EXPERIMENTAL STUDY OF HEAT PIPES

A PROJECT REPORT

Submitted in partial fulfillment of the

requirement for the award of the

Degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

By

AMRITA SHUKLA	**12BME1023**
TASMAI DAVE	**12BME1039**
SUMEET LULEKAR	**12BME1084**

Under the Guidance of

Dr. Karunamurthy K

SCHOOL OF MECHANICAL AND BUILDING SCIENCES

VIT University

CHENNAI (TN) 600127

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CERTIFICATE

This is to certify that the final project work titled "**Experimental Study of Heat Pipes**" is being submitted by **"Amrita Shukla, Tasmai Dave and Sumeet Lulekar"** is in partial fulfillment of the requirement for the award of **Bachelor of Technology in Mechanical Engineering**, is a record of bonafide work done under my guidance.

Dr. Karunamurthy K

Guide

The thesis is satisfactory / unsatisfactory

Internal Examiner **External Examiner**

Approved by

Program Chair

ACKNOWLEDGEMENT

We are extremely grateful to our Project Guide Associate Professor **Dr Karunamurthy .K**, SMBS, for the confidence bestowed upon us and entrusting our project entitled. His guidance and support at every step was helpful.

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Last but not the least we place a deep sense of gratitude to our parents and our friends who have been constant source of inspiration during the preparation of this project work.

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Sumeet Lulekar (12BME1084)

Amrita Shukla (12BME1019)

Tasmai Dave (12BME1039)

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NOTATIONS

Sr. no.	Nomenclature	Column Heading	Units
1	Q	Power input to evaporator section	W
2	k	Thermal conductivity	W/mK
3	A	Area normal to conduction direction	m^2
4	T	Temperature	°C
5	x	Distance	m
6	A_s	Solid Cross Sectional Area	m^2
7	A_a	Annular Cross Sectional Area	m^2
8	T1	Condenser region temperature	°C
9	T2	Adiabatic region temperature	°C
10	T3	Evaporator region temperature	°C
11	k_a	Thermal conductivity of pipe with annular cross section	W/mK
12	k_s	Thermal conductivity of pipe with solid cross section	W/mK

EXECUTIVE SUMMARY

In today's world, almost every device or object that we use is in some way or the other contributing to production of heat. Heat as we know is an unwanted wastage of energy in most cases. But in spite of a lot of improvement and advances made in the processes that release heat, it is nearly impossible to get rid of heat. In most cases, the steady production of heat leads to unwanted heat buildup in the region and an increase in the temperature of that particular area. This is undesirable and needs to be countered. For this, heat transfer techniques have to be looked into. Heat pipes are one efficient way of achieving this. The basic reason for this being that they are extremely good conductors of heat. This has led to them finding place in lot of areas where heat transfer is needed.

The main aim of our project is to study the performance of the heat pipes against a variety of factors namely- angle of inclination, the fill ratio of the evaporator region and presence of wick structure in the heat pipe. The material used for the container of the heat pipes is chosen to be copper because of its high thermal conductivity and compatibility with a variety of working fluids. Based on the compatibility between the working fluid and the container, water is chosen as the working fluid by the virtue of its non-volatility and working temperature range. The wick is chosen to be 400-mesh stainless steel mesh based on literature survey. Six such heat pipes were fabricated based on the factors that they were to be tested on.

Experiments were conducted on each pipe at various angles and results were tabulated till the steady state is achieved. Steady state temperatures were noted down and the thermal conductivity is calculated. This conductivity is then compared to the actual thermal conductivity of a normal copper pipe. Based on the observed data, the trends were found for thermal conductivities against different inclination angles, fill ratios and presence of mesh. Simultaneously, a model for space cooling is proposed.

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CHAPTER 1

INTRODUCTION

Efficiency of systems transferring heat through conduction can be increased by using elements with higher thermal conductivity. Heat pipes are such devices. Heat pipes are capable of achieving heat transfer with higher efficiency between very low temperature differences. This sets them apart from many other conduction devices. The project aims to develop copper heat pipes, measure their thermal conductivity, compare it with normal copper pipes and suggest proper application setup which employs heat pipes.

The heat pipe's higher conductivity is attributed to the high latent heat of the working fluid. Heat pipe comprises of two main sections – evaporator and condenser. Based on the length and application adiabatic section can also be added. The main components of heat pipe include- working fluid, wick and the container.

The working fluid absorbs heat in the evaporator region and turns to vapour state. This vapour moves from the evaporator region up the length of the pipe and condenses in the condenser region, which has a lower temperature, hence converting it back to liquid. This liquid then drops back to evaporator through capillary action.

1.1 OBJECTIVE

The project is aimed to conduct experiments on self manufactured heat pipes, determine their thermal conductivity and study the effects of various factors like inclination angle, presence of mesh (wick) and fill ratio of the evaporator section.

1.2 BACKGROUND

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by Gaugler in 1942. It was not, however, until its independent invention by Grover in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place.

The heat pipe is similar in some respects to the thermosyphon and it is helpful to describe the operation of the latter before discussing the heat pipe. The thermosyphon is shown in Fig. 1(a).A small quantity of water is placed in a tube from which the air is then evacuated and the tube is sealed. The lower end of the tube is heated causing the liquid to vaporize and the vapour to move to the cold end of the tube where it is condensed. The condensate is returned to the hot end by gravity. 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 thermosyphon has been used for many years and various working fluids have been employed. One limitation of the basic thermosyphon is that in order for the condensate to be returned to the evaporator region by gravitational force, the latter must be situated at the lowest point.

The basic heat pipe differs from the thermosyphon in that a wick, constructed for example from a few layers of fine gauze, is fixed to the inside surface and capillary forces return the condensate to the evaporator (see Fig. 1(b)). In the heat pipe the evaporator position is not restricted and it may be used in any orientation. If, of course, the heat pipe evaporator happens to be in the lowest position, gravitational forces will assist the capillary forces. The term 'heat pipe' is also used to describe high thermal conductance devices in which the condensate return is achieved by other means, for example centripetal force, osmosis or electro hydrodynamics.

The main regions of the standard heat pipe are shown in Fig. 2. In the longitudinal direction Fig. 2, the heat pipe is made up of an evaporator section and a condenser section. Should external geometrical requirements make this necessary; a further, adiabatic, section can be included to separate the evaporator and the condenser. The cross section of the heat pipe, Fig.2, consists of the container wall, the wick structure and the vapour space. The performance of a heat pipe is often expressed in terms of 'equivalent thermal conductivity'.

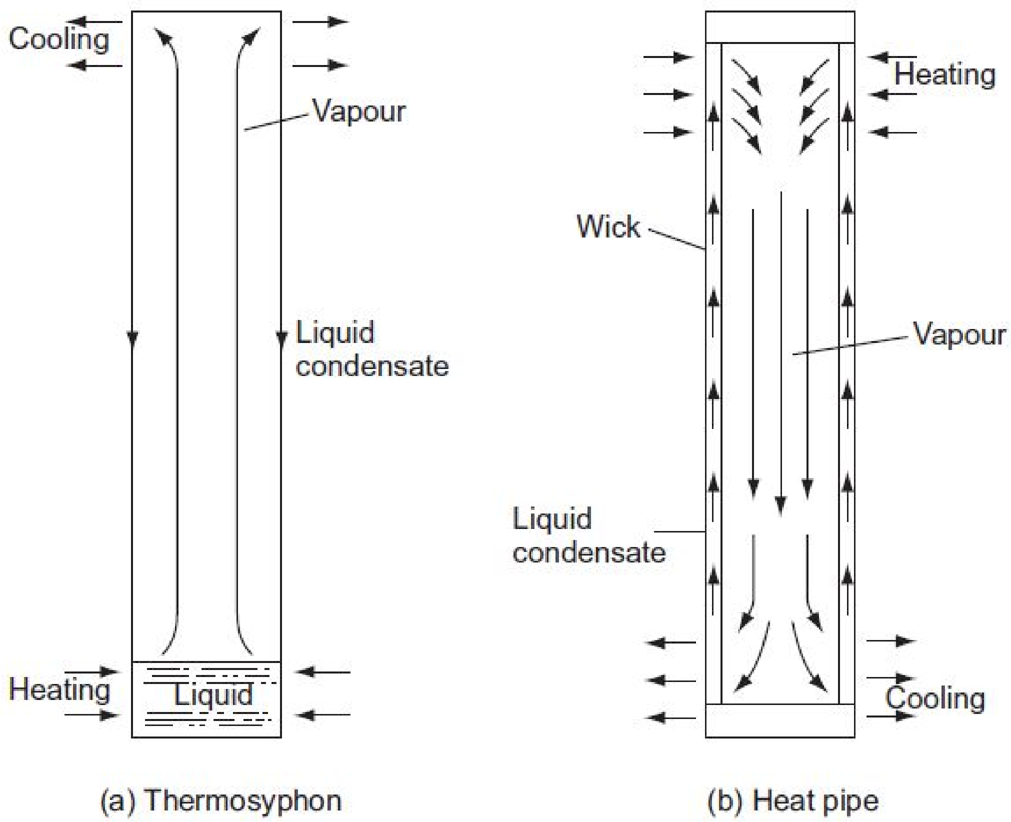

Figure 1: The heat pipe and thermosyphon

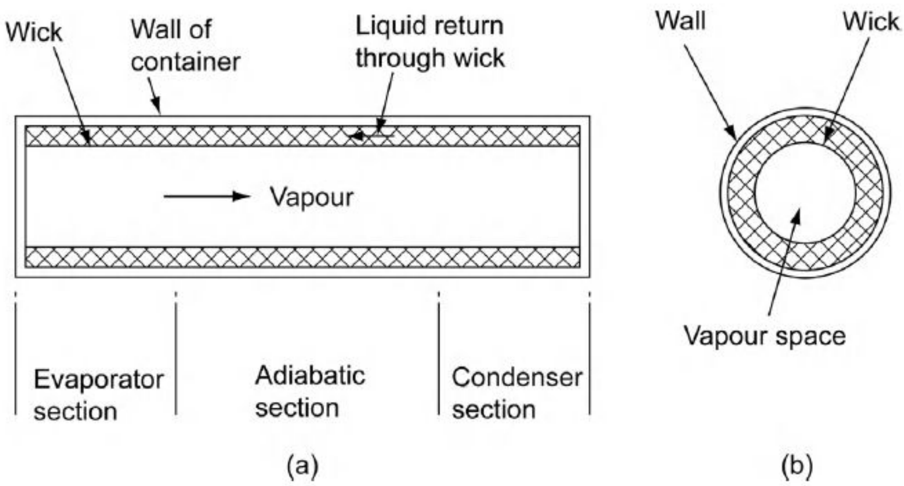

Figure 2: The main region of the heat pipe

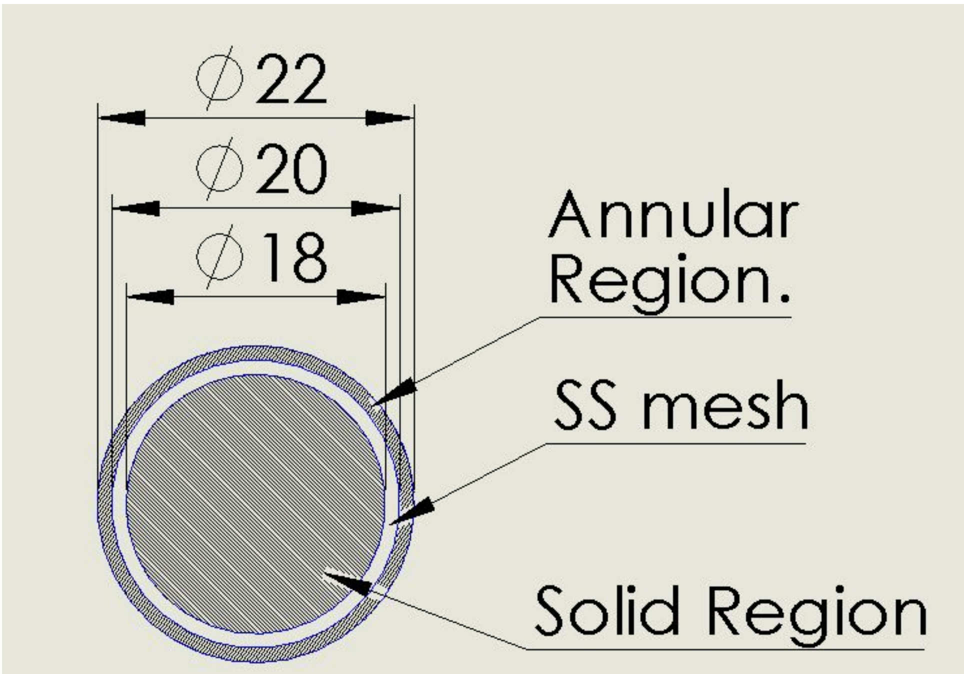

Figure 3: Dimensions and region of the heat pipe used in the experiment

CHAPTER 2

PROJECT DESCRIPTION AND GOALS

The project is aimed at proposing a design incorporating heat pipes for a heat transfer application. The application will be decided on the basis of efficiency of heat pipe observed over normal copper tubes. The project will be done in three stages:

