EXPERIMENTAL SUTDY ON THERMAL PERFORMANCE OF VERTICAL PULSING HEAT PIPE

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STUDENT DECLARATION

This is to certify that the thesis entitled, **“EXPERIMENTAL STUDY ON THERMAL PERFORMANCE OF VERTICAL PULSING HEAT PIPE”** of is an outcome of the investigation carried out by the author under the supervision of **Md. Sojib Kaisar,** Assistant Professor, Dept. of Mechanical Engineering, **[SU]**. This thesis or any part of it has not been submitted to elsewhere for the award of any other degree or diploma or other similar title or prize.

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I wish their ever success in life.

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ABSTRACT

Thermal control is an important topic for thermal management of small electrical and electronic devices. Closed loop pulsating heat pipe (CLPHP) is emerging as the best solution for thermal control. The aim of this experimental study is to search a CLPHP of better thermal performance for cooling different electrical and electronic devices. In this experiment, (50%methanol+50%ethanol), acetone and distilled water have been used as working fluid. The effect of using (50%methanol+50%ethanol) acetone and distilled water as working fluids is studied on thermal performance in different filling ratios. A copper capillary tube has been used having the inner diameter of 2.0mm, outer diameter of 4.0mm and length of 130mm. The CLPHP has 3 loops where length of the evaporation section is 30mm, adiabatic section is 40mm and condensation section is 60mm. The experiment is done using FR of 0% ,30%, 50% with 70% of interval varying heat input from 6 watt to 35 watt. The results are compared on the basis of evaporator temperature, condenser temperature and their differences, thermal resistance, effect of filling ratios. The results demonstrate (50%methanol+50%ethanol) as the most suitable working fluid at 70% filling ratio. Because, (50%methanol+50%ethanol) at 70% filling ratio.

LIST OF CONTENTS

NOMENCLATURE

C_P	=	Specific Heat (kJ/Kg-K)
D	=	Diameter (mm)
D_i	=	Inner Diameter (mm)
D_o	=	Outer Diameter (mm)
F_R	=	Filling Ratio (%)
h	=	Heat transfer Co-efficient (W/K-m^2)
L	=	Length (mm)
Q	=	Heat input (W)
Re	=	Reynold Number
R_{th}	=	Thermal resistance (K/W)
T_c	=	Condensation Section Temperature (°C)
T_e	=	Evaporator Temperature (°C)
ΔT	=	Temperature difference (°C)
V	=	Specific Volume (m^3/kg)
W	=	Watt

GREEK SYMBOLS

ρ	=	Density of water (kg/m^3)
μ	=	Dynamic viscosity (kg/m.s)

SUBSCRIPT

dw	=	Distilled Water
e	=	ethanol
in	=	Inlet
liq	=	liquid
m	=	Methanol
max	=	Maximum
min	=	Minimum
out	=	Outlet
vap	=	vapor

CHAPTER 1
INTRODUCTION

1.1 Motivation

Heat pipes are one of the most effective procedures to transport thermal energy from one point to another, mostly used for cooling which is based on a combination of conduction and convective heat transfer. it is drawing a great deal of attention to the thermal management system. Thermal management has become and will continue to be one of the most critical technologies in the electronic product development.

Contemporary trends in thermal management of electronics are very demanding and the limits are being stress in every aspects of design. By analyzing the market, it has been found that the demand includes [1]:

a) Thermal resistance from chip to heat sink < 1K/W
b) High heat transport capability up to 250W
c) Heat flux spreading up to $60 W/cm^2$
d) Mechanical and Thermal compatibility
e) Long term reliability
f) Miniaturization
g) Low cost.

A heat pipe is a container tube filled with the working fluid. One end of this tube (called evaporator section) is brought in thermal contact with a hot point to be cooled. The other end (called condenser section) is connected to the cold point where the heat can be dissipated. A portion of the tube between evaporator and condenser is called adiabatic section.

The working fluid and its pressure are chosen in such a way that the saturation temperature is between the evaporator temperature T_e and condenser temperature T_c. The fluid is thus vaporized in the evaporator section. The created vapor is transported to the condenser section and condenses there. The liquid is transported back to the evaporator section. The heat is transferred mainly due to the latent heat absorption in the evaporator and its release in the condenser. Since the latent heat is large, the heat pipes are quite efficient. They are capable of evacuating up to 100-200 W/cm^2. There are different kinds of heat pipes. They differ by their geometry and a mechanism of fluid transport inside the heat pipe

1.2 Objectives

The aim of this thesis is:

- To understand the mechanism of CLPHP
- To Study the Properties of the working fluid of CLPHP
- To compare the temperature distributions of the Evaporator, Adiabatic and Condenser sections in different power Input
- To compare the thermal resistances of the system with different fill ratio of working fluid varying power input and different working fluid
- To find out the optimum set of working variables in CLPHP

CHAPTER 2

LITERATURE REVIEW

2.1 Heat Pipe:

In recent years, the miniature heat pipe used for heat dissipation and homogenous temperature of computer and numerous electronic instruments has displayed its remarkable effect. So a thorough investigation on miniature heat pipe is indispensable for further development and improvement of its performance.

