International Engineering Research Journal

Experimental Investigation of Effect of length on Performance of Axially Grooved Heat Pipe.

Anuradha V. Patil.†, Dr. Pradeep A. Patil.‡

†Department of Mechanical Engineering, JSPM's JSCOE, Hadapsar, Pune, Maharashtra, India 411 028
‡Professor, Head of Department, Department of Mechanical Engineering, JSPM's JSCOE, Hadapsar, Pune, Maharashtra, India 411 028

Abstract

Heat Pipes are commonly used effectivedevices of heat transfer. It is the combination of principle of thermal conductivity and phase transition for enhanced heat transfer between two interfaces. This passive heat transfer device transports the thermal energy from one section to another section i.e. from Heat Source to Heat Sink of Heat Pipe. Heat pipes are better thermal conductive in nature as compared to other devices. In the present work, A Composite type of Heat pipe i.e. mesh covered Axially Grooved wick structured design is considered for investigation. Important aspects to be studied in this project work are the effect of length on the performance of Heat Pipe and thermal performance enhancement of Heat Pipe using Copper Nano Fluid of 2% concentration with water as abase medium. For experimental investigation, the length of pipes considered are 300mm, 400mm, 500mm, 600mm. Another important aspect in this project work is Constant Evaporator section length of 150mm and Constant Condenser section length of 100mm. Investigations are done on various factors affecting the heat transfer characteristics of Heat pipe such as Natural and forced cooling, effect of heat input on the thermal efficiency and thermal resistance, Different angle of inclinations, different working fluids, different concentrations of base fluid and Nano Fluid. It is necessary to have the relevant knowledge of Nano Fluid heat transfer effect and settlement of Nano particles present in Nano fluids over a time; while using and replacing any type of Nano Fluid with base fluid in Heat Pipe.

Keywords:*Heat Pipe, Axially Grooved Heat Pipe, CuO Nanoparticle, Effect of Length, Constant Evaporator section Length, Constant Condenser section Length.*

1. Introduction

Heat pipes are one of the most effective passive device to transport thermal energy from one end to another end of two solid interfaces. It combines conduction and convective heat transfer, what makes it to a complex heat transfer phenomenon. This passive heat transfer device transports the thermal energy from one section to another section i.e. from Heat Source to Heat Sink of Heat Pipe. Most commonly heat pipes are used due to their following features as very high thermal conductivity, relatively lower weight, flexibility, reliability in operation, and wide range of operating temperatures.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) that are Capillary Driven Heat Pipe, Annular Hear Pipe, Vapor Chamber, Rotating Heat Pipe, Gas-Loaded Heat Pipe. Heat Pipes majorly found the applications in Electronic Cooling, Heat Exchangers, Aerospace, Production Tool, Engines, and Automotive Industry.

The Heat Pipe is an evacuated and sealed pipe, filled with specific amount of fluid. It consists of major three sections namedEvaporator Section, Adiabatic Section, and Condenser Section. Connection of heat pipe can be done to more than one heat source and heat sink; they may or may not have adiabatic sections depending onapplications specification and design consideration of application. Heat Pipe has three main construction parts as Container, Wick Structure, and Working Fluid.

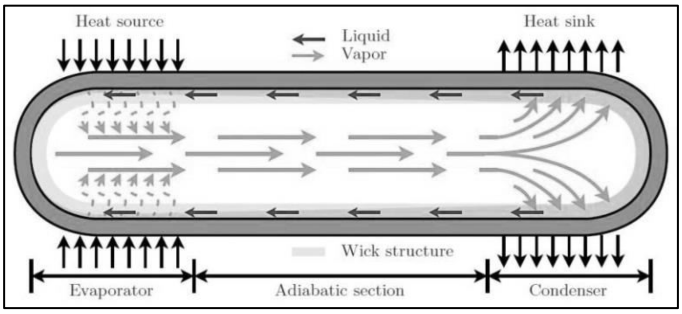

Figure 1 – Working Principle of Heat Pipe.

The above figure shows the operating principle of Heat Pipe. The operating thermal cycle can be explained as the heat input given to a Heat Pipe through Evaporator section increases the latent heat of Evaporation of Working Fluid present in Heat Pipe, causing the vapors of working fluid. This vapor travels to the other end of Heat pipe, while travelling it dissipates the heat and transforms into liquid state. The Liquid at Condenser section again travels back to Evaporator section through the medium of Wick structure present in Heat Pipe. This cycle continues until steady state is reached throughout the Heat Pipe. For enhancing the heat transfer from evaporator section to condenser section, external cooling force is attached at condenser end like water bath. The Adiabatic Section present in Heat Pipe is Covered with Insulating Materials Such as Glass Wool, Fiber Glass, Cotton Rope to minimize the heat losses from pipe to surrounding along the distance travelled by vapor.