Stage 1: Manufacturing a heat pipe which includes the following

i. Selection of heat pipe material
ii. Selection of working fluid
iii. Designing and fabrication of experimental setup
iv. Fabrication of heat pipe

Stage 2: Experimentation

i. Testing of thermal conductivity of heat pipes
ii. Comparison of thermal conductivity of heat pipe over normal copper pipe
iii. Comparison of thermal conductivity with different fill ratios of evaporator section
iv. Comparison of thermal conductivity at different tilt angles
v. Comparison of heat pipe with and without wick

Stage 3: Proposing an application based on the efficiency of heat pipe observed

CHAPTER 3

TECHNICAL SPECIFICATION, DESIGN STANDARDS AND CONSTRAINTS

3.1 TECHNICAL SPECIFICATION

3.1.1 Heat Pipe

Outer Diameter	22 mm
Inner Diameter	20 mm
Material	Copper
Working Fluid	Distilled water
Mesh Material	Stainless Steel
Mesh Size	400 sq per inch
Length	300 mm
Evaporator Section Length	100 mm
Adiabatic Section Length	100 mm
Condenser Section Length	100 mm

3.1.2 Thermocouple

Type	K

3.1.3 Temperature Indicator

No. of channels	6 (with digital display)

3.1.4 Water Pump

Type	Submersible
Flow Rate	300 ml/s

3.2 COMPLIANCE TO DESIGN STANDARDS

1. The techniques described in the standard **ASTM B828** are used to produce leak-tight soldered joints between copper and copper alloy tube and fittings, either in shop operations or in the field.
2. Copper tube standards: **ASTM B88** – for HVAC applications, size 22 mm diameter and thickness 1 mm.
3. **B3140**: 22mm copper pipe clamping standard.

3 3 REALISTIC CONSTRAINTS

1. Achieving nearly perfect vacuum isn't possible without sophisticated precision instruments.
2. Perfect insulation is difficult to achieve. Hence, 100% heat transfer from heating element to evaporator region is not possible.
3. The fluid dynamics inside the heat pipe cannot be accurately monitored and is hence difficult to diagnose any problems that may have occurred inside the heat pipe.

CHAPTER 4

METHODOLOGY

4.1 SELECTION OF THE MATERIAL OF THE HEAT PIPE*:*

The main materials that are used for fabricating a heat pipe are Copper, Stainless Steel and Aluminium. Based on the applications, the appropriate material is selected. For this project, copper pipes were chosen as the material. It was selected as it is widely used material for HVAC applications.

4.2 SELECTION OF THE WORKING FLUID:

The selection of the working fluid depends upon the following factors:

i. Compatibility with wick and wall materials
ii. Good thermal stability
iii. Wetting ability of wick and wall materials
iv. Vapour pressures not too high or low over the operating temperature range
v. High latent heat
vi. High thermal conductivity
vii. Low liquid and vapour viscosities
viii. High surface tension
ix. Acceptable freezing or pour point.

Based on the factors mentioned above, the working fluids shortlisted were; Acetone, Water, Freon and Methanol. Among these, the usage of Freon is prohibited due to environmental issues. Acetone and Methanol were eliminated due to their high volatility and hence proved to be a constraint in the manufacturing of the heat pipe. Water being easily available and being non flammable fluid was chosen as the working fluid.

4.3 SELECTION OF WICK:

Low-performance wicks in horizontal and gravity-assisted heat pipes should permit maximum liquid flow rate by having a comparatively large pore size, as with 100 or 150 mesh. Where pumping capability is required against gravity, small pores are needed. For HVAC application and by literature survey it was decided that 400 mesh size Stainless Steel mesh would be used as the wick for the heat pipe. [1]

4.4 **DIMENSIONS OF THE HEAT PIPE:**

According to literature survey [2], it was found that increasing the diameter of the heat pipe increases the heat transfer rate. Based on this, it was decided that 22mm diameter copper pipe would be used. For experimental purposes, the length of the pipe was fixed at 300mm with 100mm of evaporator and condenser sections each. Although adiabatic section does not affect heat transfer in the pipe, it was decided to keep 100mm of adiabatic section in the pipe for reducing the complexity of the pipe.

4.5 **MANUFACTURING OF THE HEAT PIPE:**

i. Cleaning of wick, container and end caps.
ii. Removal of minute metal components from the container.
iii. Inserting and fitting of the wick in the container.
iv. Sealing one end of the pipe.
v. Check for leakage.
vi. Purification of working fluid (distillation of water).
vii. Filling of working fluid in the evaporator region according to the fill ratio.
viii. Evacuating the heat pipe.
ix. Sealing of the heat pipe.
x. Check for leakage.

4.6 **FABRICATION OF THE EXPERIMENTAL SETUP:**

i. Manufacture of inclined plane for various tilt angles and mounting of heat pipe.
ii. Coiling of the evaporator section with a heating element (Nichrome wire).
iii. Thermal insulation of the heating element for directing heat flux radially towards the axis using asbestos rope (6mm thickness).
iv. Fabrication of a cylindrical structure around the condenser region for facilitating continuous flow of cold water to maintain a temperature difference between the evaporator and condenser region.
v. Continuous inflow and outflow of water in the cylindrical structure is facilitated by a submersible pump.
vi. Thermocouples are mounted at four different locations across the length of the pipe for noting the temperature change along the length.
vii. Connection of thermocouples to temperature indicator for noting the temperatures.

CHAPTER 5

EXPERIMENT DESCRIPTION

5.1 EXPERIMENTAL PROCEDURE

i. Attach thermocouples to the heat pipe at evaporator, adiabatic and condenser region at distances 0cm, 15cm and 23cm respectively.
ii. Connect thermocouples to the temperature display monitor.
iii. Switch on the water supply.
iv. Switch on the electricity supply to the heater.
v. Measure temperature through temperature display monitor at all three points till steady state is achieved.

5.2 THEORY

The apparatus consists of a heat pipe mounted on a plank with variable inclination angles. One end of the pipe is heated by an electric heater while the other end projects inside a cooling water jacket. Three temperature sensors are provided to measure temperature of heat pipe at different section- one at evaporator, adiabatic and condenser region each. The heater coil has a power rating of 45 W per m. According to power requirement this coil is wrapped around evaporator section. Water under constant head conditions is circulated through the jacket.

The heater will heat the rod at evaporator end and heat will be conducted through the rod to the condenser region. Since the evaporator section is insulated from outside using asbestos rope, it can be safely assumed that the heat transfer along the copper rod is mainly due to axial conduction.

Heat conducted axially through the pipe is given as:

$$Q = -kA \frac{dT}{dX}$$

Where,

Q = Power input to evaporator section (W)

k = Thermal conductivity of pipe (W/mK)

A = Area normal to conduction direction (m2)

$\frac{dT}{dX}$ = Slope of temperature Vs distance curve (K/m)

5.3 PARAMETERS MONITORED

i. Evaporator temperature
ii. Condenser temperature

iii. Adiabatic Temperature
iv. Flow rate of water pump

5.4 PARAMETERS CALCULATED

i. Thermal Conductivity of heat pipe

5.5 EXPERIMENTATION

The following experiments were conducted:

Type	% Liquid in the evaporator region	Angle of inclination(°)
With Mesh	100%	60
		45
		30
	85%	60
		45
		30
	55%	60
		45
		30

Table 1: List of experiments on heat pipe with mesh.

Type	% Liquid in the evaporator region	Angle of inclination(°)
Without Mesh	100%	60
		45
		30
	85%	60
		45
		30
	55%	60
		45
		30