Heat pipes are the most widely recognized medium to transfer heat which are consisting of the two-stage frameworks. Two-stage heat exchanger includes the fluid vapor stage change (bubbling/vanishing and buildup) of a working liquid. The Heat pipe innovation industry pioneer, Thermal center has spent significant time in the plan, advancement and assembling of uninvolved, two-stage Heat exchange gadgets since 1970. Heat pipes have a great degree of high thermal conductivity. While strong channels, for example, aluminum, copper, graphite and precious stone have Heat conductivities extending from 250 W/m-K to 1,500 W/m-K, heat pipes have high thermal conductivities that range from 5,000 W/m-K to 200,000 W/m-K. Heat channels exchange Heat from the Heat source (evaporator) to the Heat sink (condenser) over generally long separations through the idle Heat of vaporization of a working liquid.

Heat pipes typically have 3 sections:

- an evaporator section (heat input/source),
- adiabatic (or transport) section and
- a condenser section (heat output/sink).

Heat Pipes which have also be termed heat pipes or even thermal pipes, are used across a wide range of markets and applications, and we're known for producing high-quality copper heat pipes. In fact, ACT is the only US manufacturer that routinely delivers heat pipes for terrestrial electronics cooling (copper-water), on orbit satellite thermal management (aluminum-ammonia) and high temperature calibration equipment (liquid metal heat pipes). Navigate through the products section below for more information on any of these highly reliable products.

2.1.1. History of heat pipe:

Heat pipe is a device used for maintaining temperature of micro, power electronics devices and aerospace industry. Initially origin of heat pipe occurred since 1836s by A. M. Perkins and J. Perkins [4], but he toyed with concept of working fluid in only single phase at high temperature. In 1909, C. Emmet creates the first tube with a vacuum [5]. Then in 1942, R.S. Gaugler [2] fromGeneral Motors comes up with an idea to improve the heat pipe by using capillarity to circulate the condensation into the vaporization zone. However, the technology of that period presented no clear need for such a device and it lay dormant for two decades. Then it was in 1963 when a Los Alamos National Research Laboratory engineer named George Grover demonstrated the first heat pipe. Heat pipe technology was borrowed from simple heat conducting pipes used by English bakers 100 years ago. Since 1963, heat pipes progressed and modern applications of this technology range from miniature heat pipes for cooling processors inside laptop computers, to groups of half inch diameter and five feet long pipes that will be used in NASA spacecraft, to pipes of two inch diameters (or more) which are used to cool injection molds used in plastic forming. The lengths of the pipes can vary from inches to 24 feet or more [5].

Starting in the 1980s Sony began incorporating heat pipes into the cooling schemes for some of its commercial electronic products in place of both forced convection and passive finned heat sinks. Initially they were used in tuners and amplifiers, soon spreading to other high heat flux electronics applications.

Heat pipe is a device based on the principal of thermos-hydrodynamics of working fluid. It is comprising of three section evaporator, adiabatic and condenser section. Working fluid carries the heat from heat source by evaporation and rejected it at condenser by condensation. Vapor pressure difference between evaporator and condenser drive the vapor from evaporator to condenser. Latent heat liberates at condenser to due to phase change phenomenon. It gives the advantage of heat transfer between small temperatures difference over a considerable distance.

2.1.2 Types of heat pipe

There are various types of heat pipe [6]. They are listed below:

(a) Vapor chamber (Flat heat pipe)

(b) Variable conductance heat pipe (VCHP)

(c) Pressure controlled heat pipe (PCHP)

(d) Diode heat pipe

(e) Thermo-syphon

(f) Rotating heat pipe

(a) Vapor chamber/ Flat heat pipe: This type of heat pipe closed loop at both the end and hermetically sealed hollow vessel. This is used mainly where high power and high heat fluxes applied to a relatively small evaporator.