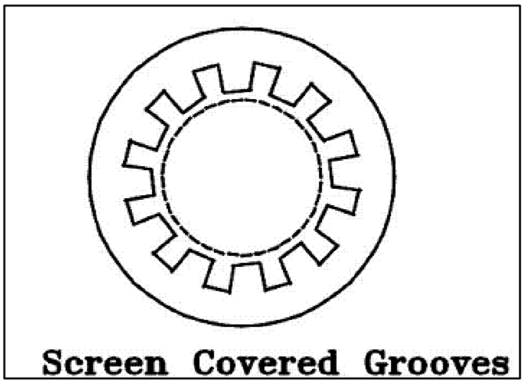

Figure 2 – Screen Covered Axially Grooved Wick Structure

This project work is to perform Composite axially grooved wick structure (shown above) copper heat pipe manufacturing, testing, and theoretical analyses. The details are presented in the corresponding chapters in this dissertation report. A detailed heat pipe manufacturing process is introduced, including primary design consideration, component assembly. The corresponding solutions are discussed. A series of experiments are conducted. The experiments involve five heat pipe configurations of Length 300mm, 400mm, 500mm, and 600mm with Constant Evaporator section length 150mm, and Constant Condenser section 100mm. Detailed experimental analyses focused on performance parameters such as effect of length on overall performance of Heat Pipe, the heat pipe transfer capacity and effective axial thermal conductivity, Thermal Resistance, Liquid viscosity, Phase change, efficiency, Fill ratio with regards to specific testing conditions. The study is to be carried out on heat pipe using copper nanofluid of concentration 2% with Water as a base medium for investigation of thermal performance enhancement.

2. Literature Survey

Naphon et al. (2008) investigated that the thermal efficiency is increased with angle of inclination of the heat pipe.Adding them nanoparticles of metals of specific amount of mass/volume fraction with base fluids enhances the heat pipe efficiency.maximum efficiency is obtained at 60^0 angle for DI water. When the DI water is replaced with alcohol, the maximum efficiency is obtained at 45^0 angle of inclination.
Mozumder et al. (2010), investigated the performance of heat pipe for various fill ratio and working fluid and lowest thermal resistance is obtained for 85% fill ratio
Shafahi et al., (2010) Studied the DI water filled Heat Pipe for various angles of inclination. For the value of heat input 80 W and inclination angle 75^0deep study was done and DI water, CuOnanofluids were used for experimentation. By using CuONano Fluid the temperature gradient was obtained for different lengths of pipes.
Hung et al. (2012) experimentally investigated the CuO–water nanofluid heat pipe for varying lengths of 0.3 m, 0.45 m and 0.6 m with a pipe diameter of 9.52 mm. This study gives idea about the charged volume ratio (CVR), input power andangle of inclination. The thermal conductivity was increased with heat input power. For the given heat input of40 W shown maximum performance. The charged volume ratio was varied from 20–80%. The maximum thermal conductivity for a 0.3 m length heat pipe was achieved at a CVR of 20% with weight fraction0.5 wt.%, tilt angle 40^0, and heat input of 40 W.It shows 22.7 % enhancement in conductivity.
Z H Liu et al (2011) conducted study with nanoparticle Cu, CuO and SiO with DI water as base fluid. Heat transfer coefficients at both ends were increased in case of Cu and CuO. Heat transfer was increased with increase in particle size.
P.G. Anjankar (2012) tested the setupof heat pipe for different heat inputs, condenser length and constant evaporator length of 300 mm. The experimental results shown the temperature distribution of the CTPCT almost uniformly and it lean toward the adiabatic section of heat pipe, because there may be chances of energy losses in adiabatic section of pipe.

3. Proposed Experimental work

3.1 Problem statement

The corresponding work is done for 'Experimental investigation of effect of length on performance of screen wrapped axially grooved heat pipe using DI water as working fluid'.The Heat pipes of length 300mm, 400mm, 500mm, 600mm and 600mm copper pipe (internally bored) are considered. For experimentation purpose the evaporator section length is fixed as 150 mm and condenser section length is 100 mm.Alongside of this effect the other effects are to be investigated such as Heat transfer rate variation with changing heat pipe length, efficiency, thermal resistance.