Table 2: List of experiments on heat pipe without mesh

5.6 EXPERIMENTAL SETUP

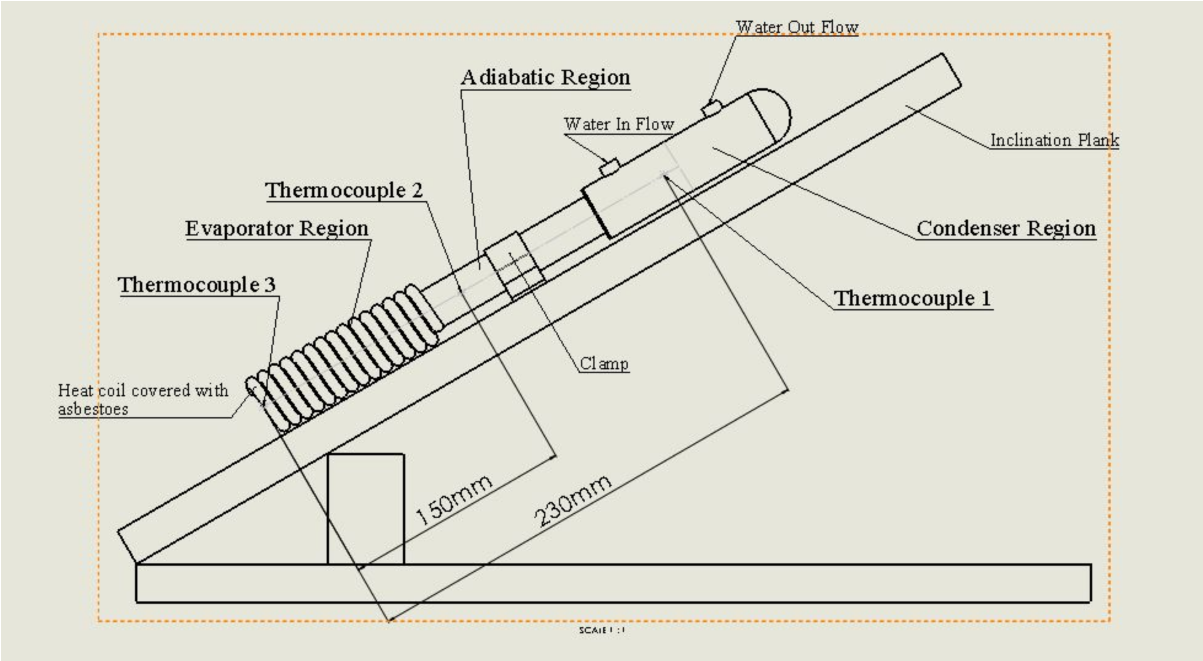

Figure 4: Schematic diagram of experimental setup

Figure 5: Experimental Setup

Figure 6: Heat pipe assembly at 60°

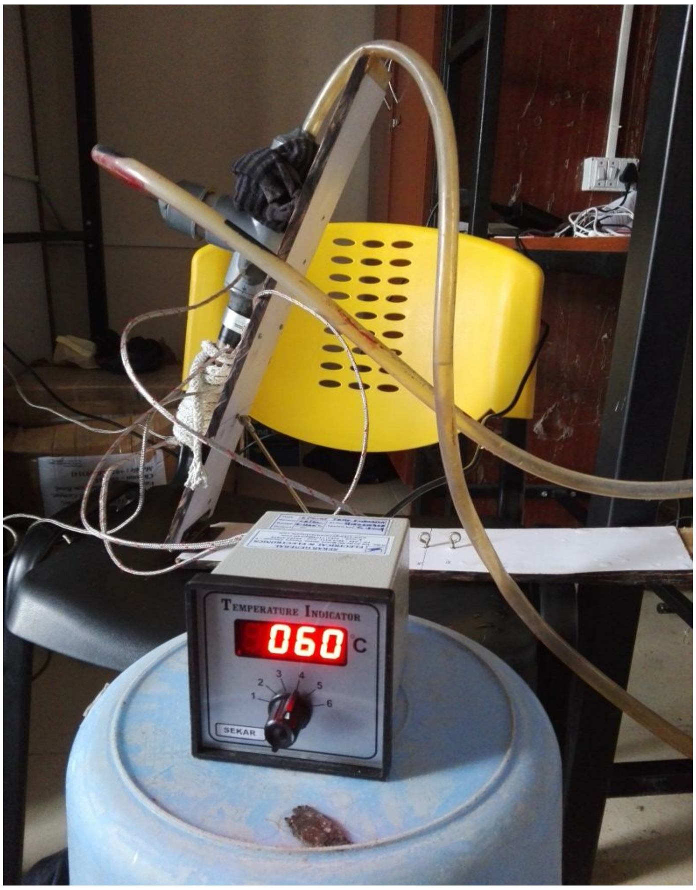

Figure 7: Heat pipe assembly with temperature indicator

CHAPTER 6

TASKS AND SCHEDULE

6.1 MAJOR TARGETS OF THE PROJECT

1) Literature survey

Expected completion date: 25^{th} January 2016

Actual completion date: 25^{th} January 2016

Work Division:

Sumeet Lulekar- Heat pipe types and components

Amrita Shukla- Heat pipe experimental setup design

Tasmai Dave- Experiments to be conducted

2) Test Rig setup

Expected completion date: 4^{th} March 2016

Actual completion date: 8th March 2016

Creating a successful vacuum was a challenge and hence the delay.

Work Division:

Sumeet Lulekar- Heat pipe fabrication

Amrita Shukla- Insulation and temperature measurement setup

Tasmai Dave- Experimental setup structure

3) Experiments

Expected completion date: 27th March 2016

Actual completion date: 27th March 2016

Work Division:

Sumeet Lulekar- Heat pipe with 100% fill ratio with and without mesh at different angles

Amrita Shukla- Heat pipe with 85% fill ratio with and without mesh at different angles

Tasmai Dave- Heat pipe with 55% fill ratio with and without mesh at different angles

4) Calculations, Results and Conclusions

Expected completion date: 12th April 2016

Actual completion date: 13th April 2016

CHAPTER 7

OBSERVATIONS

7.1 SAMPLE CALCULATIONS

For calculating the area, two cross sections were considered- A solid copper pipe with outer diameter equal to the inner diameter of heat pipe and other a annular copper pipe with dimensions same as that of heat pipe.

Solid Area (m^2) (As)= $\frac{\pi 0.02^2}{4}$ (without mesh) =0.000314 m^2

= $\frac{\pi 0.018^2}{4}$ (with mesh)= 0.000254 m^2

Annular Area (m^2) (Aa) = $\frac{\pi 0.022^2}{4}$ - $\frac{\pi 0.02^2}{4}$ = 6.59734E-05 m^2

Heat input (W)(Q) = No. of turns * circumference of the heat pipe * power rating per unit length

= 7*π*0.022*45

= 21.77 W

For 100% fill ratio with meshed heat pipe at 60° inclination angle, the steady state temperatures are:

T1 (°C) at condenser region = 28

T2 (°C) at adiabatic region = 57

T3 (°C) at evaporator region = 62

The graph of Temperature Vs Distance is shown below:

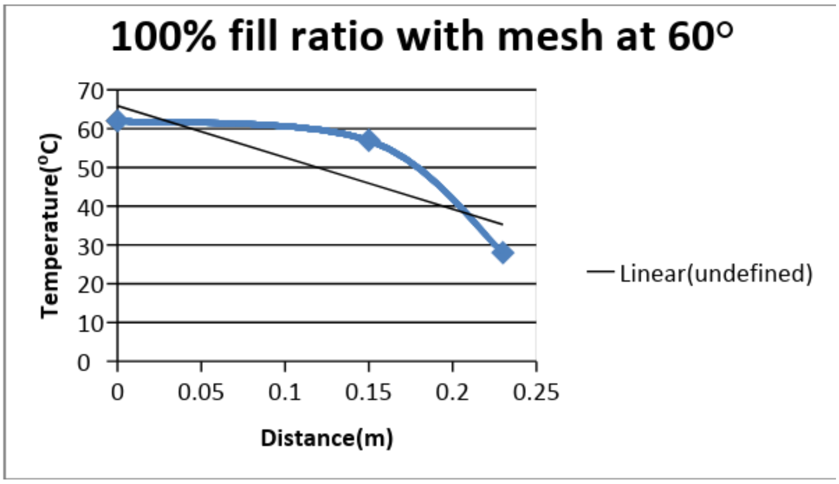

Figure 8: Temperature vs Distance for 100% fill ratio with mesh at 60°

From the graph,

$$\frac{dT}{dX} = -133.13 \text{ K/m}$$

Conductivity through solid cross sectional area (k_s) (W/mK)= $-\frac{Q}{As\ \frac{dT}{dX}}$

$$= -\frac{21.77}{0.000254*(-133.13)}$$

$$= 642.6467 \text{ (W/mK)}$$

Conductivity through annular cross sectional area (k_a) (W/mK)= $-\frac{Q}{As\ \frac{dT}{dX}}$

$$= -\frac{21.77}{6.59734E{-}05*(-133.13)}$$

$$= 2478.78 \text{ (W/mK)}$$

Normal Conductivity of copper (k) = 385 (W/mK)