(b) Variable conductance heat pipe: This type of heat pipe is used to maintain the temperature of electronics being cooled while the power and sink condition is changing with time. This have two additional arrangements as compared to standard heat pipe are (i) Reservoir (ii) non condensable gases in addition to working fluid. NCG in standard VCHP is argon and helium in thermos-syphon heat pipe.

(c) Pressure controlled heat pipe: The PCHP heat pipe have tight temperature controlled ability. Here evaporator temperature is responsible for either vary the volume of reservoir or change the mass of non-condensable gases.

(d) Diode heat pipe: This heat pipe which have high thermal conductivity in forward direction and low thermal conductivity in reverse direction.

(e) Thermo-syphon: This is the gravity assisted heat pipe because condenser is located above the evaporator so after the condensation liquid returns to evaporator by gravity action.

(f) Rotating heat pipe: In this type of heat pipe centrifugal action is used for returning of working fluid to evaporator.

2.1.3 Key Components of a Heat Pipe

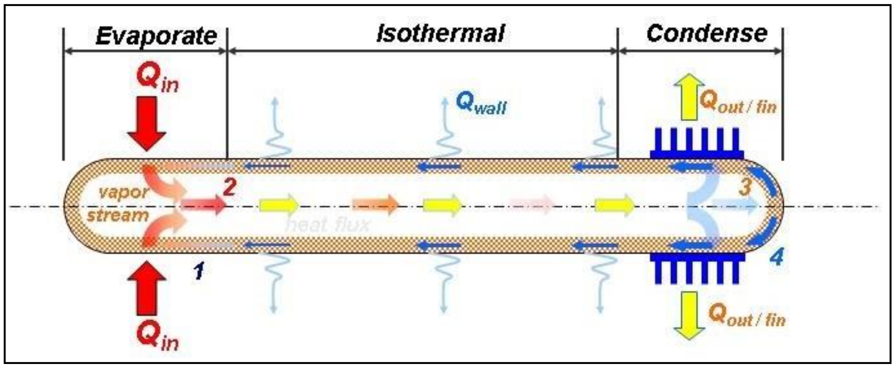

Fig 2.1: Heat Pipe

Mechanism Two major components of a heat pipe include:

(a) Container/ shell

(b) Working fluid

(a) Container: Container is a shell or tube to contain the working fluid within itself. It is made up of different types of material are copper, aluminum, steel, tungsten, titanium. Material used for container must have higher thermal conductivity and must be compatible with working fluid used. Generally, copper is used for higher thermal conductivity approximately 400 w/m° C and low cost as compared to other material.

(b) Working Fluid: Working fluid selection in heat pipe depends on the type of material used. Different types of working fluids are water, ammonia, ethanol, methanol, acetone, lithium, sodium, bismuth, nitrogen, helium. Nitrogen or helium used for low temperature application and lithium, sodium and potassium used for high temperature applications.

In the evaporator section i.e. at heat source working fluid vaporizes and converts into vapor. Then this vapor is passed through an adiabatic section (where no heat loss occurs) to condenser section (heat sink) where latent heat of fluid releases to surroundings. Temperature of working fluid always exists between triple point and critical point. Working fluid always remains in saturated state inside the heat pipe.

The vapor pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapor pressure over the condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapor condenses, releases its latent heat, and warms the cool end of the pipe. Non- condensing gases (caused by contamination for instance) in the vapor impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapor pressures are low. The speed of molecules in a gas is approximately the speed of sound, and in the absence of noncondensing gases (i.e., if there is only a gas phase present) this is the upper limit to the velocity with which they could travel in the heat pipe. In practice, the speed of the vapor through the heat pipe is limited by the rate of condensation at the cold end and far lower than the molecular speed. The condensation rate is very close to the sticking coefficient times the molecular speed times the gas density, if the condensing surface is very cold. However, if the surface is close to the temperature of the gas, the evaporation caused by the finite temperature of the surface largely cancels this heat flux. If the temperature difference is more than some tens of degrees, the evaporation from the surface is typically negligible, as can be assessed from the vapor pressure curves. In most cases, with very efficient heat transport through the gas, it is very challenging to maintain such significant temperature differences between the gas and the condensing surface. Moreover, this temperature differences of course corresponds to a large effective thermal resistance by itself. The bottleneck is often less severe at the heat source, as the gas densities are higher there, corresponding to higher maximum heat fluxes.