3.2 Objectives

1. Investigate of effect of varying length on heat transfer rate of Heat Pipe.
2. Development and experimental analysis of Heat Pipe with CuO Nano fluid of concentration 2%, specific gravity 1.01 Kg/m^3, and pH 9 for screen covered Axially Grooved wick structure.
3. Investigation performance of DI water Heat Pipe and CuO-water Heat Pipesunder various working conditions and parameters like Angle of inclination, Method of cooling – Natural and Forced, Length wise heat transfer rate, Thermal Conductivity, Thermal Resistance, Efficiency.

3.3 Methodology

Using reviewed literature knowledge, we can perform Heat Pipe Experiment is performed. Also, the CAD model is to be generated. The required conditions for running setup and how the values after steady state are achieved is referred from the technical papers referred.

1. Fabrication of Experimental Set Up

- Fabrication of Setup with 5 Heat Pipes with length 300 MM, 400 MM, 500 MM, 600 MM, 700MM, One Plain Cu-Water Pipe
- The Heat Pipe refilling facility has to be made for replacing working fluid.

2. Generation of CAD Model
- Input data based on dimensions of Heat Pipe Manufactured is given
- 3D model in CATIA is created.

3. Determination of loads
- Determination of different boundary condition acting on the component by studying various reference papers, and different resources available

4. Testing of Heat Pipe CAD Model and Analysis
- CAD model meshing is done and the boundary conditions are applied
- Solving meshed model using ANSYS.

5. Re-Designing according to previous readings, Re-Analysis and Results
- In CAD model changes are done for optimization
- Analyzing new model

6. Experiment validation, final Result
- Suitable experimentation is done as per requirement and comparison with present Heat Pipes result is done.
- Final results validation is done with experimental setup and it is compared with software result.

3.4 Work to be completed

Ones the readings of Heat Pipes of different lengths are obtained; there is needfor the comparison of Heat transfer enhancement. Hence the working fluid in heat pipe i.e. DI water is to be Replaced CuO Nano Fluid for this project work. The efficiency, heat transfer rate increased by using CuONano fluid can state the augmentation effect.The required amount of CuO Nano Fluid is Charged like DI water through Angle valve fitted at one end of heat pipe.
This is done to find out the Heat transfer enhancement due to infusion of CuONano particles with Water as a base fluid. From literature review, we can surely say that there are chances of better Heat transfer rate, Less Thermal Resistance and High Thermal Conductivity is observed over the length by using CuO Nano Particle with water as a base fluid.

4. Experimental Setup and Procedure

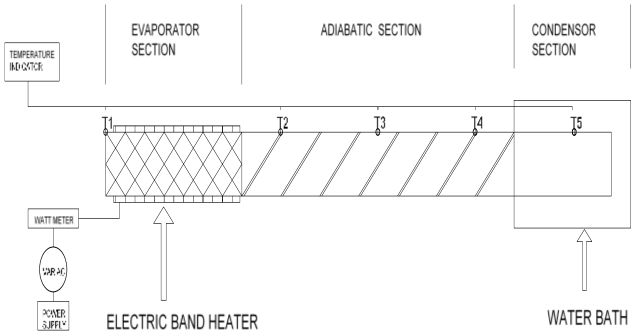

Figure 3 -Schematic layout of Test Rig.

Above shown the schematic representation of experimental Test Rig of Heat Pipe (Figure. 3). In this work, primarily the Heat Pipe with DI water as working Fluid is considered for experimentation purpose.
Basically, the Heat pipe is designed considering following steps and materials, specifications as

Sr. No.		Material / Specification
1	Working Fluid	Water
2	Wick Structure Type	Screen Covered Axial Grooves
3	Container Material	Copper
4	Type of Container	Cylindrical
5	Diameter	Inner Diameter – 25 mm
		Outer Diameter – 32 mm
6	Length of pipes	300mm, 400mm, 500mm, 600mm, 600mm (Internally Bored)
7	Thickness	3.5 mm
8	Heat Source	Electric Band Heater
9	Heat Sink	Water Bath
10	Thermocouple	k-type
11	Band Heater capacity	250 Watt
12	Wick material	Phosphor bronze