7.2 TEMPERATURE VS DISTANCE GRAPHS FOR DIFFERENT EXPERIMENTS

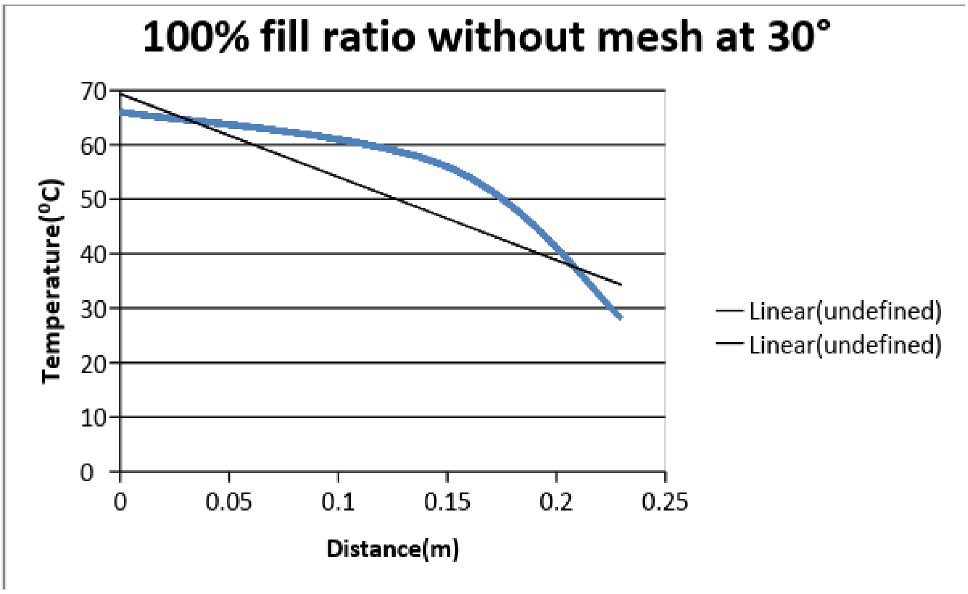

Figure 9:Temperature vs Distance for 100% fill ratio without mesh at 30°

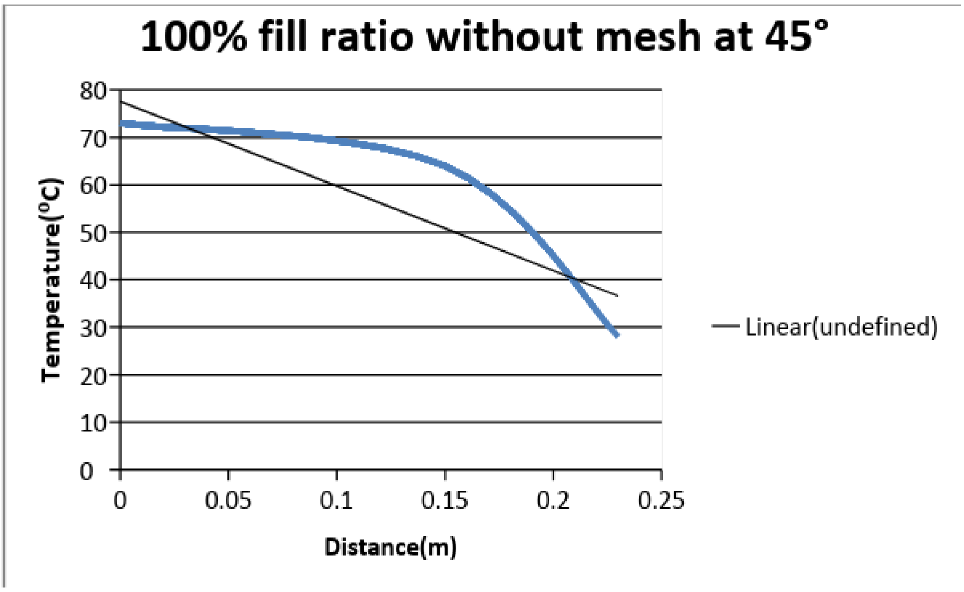

Figure 10: Temperature vs Distance for 100% fill ratio without mesh at 45°

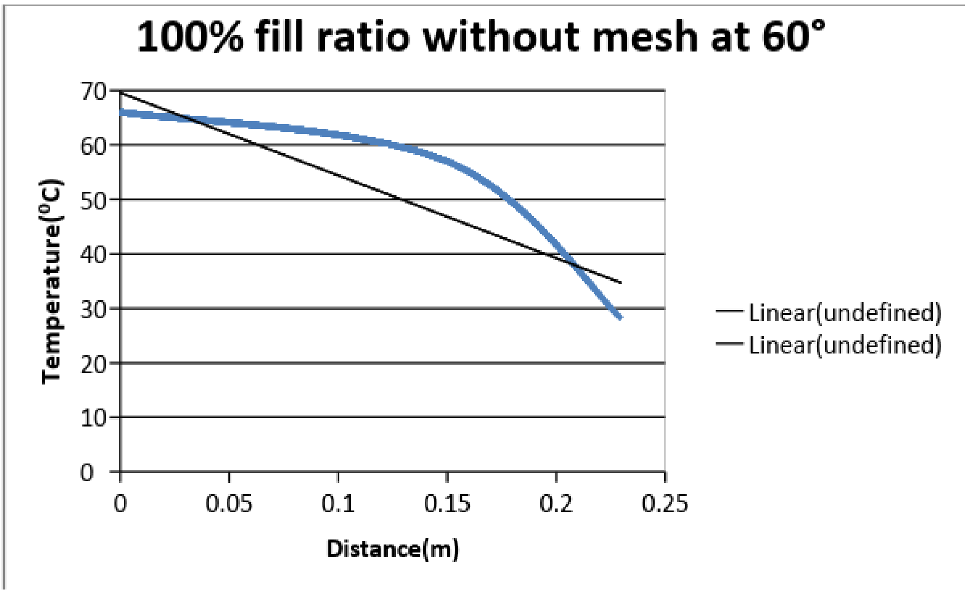

Figure 11:Temperature vs Distance for 100% fill ratio without mesh at 60°

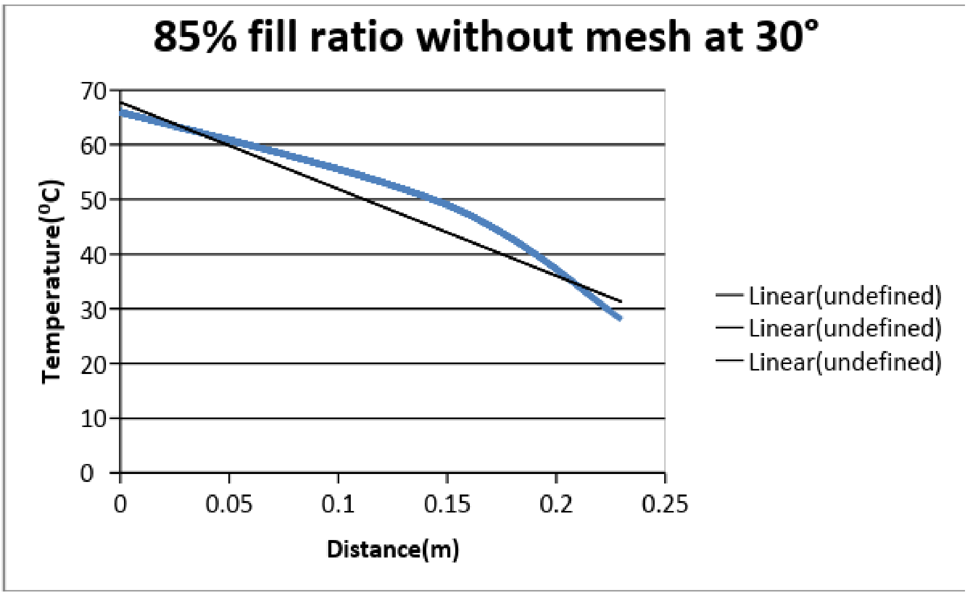

Figure 12: Temperature vs Distance for 85% fill ratio without mesh at 30°

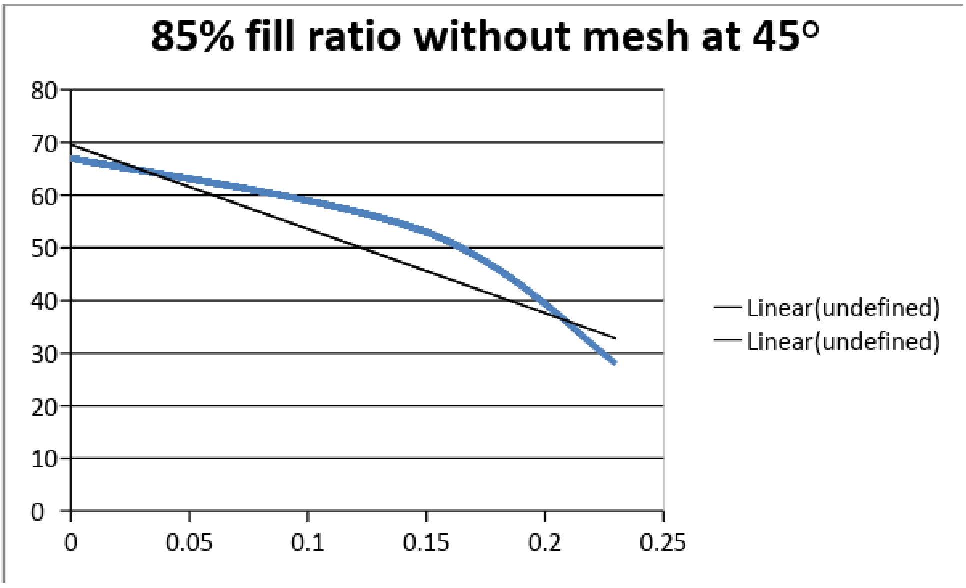

Figure 13:Temperature vs Distance for 85% fill ratio without mesh at 45°

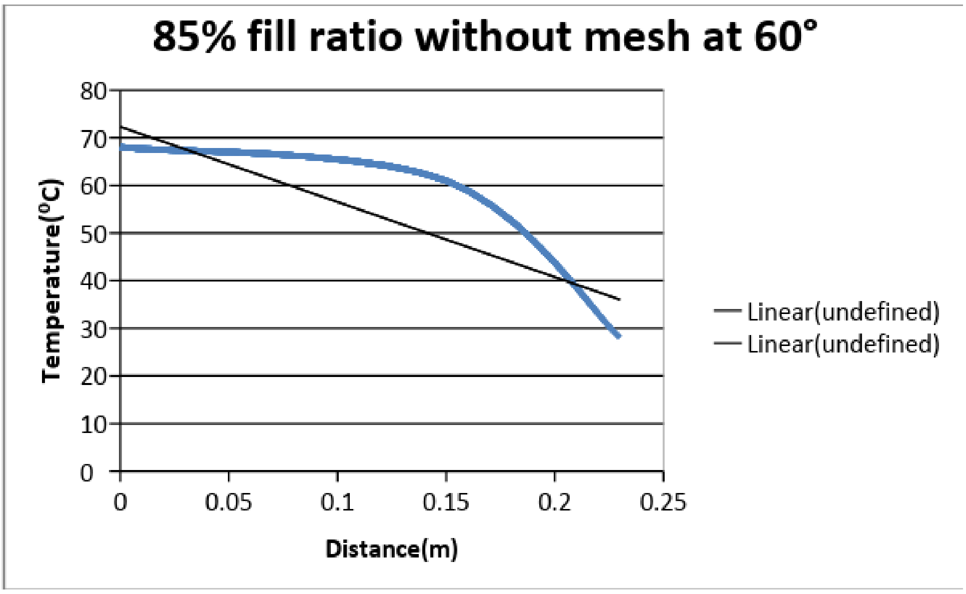

Figure 14:Temperature vs Distance for 85% fill ratio without mesh at 60°

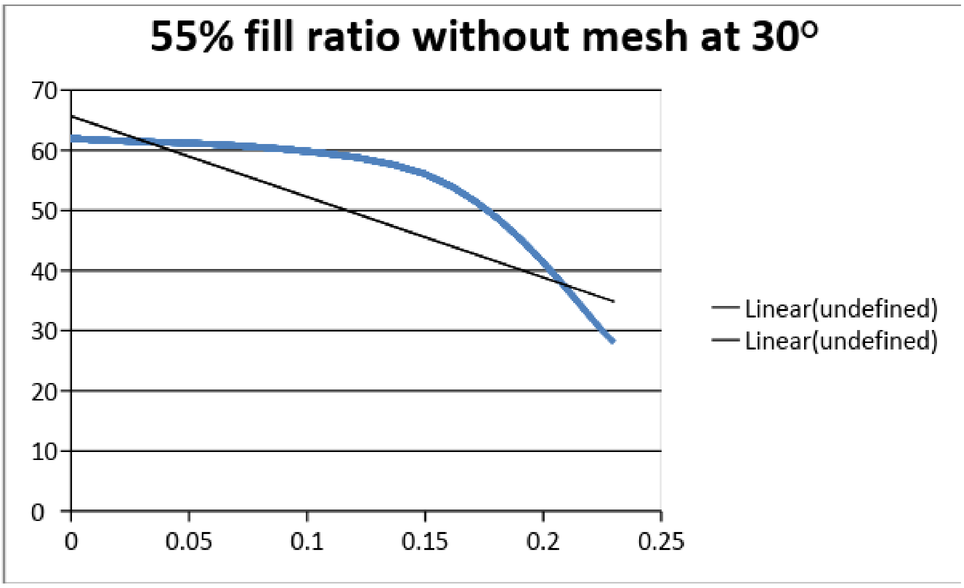

Figure 15:Temperature vs Distance for 55% fill ratio without mesh at 30°

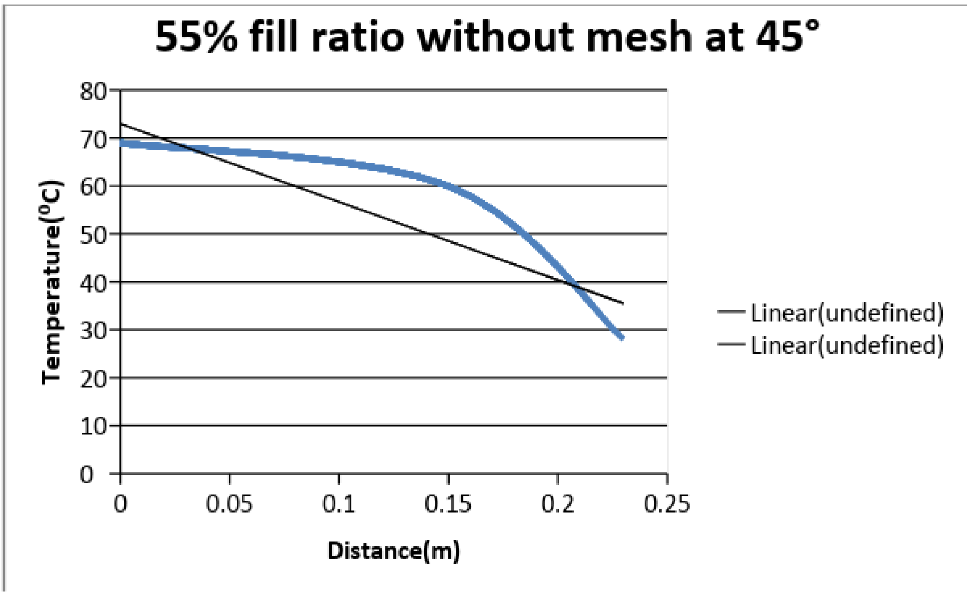

Figure 16:Temperature vs Distance for 55% fill ratio without mesh at 45°

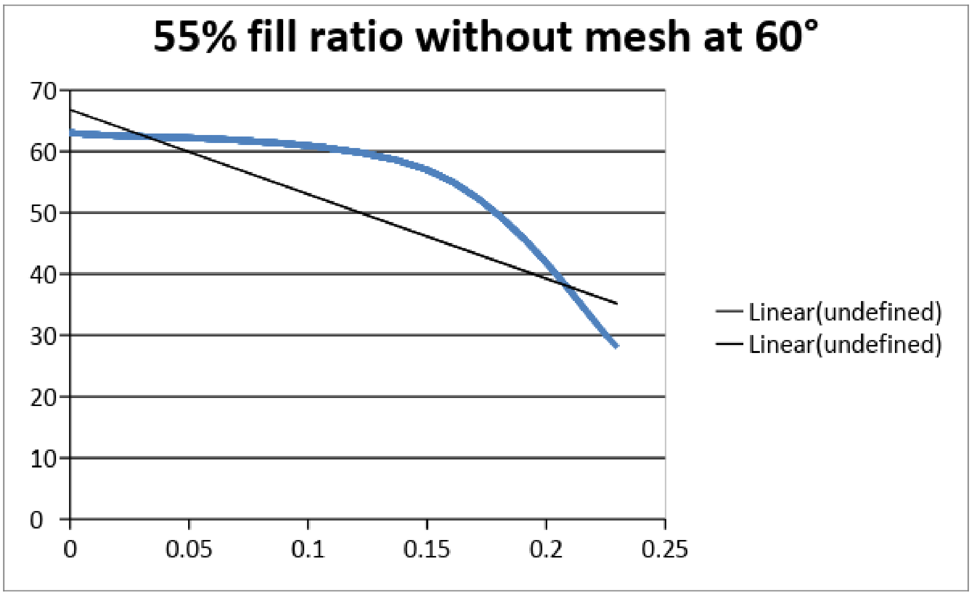

Figure 17: Temperature vs Distance for 55% fill ratio without mesh at 60°

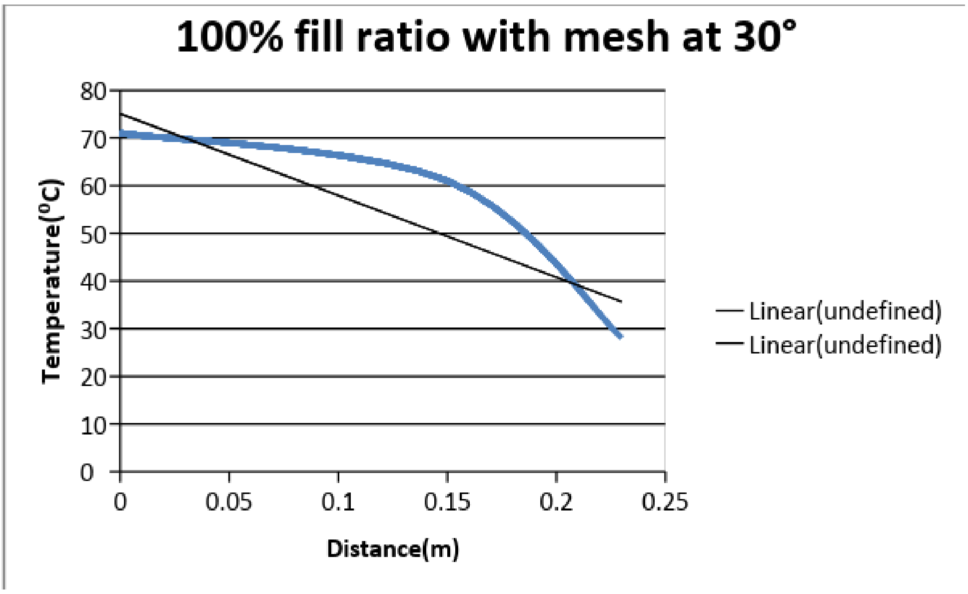

Figure 18:Temperature vs Distance for 55% fill ratio with mesh at 30°

