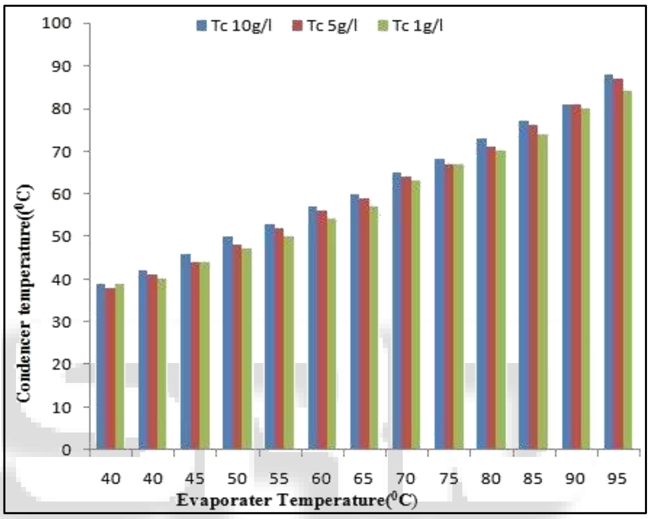

Fig. 4: variation of T_c over T_e

Variation of efficiency with respect to heat transfer rate of heat pipe:

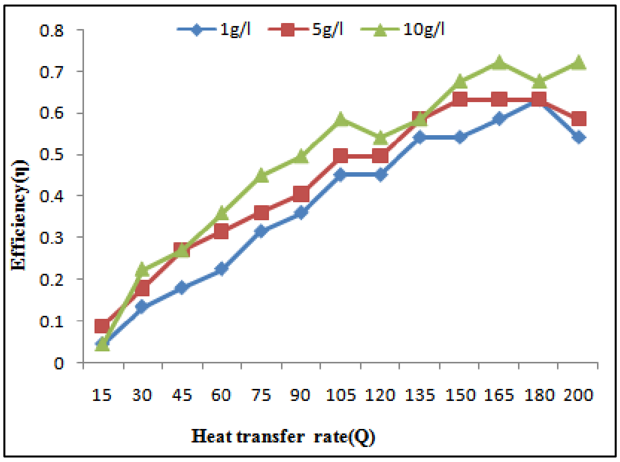

Fig. 5: Variation in efficiency for different fluid concentrations

IV. CONCLUSION

The following are the main conclusions of this experimental investigation:

1) The experimental results shows that the maximum value of heat transfer rate of heat pipe is obtained as

144.32W at 100^0C with 10g/l nanofluid which is 33.3% higher than that of fluid concentration of 1g/l.

2) The thermal efficiency of the heat pipe increases with increasing nanoparticle concentration in the base fluid. The maximum value of thermal efficiency is obtained 72.16% with 10 g/L nanofluid which is 45.4 % higher than that of fluid concentration of 1g/l.
3) The thermal performance of heat pipe is enhanced by alteration of different concentrations of nano particles in the working fluid.

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