In this assembly, the evacuated Heat Pipe is charged with working fluid through angle valve using charging port. After charging the seal is closed to maintain the vacuum inside pipe. The Heat pipe is then connected to the heat source i.e. electric band heater at one section which will act as Evaporator section and another end of Heat pipe is immersed in water bath, this end will act as Condenser section. After the supply of heat to evaporator end, vapor is generated and it get travelled towards condenser section. The Evaporator section is of 150 mm and Condenser section is of 100 mm. The readings are taken at the interval of specific time e.g. 10 min, 15 min.
The specific unit of power is supplied; after approximately 1 and half hour steady state conditions are achieved. Then the thermocouple readings, mass flow rate, voltage or wattage is recorded to find out applied Heat Flux, Thermal Conductivity, Thermal resistance of Heat Pipe.
The actual manufactured test rig photograph is attached below; which facilitate the experimentation of different Heat pipes of varying length and at various angles of inclination.

Figure 4. – Photograph of Heat Pipe Setup.

5. Mathematical Modelling

Following expressions can be used to find out Overall Thermal conductivity, Overall Thermal Resistance, Efficiency. Rate of Heat Conduction of one dimensional plane wall under steady state condition is given by

$$q\ (W/m^2) = -k\frac{dr}{dx}$$

Hence, Overall Thermal Conductivity

$$k(W/mk) = \frac{Q_{in}.L}{A.\Delta T}$$

Where, Area can be given as,

$$A\ (m^2) = \frac{\pi D^2}{4}$$

From Energy Balance equation,

$$Q_{out}(W) = \dot{m}.c_p.(T_{out} - T_{in})$$

The Overall Thermal Resistance is given by

$$RHP\ (k/W) = \frac{\Delta T}{Q_{out}}$$

The Efficiency Can be given as,

$$\eta\ (\%) = \frac{Q_{in}}{Q_{out}}$$

5.1 Expected results

- Comparison of effectiveness of heat pipe charged with Nano fluid to that of heat pipe with conventional fluid available from literature.
- The Heat transfer rate should be increased in the range of 13-20%
- The increase in thermal Conductivity should be in Range of 55-70%
- As the angle of inclination increases, the thermal resistance decreases and the heat transfer coefficient of heat pipe increases.

6. Results and Discussion

The experiment is carried out on DI Water filled heat pipes of length 300 mm, 400mm, 600 mm bored pipe at an inclination of 0^0, 45^0 and 90^0.
Following graph shows the variation in temperature along length.

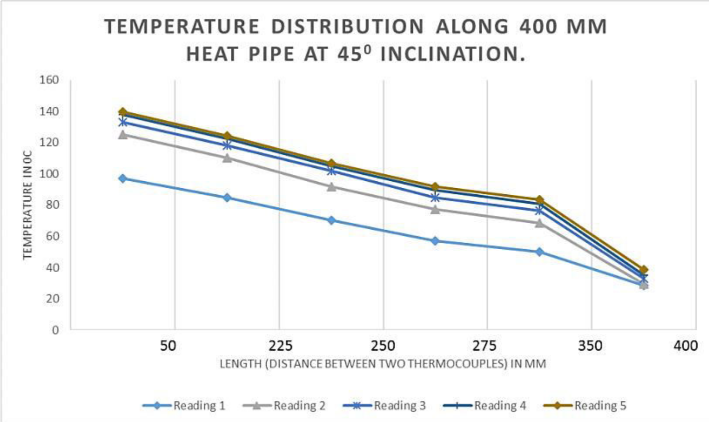

Figure 5.- Temperature distribution along 400 mm Heat pipe at inclination angle 45^0

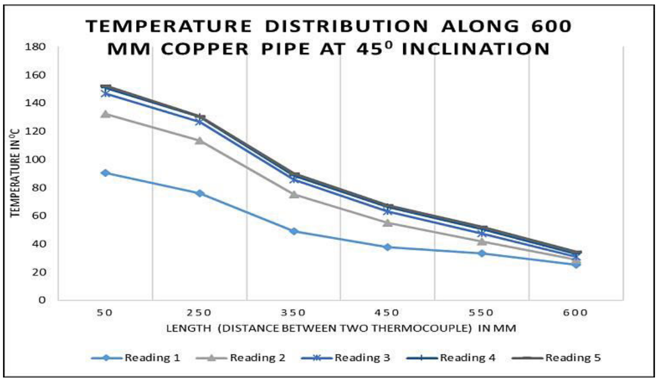

Figure 6. –Temperature distribution along 600 mm Heat pipe at inclination angle 45^0

At evaporator section general phenomenon of temperature rise is observed and as the heat is transferred toward condenser section the temperature variation minimises and shows stable readings.
After calculations, it is seen that as Naphon et al. (2008)investigations, the efficiency of heat pipe is maximum at 45^0Angle of inclinations. Hence, a heat pipe can transfer a high amount of heat over a relatively long length with a comparatively small temperature differential.
Heat pipe with liquid metal working fluids can have a thermal conductance of a thousand or even tens of thousands of times greater than the best solid metallic conductors, silver or copper. The results of former researchers were presented the effect of filling ratio on thermal efficiency of heat pipe with different design to study. No measurements with heat pipe that long adiabatic (adiabatic length ratio is higher than 0.5) have been found in literature.