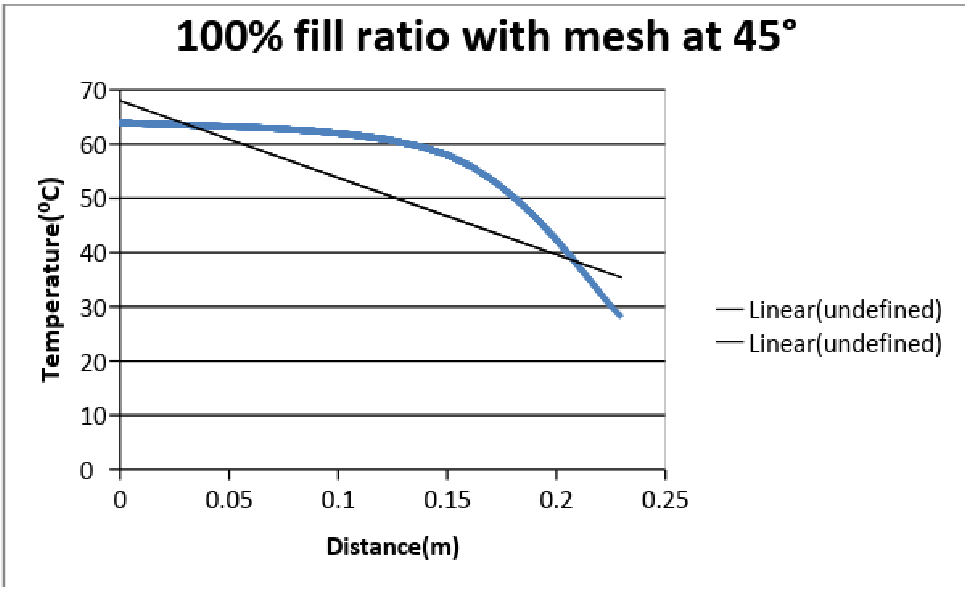

Figure 19: Temperature vs Distance for 100% fill ratio with mesh at 45°

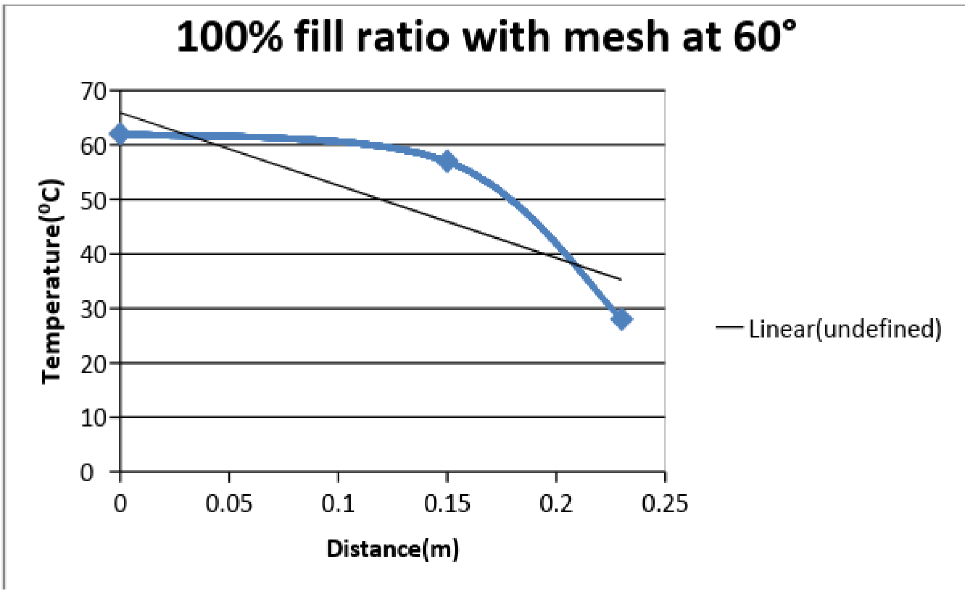

Figure 20: Temperature vs Distance for 100% fill ratio with mesh at 60°

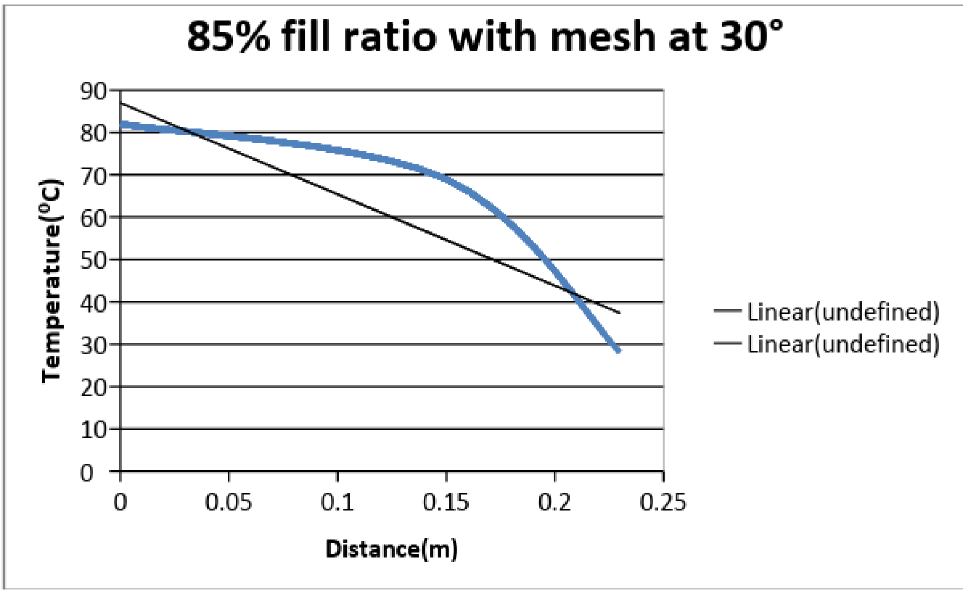

Figure 21: Temperature vs Distance for 85% fill ratio with mesh at 30°

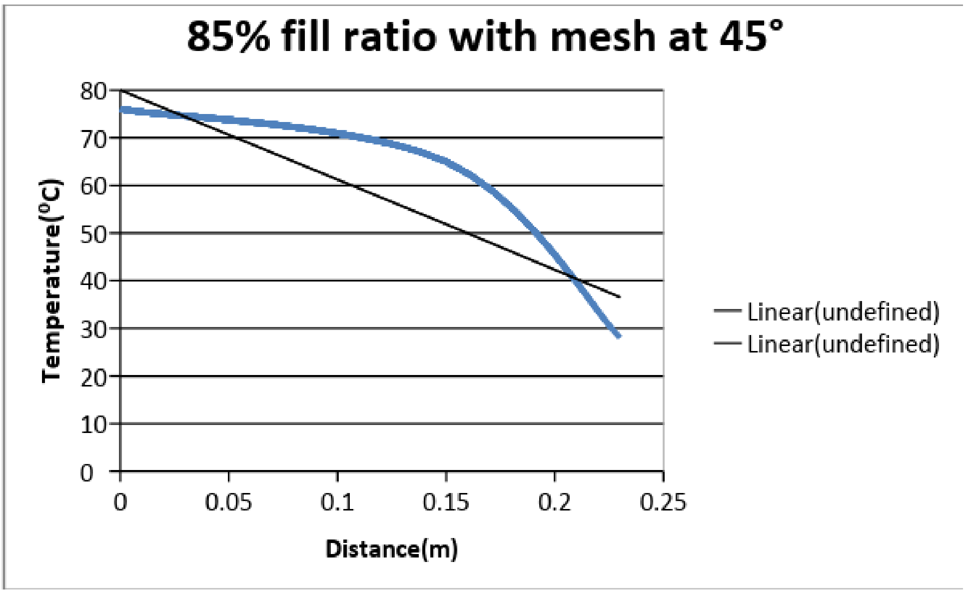

Figure 22: Temperature vs Distance for 85% fill ratio with mesh at 45°

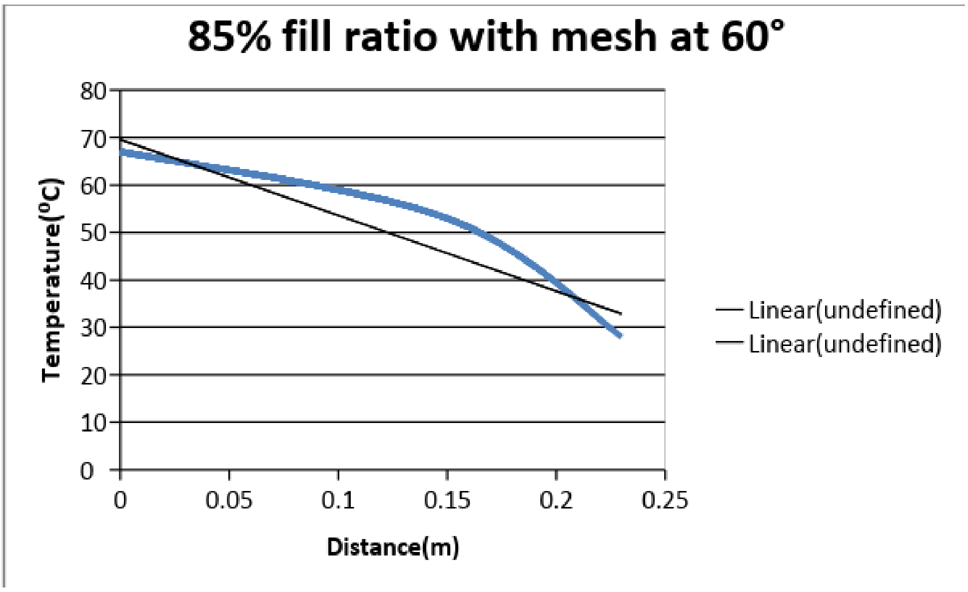

Figure 23: Temperature vs Distance for 85% fill ratio with mesh at 60°

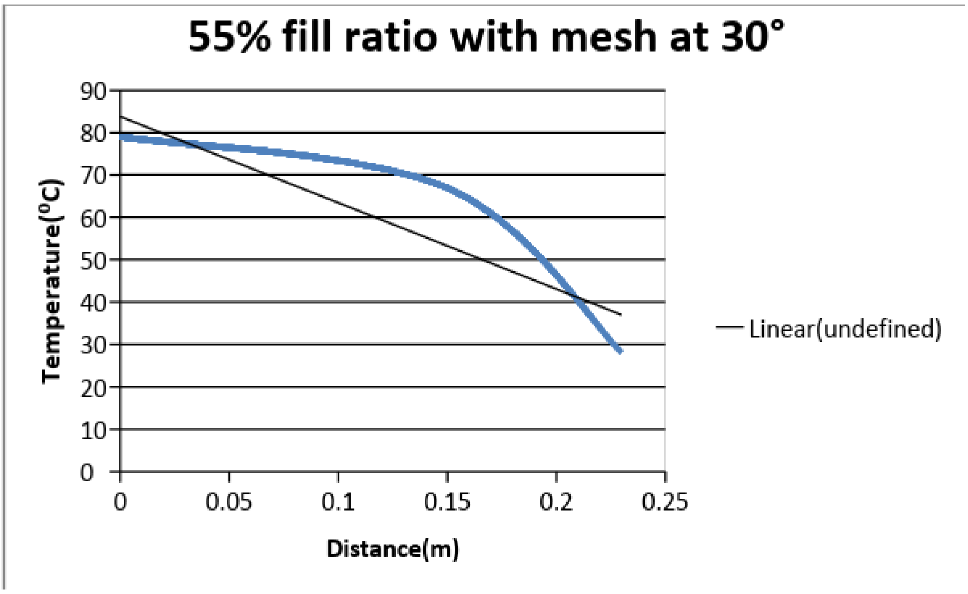

Figure 24: Temperature vs Distance for 55% fill ratio with mesh at 30°

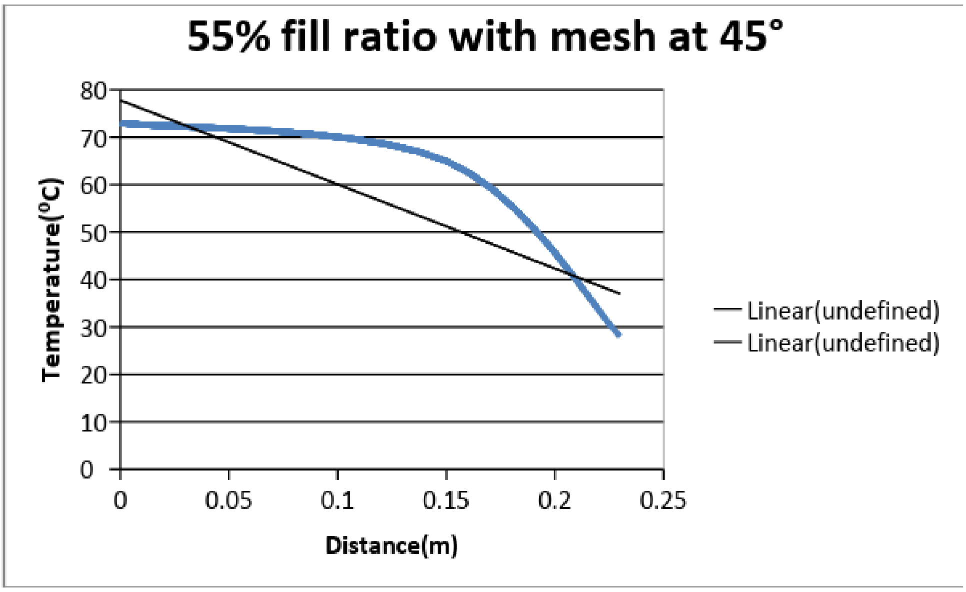

Figure 25: Temperature vs Distance for 55% fill ratio with mesh at 45°

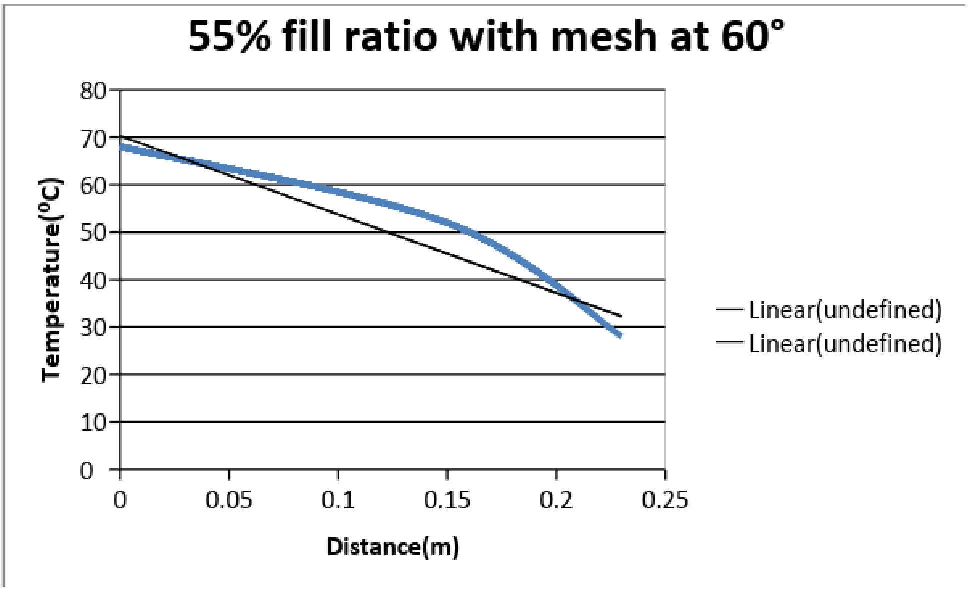

Figure 26: Temperature vs Distance for 55% fill ratio with mesh at 60°

7.3 OBSERVATION TABLES

With Mesh		Angle of Inclination(^{0})		
		30	45	60
% liquid in evaporator region	100	1923.974	2331.167	2478.78
	85	1529.406	1724.858875	2065.34
	55	1621.223	1860.412673	1996.612
Annular				

Table 3: Annular thermal conductivity of heat pipe with mesh

With Mesh		Angle of Inclination(^{0})		
		30	45	60