Nomenclature

dx: Thickness (m)
dT: Temperature difference (0C)
k: Thermal conductivity [W/m K]
RHP: Total thermal resistance (^{0}C/W)
A: Surface Area (m2)
D: Outer diameter (m)
U: Overall thermal conductivity of heat pipe (W/m0C)
L: Length of the heat pipe (m)
Qin: Heat transfer rate (heating power) (W)
Qout: outlet heat by condensation (W)

Tin: Inlet temperature of cooling water (K)
Tout: Outlet temperature of cooling water (K)
ṁ: mass flow rate of water (Kg/s)
V: Volume flow rate of liquid (L/sec.)
c_p : Specific heat of water (J/kg K)
ΔT: Temperature difference (K)

Subscripts
Out: output
In: input

Greek symbols
η: Thermal efficiency of heat pipe (%)
Δ: Change/Difference Acronyms
TPCT: Two-Phase Closed Thermosyphon
PHPs: Pulsating Heat Pipes
OHPs: Oscillating Heat Pipes
HP: Heat Pipe

Conclusions

By analyzing the experimental investigation, following conclusions can be stated as

- The Thermal conductivity of water is increased by 30 % in DI water Heat Pipe.
- A heat pipe can transfer a high amount of heat over a relatively long length with a comparatively small temperature differential.
- The heat pipe performance varies with surrounding environmental conditions gravitation, cooling condition.
- Heat Sink i.e. Electric band Heater and Heat sink i.e. Water Bath assemblies are suitable for the experimental investigation of cylindrical heat pipe.
- The heat transfer capacity of copper tube is proportional to pipes cross sectional area.
- The heat transfer effectiveness of heat Pipe, expressed in the form of effectivethermal conductivity is up to 20% greater than base material Copper.
- Forced convection cooling provided to heat pipe increases the effectiveness along the length but decreases the efficiency of Heat pipe.
- On comparison with solid pipe of same dimensions,heat pipe can give minimum axial temperature gradient within optimized length.

References

G. Kumaresan, S. Venkatachalapathy, (2012), “a review on heat transfer enhancement studies of heat pipes using nanofluids”, Frontiers in Heat Pipes (FHP), 3, 043001, DOI:10.5098/fhp.v3.4.3001

Hung, Y., Teng, T., and Lin, B., 2012, “Evaluation of the Thermal Performance of a Heat pipe using Alumina Nanofluids,” *Experimental Thermal and Fluid Science*, 44, 504–511

Naphon, P., Assadamongkol, P., and Borirak, T., (2008), “Experimental Investigation of Titanium Nanofluids on the Heat Pipe Thermal Efficiency,” *International Communications, in Heat and Mass Transfer*, 35(10), 1316–1319

Shafahi, M., Bianco, V., Vafai, K., and Manca, O., (2010), “An Investigation of the Thermal Performance of Cylindrical Heat Pipes using Nanofluids,” *International Journal of Heat and Mass Transfer*, 53(1–3), 376–383

P.G. Anjankar, Dr. R. B. Yarasu, (2012), “Experimental Analysis of Condenser Length Effect on the Performance of Thermosyphon”,*International Journal of Emerging Technology and Advanced Engineering (IJETAE),* (ISSN 2250-2459, Volume 2, Issue 3,

Zhen-Hua Liu, Yuan-Yang Li, Ran Bao (2011), “Composite effect of nanoparticle parameter on thermal performance of cylindrical micro-grooved heat pipe using nanofluids”, *International journal of Thermal Sciences* 50 , pp. 558-568

A. K. Mozumder, A. F. Akon, M. S. H. chowdhury and S. C. Banik, (2010) “Performance of Heat Pipe for Different Working Fluids and Fill Ratios”, *Journal of Mechanical Engineering, Transaction of the Mech. Eng. Div., The Institution of Engineers*, Bangladesh Vol. ME 41, No. 2