% liquid in evaporator region	100	498.808	604.377	642.6467
	85	396.5127	447.1856	535.4585
	55	420.3171	482.3292	517.6401
Solid				

Table 4: Solid thermal conductivity of heat pipe with mesh

Without Mesh		Angle of Inclination(^{0})		
		30	45	60
% liquid in evaporator region	100	2162.94	1851.747938	2175.203
	85	2081.362	1932.310	2094.174
	55	2462.870	2023.546726	2395.123
Annular				

Table 5: Annular thermal conductivity of heat pipe without mesh

Without Mesh		Angle of Inclination(^{0})		
		30	45	60
% liquid in evaporator region	100	454.218	388.8671	456.7926
	85	437.086	405.785	439.7766

55	517.203	424.944 8	502.9758
Solid			

Table 6: Solid thermal conductivity of heat pipe with mesh

CHAPTER 8

RESULT AND CONCLUSIONS

The factors responsible for variation in the performance of heat pipe include the following:

i. Normal Conduction Area (Solid Cross Section or Annular Cross section)
ii. Fill Ratio
iii. Angle of inclination
iv. Presence/Absence of Mesh

Comparisons were performed for all heat pipes on basis of all factors stated above.

8.1 COMPARISON OF CONDUCTIVITY BASED ON NORMAL CONDUCTION AREA

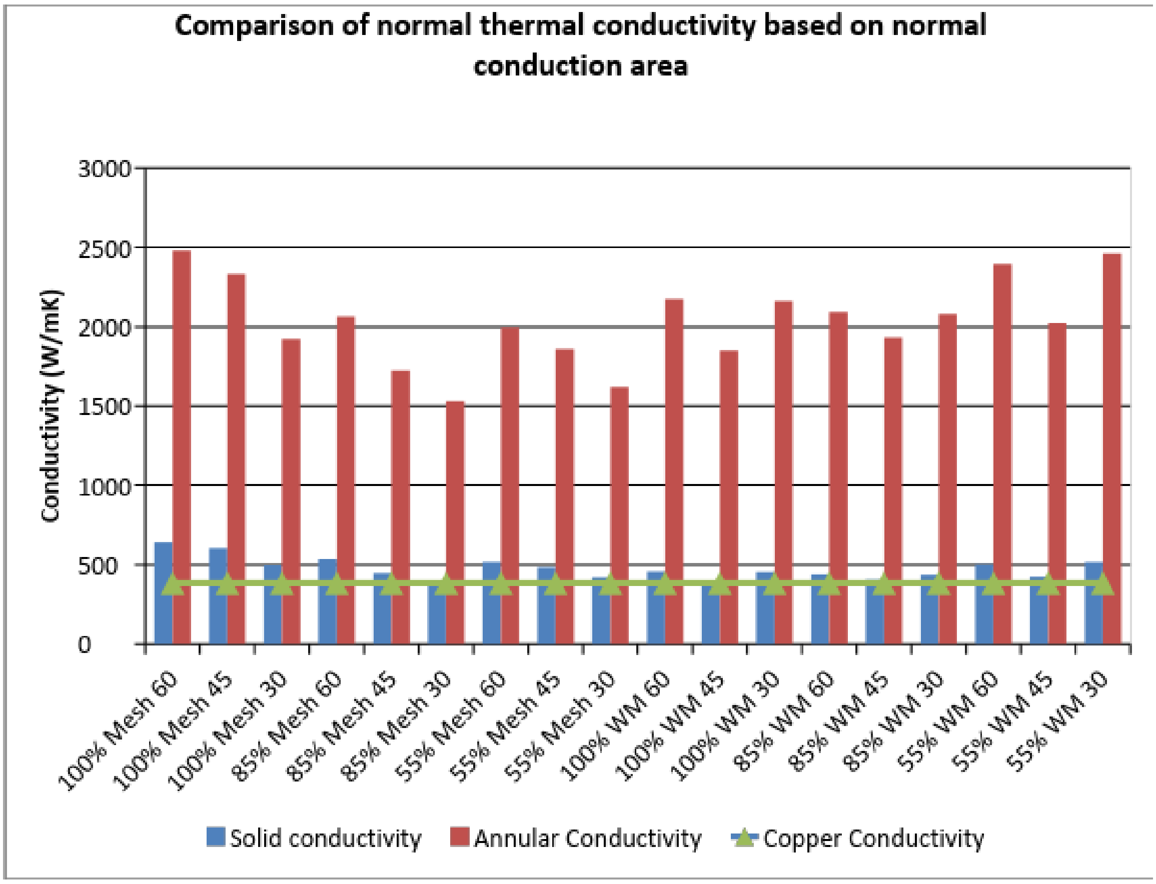

Figure 27: Comparison of normal thermal conductivity based on normal conduction area

On comparing the thermal conductivity of heat pipes with normal copper tubes, following increase ratio were observed:

Type	% Liquid in the evaporator region	Angle of inclination	Increase ratio
With Mesh(Annular)	100%	60	6.438389973
		45	**6.522164489**
		30	4.997334755
	85%	60	5.364519071
		45	4.480152923
		30	3.972483928
	55%	60	5.186004702
		45	4.83224071
		30	4.210969576

Table 7: Comparison between annular thermal conductivity of heat pipe with mesh and Copper pipe

Type	% Liquid in the evaporator region	Angle of inclination	Increase Ratio
Without Mesh(Annular)	100%	60	5.649877115
		45	4.809734903
		30	5.618030131
	85%	60	5.439413994
		45	5.018988507
		30	5.406135964
	55%	60	6.221097816
		45	5.255965521
		30	**6.397065879**

Table 8: Comparison between annular thermal conductivity of heat pipe without mesh and Copper pipe

Type	% Liquid in the evaporator region	Angle of inclination	Increase ratio
With Mesh(Solid)	100%	60	1.669212215
		45	**1.690931534**
		30	1.295605307
	85%	60	1.390801241
		45	1.161521128
		30	1.029903241
	55%	60	1.344519738
		45	1.252803147
		30	1.091732853

Table 9: Comparison between solid thermal conductivity of heat pipe with mesh and Copper pipe

Type	% Liquid in the evaporator region	Angle of inclination	Increase Ratio
Without Mesh(Solid)	100%	60	1.186474
		45	1.010044
		30	1.179786
	85%	60	1.142277
		45	1.053988
		30	1.135289
	55%	60	1.306431
		45	1.103753
		30	**1.343384**

Table 10: Comparison between solid thermal conductivity of heat pipe without mesh and Copper pipe

In all cases, increase ratio is greater than 1. Thus ***in all cases heat pipe shows better thermal conductivity than normal copper tubes.***

Also, it can be seen in the above graph, the highest thermal conductivity is achieved in case of a 100% Mesh 45^0 pipe. For 85% fill ratio with mesh, the highest conductivity is obtained at angle of 60^0. The same applies for fill ratio of 55%. For pipes without mesh, at 100% fill ratio, it was observed that thermal conductivity is highest at 60^0. At 85% fill ratio, it was again observed that the conductivity is highest at 60^0. In case of 55% fill ratio, the highest thermal conductivity was observed at 30^0.

8.2 COMPARISON OF CONDUCTIVITY BASED ON FILL RATIO

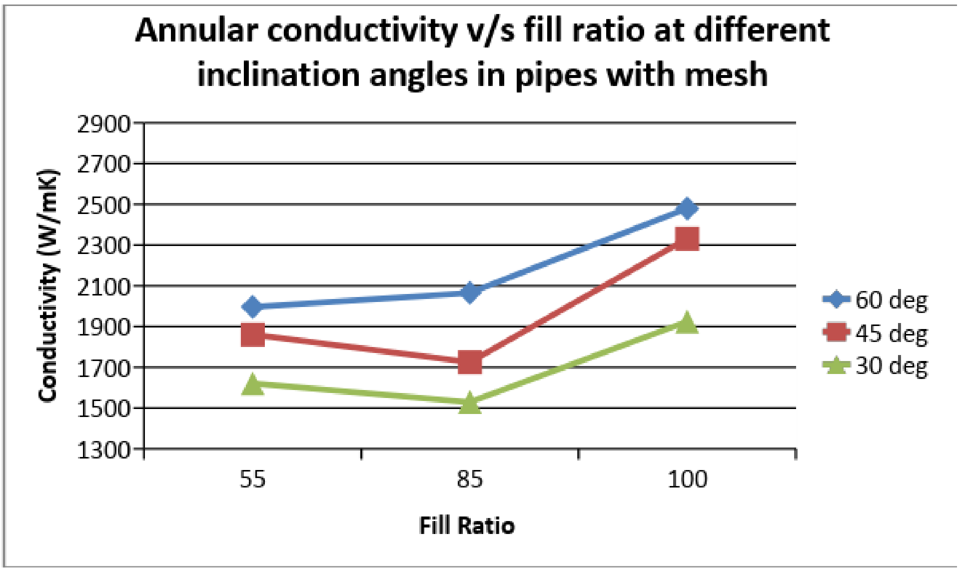

Figure 28: Annular conductivity v/s fill ratio at different inclination angles in pipes with mesh

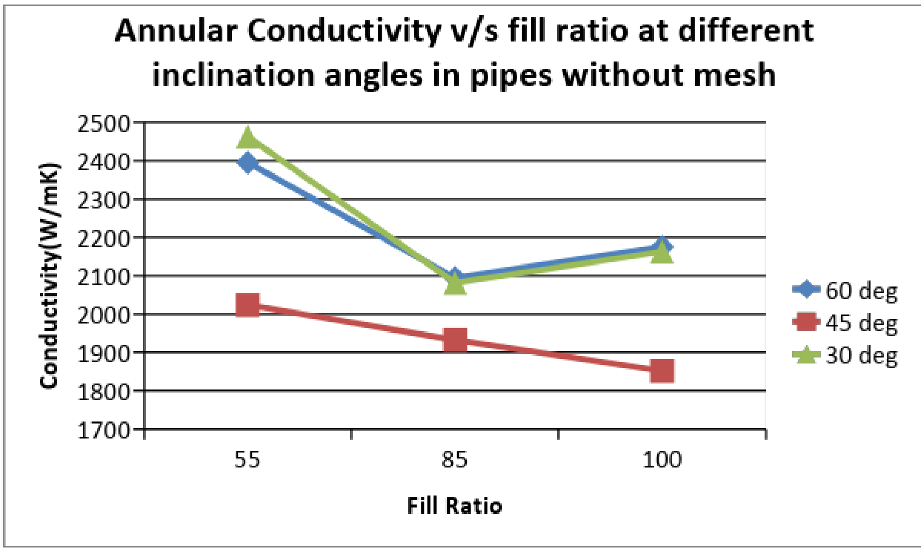

Figure 29: Annular conductivity v/s fill ratio at different inclination angles in pipes without mesh

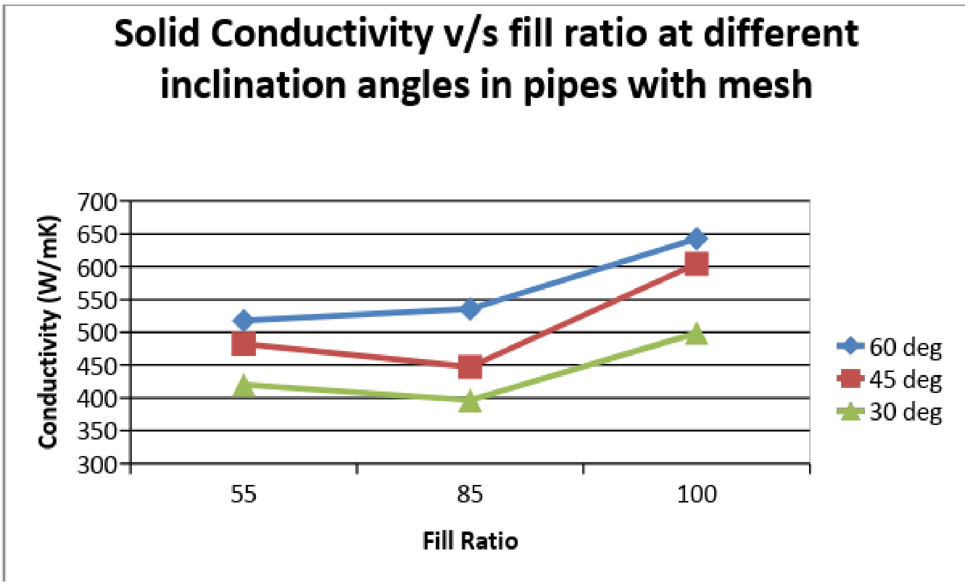

Figure 30: Solid conductivity v/s fill ratio at different inclination angles in pipes with mesh

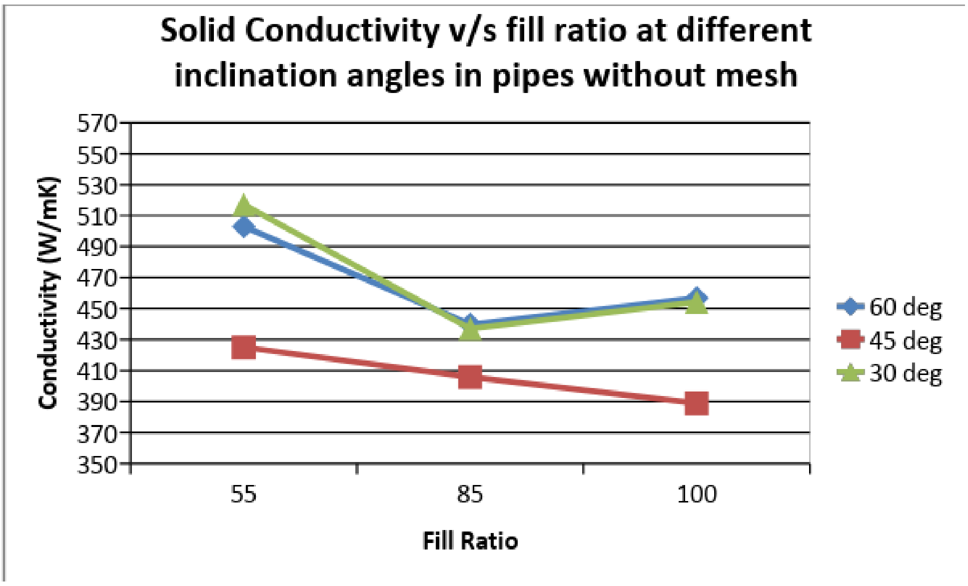

Figure 31: Solid conductivity v/s fill ratio at different inclination angles in pipes without mesh

The trends observed for the annular and the solid conductivity plotted against fill ratio for different inclination angles are nearly the same which enables us to analyze them in a similar manner. From the graph it is observed that with increase in the fill ratio, thermal conductivity for heat pipes with mesh increases. The increase in conductivity with fill ratio is due to the increase in working fluid with fill ratio. As the amount of liquid increases, more heat can be conducted. In heat pipes without mesh decrease in conductivity is observed with increase in fill ratio due to the entrapment of condensed liquid by the vapours. In pipes with a mesh this issue is solved by the presence of a mesh. On comparison of all the cases, it can be concluded that the highest conductivity is observed for 100% fill ratio at 45^0 for heat pipes with mesh. And for getting high conductivity without using mesh, we can replace the system with 100% fill ratio at 30^0 inclination angle.

8.3 COMPARISON OF CONDUCTIVITY BASED ON INCLINATION ANGLE

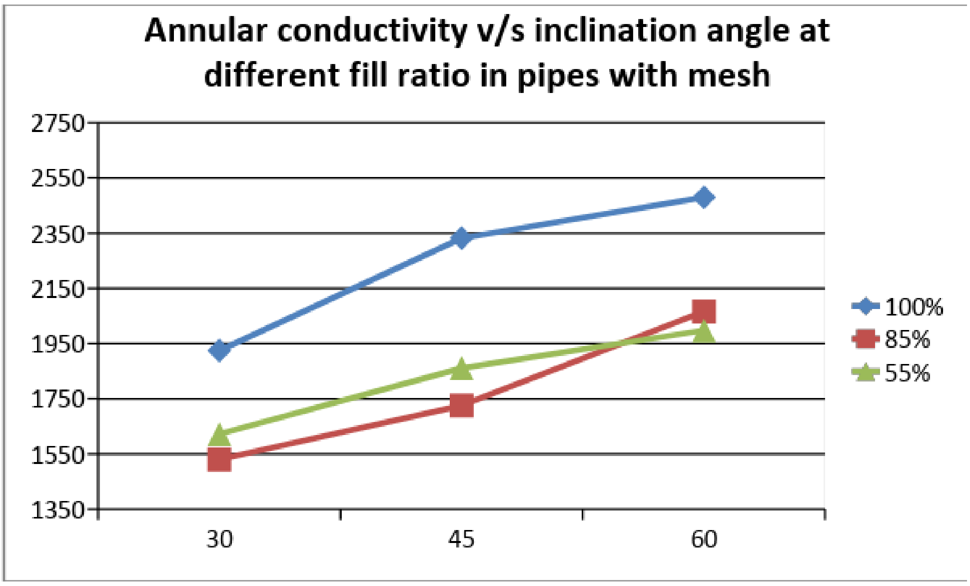

Figure 32: Annular conductivity v/s inclination angle at different fill ratio in pipes with mesh

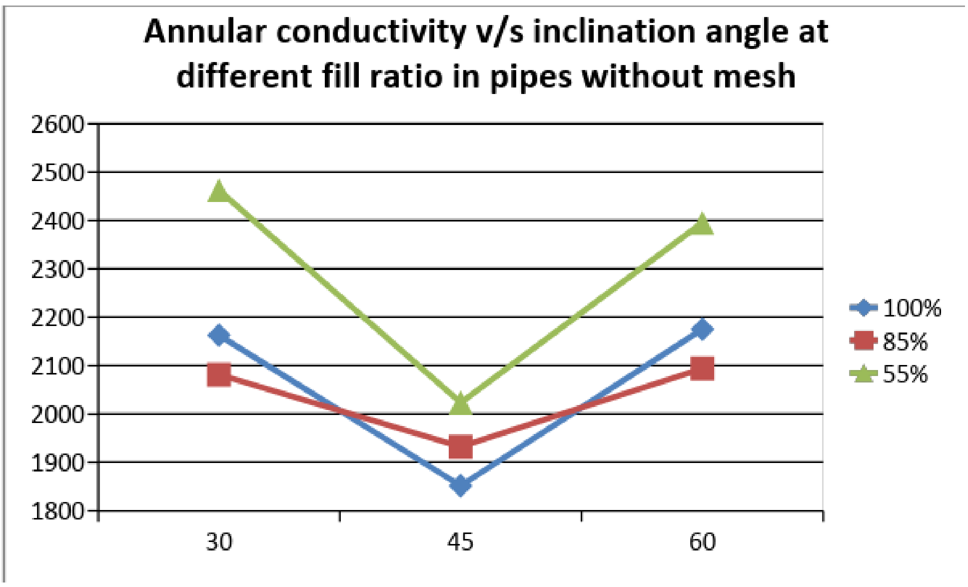

Figure 33: Annular conductivity v/s inclination angle at different fill ratio in pipes without mes

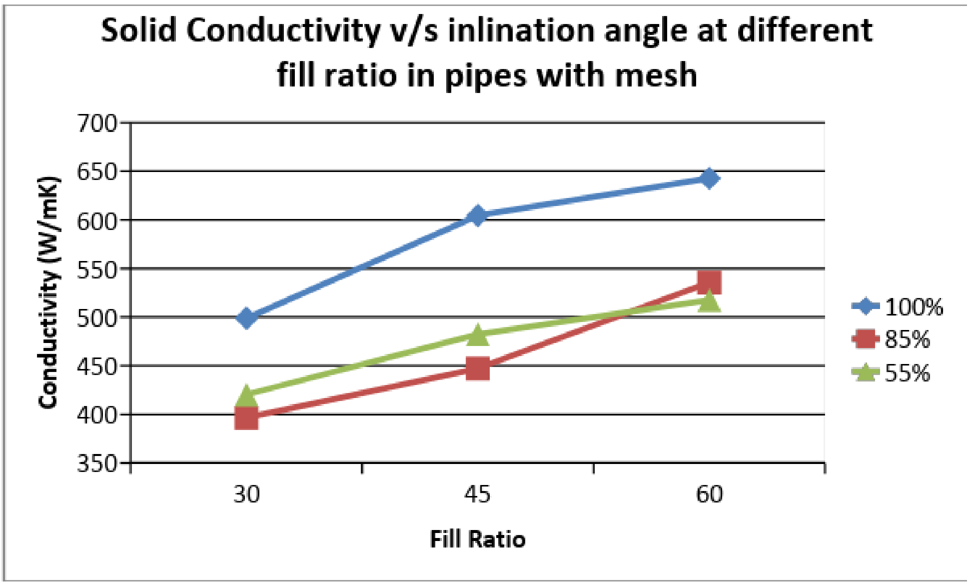

Figure 34: Solid conductivity v/s inclination angle at different fill ratio in pipes with mesh

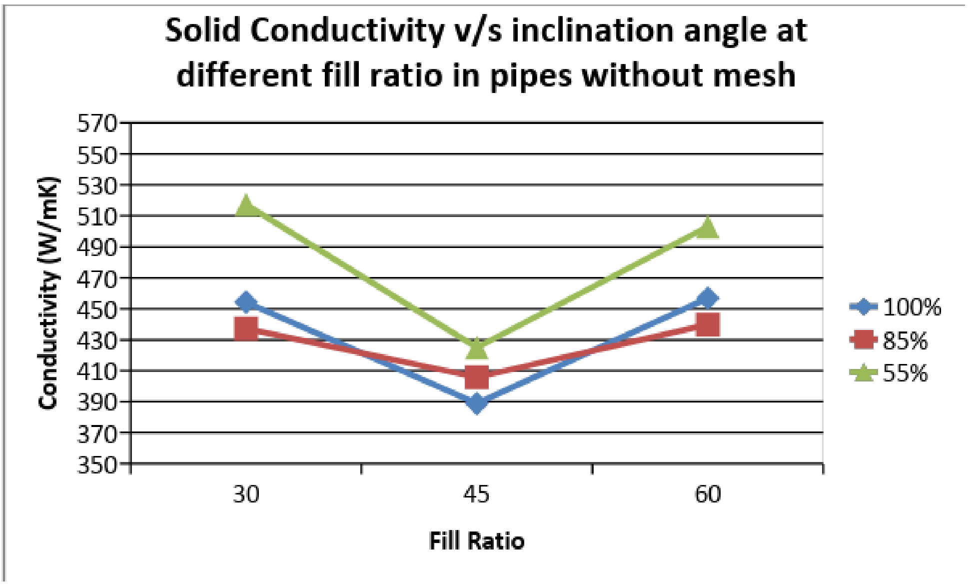

Figure 35: Solid conductivity v/s inclination angle at different fill ratio in pipes without mesh

When plotting thermal conductivity v/s. the angle of inclination at different fill ratios, it can be inferred that the thermal conductivity for heat pipes with mesh increases with the angle of inclination for different fill ratios. When the inclination angle increases, along with capillary action of mesh, the gravitational force also helps in bringing the condensate back to the evaporator section. More liquid will be present for next cycle of heat transfer, thus increasing the effective thermal conductivity. Similar trends are observed for both solid and annular conductivities. For heat pipes without mesh, a drop in conductivity is observed first and then the conductivity rises as the angle increases. When the angle of inclination is very small, the gravitational force is not effective enough to bring the liquid back to the evaporator section and since there is no mesh, capillary action is also not effective enough. Hence the decrease is observed initially. As the angle increases, gravitational pull draws sufficient amount of liquid back to evaporator section and hence there is an increase in trend for higher inclination angles. The maximum conductivity is observed for the 100% fill ratio heat pipe with mesh at 45^{0}.

CHAPTER 9

APPLICATION

9.1 **APPLICATION CATEGORIES**

In general, the applications of heat pipes come within a number of broad groups, each of which describes a property of the heat pipe. These groups are:
i. Separation of heat source and sink
ii. Temperature flattening or isothermalisation
iii. Heat flux transformation
iv. Temperature control

9.1.1 Separation of heat source and sink

In many applications where component cooling is required, it may be inconvenient or undesirable thermally to dissipate the heat via heat sink or radiator located immediately adjacent to the component. In such applications heat can be transferred through long distances at higher efficiency.

9.1.2 Temperature Flattening or isothermalisation

Heat pipe can be used to reduce temperature gradient within a body by placing heat pipes within the body.

9.1.3 Heat flux transformation

Heat pipes can also transform low heat flux to higher heat flux. Lower heat flux can be applied at evaporator region. This heat flux can be increased by decreasing the area of condenser.

9.1.4 Temperature control

It is used to control accurately the temperature of devices mounted on the heat pipe evaporator section.

9.2 **PROPOSED APPLICATION**

From the above stated four categories, we chose our application based on the second category.

"Heat pipes in a passive cooling system for relieving air-conditioning loads"

Phase Change Materials have very high latent heat. Using this property, they can be used along with room air conditioners to passively cool the room. The problem with PCMs is their low thermal conductivity. Thus the temperature gradient within the PCM is too high. Hence, only the surface layer of PCM melts and the succeeding layers remain unaffected in turn reducing the effective heat absorbed. For transferring the heat to the underlying layers, heat pipes are effective.

Proposed model consists of a container with PCM with heat pipes in the container. One half of the heat pipe is inside the container while the other half is exposed to air. The heat pipe will be kept in horizontal direction to allow it to work in cycle. During day, the part exposed to air will act as evaporator region. The heat will be transferred to PCM around the condenser region in the container and phase change will occur. At night, when the ambient temperature drops down, the part inside container will act as evaporator section and the one exposed to air will be condenser region. Heat will be transferred from the PCM and it will change its face again.

CHAPTER 10

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