2.2 Close Loop Pulsating Heat Pipe

2.2.1 Pulsating heat pipe

Pulsating heat pipes (PHPs) are made from long capillary tubes bent into many turns, with the evaporator and condenser sections located at these turns. The unique feature of PHPs, compared with the conventional heat pipe is that there is no wick structure to return the condensate to the heating section. Therefore, there is no countercurrent flow between the liquid and vapor. PHPs can be applied in a wide range of practical problems, including electronics cooling. In this sector, Gi et al. [7] investigated an O-shaped oscillating heat pipe as it applied to cooling a CPU of a notebook computer. Because of the simplicity of the PHP structure, its weight will be lower than that of a conventional heat pipe, which makes PHPs ideal candidates for space applications. Since the PHP was invented in the early 1990s, limited experimental and analytical/numerical investigations on PHPs have been reported. The experiments mainly focused on some preliminary results for visualization of flow patterns and measurement of temperature and effective thermal conductivity.

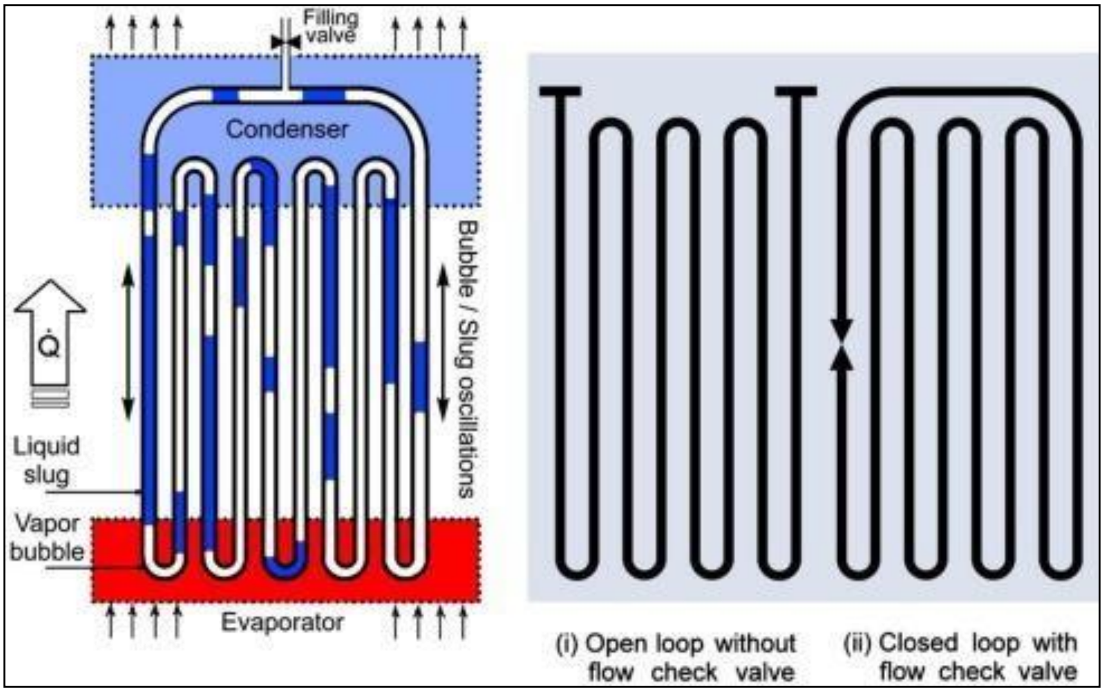

Figure 2.2: Schematic Diagram of Pulsating Heat Pipe

Pulsating heat pipes, like conventional heat pipes, are closed, two-phase systems capable of transporting heat without any additional power input, but they differ from conventional heat pipes in several major ways. A typical PHP is a small meandering tube that is partially filled with a working fluid, as seen in Figure 2.2. The tube is bent back and forth parallel to itself, and the ends of the tube may be connected to one another in a closed loop, or pinched off and welded shut in an open loop (see Figure 2.2). It is generally agreed by researchers that the closed loop PHP has better heat transfer performance. For this reason, most experimental work is done with closed loop PHPs. In addition to the oscillatory flow, the working fluid can also be circulated in the closed-loop PHP, resulting in heat transfer enhancement. Although an addition of a check valve could improve the heat transfer performance of the PHPs by making the working fluid move in a specific direction, it is difficult and expensive to install these valves. Consequently, the closed-loop PHP without a check valve becomes the m-ost favorable choice for the PHP structures.

Recently, PHPs with a sintered metal wick have been prototyped by Zuo et al. [8][9] and analyzed by Holley and Faghri [10]. The wick should aid in heat transfer and liquid distribution. A PHP must be heated in at least one section and cooled in another. Often the evaporators and condensers are located at the bends of the capillary tube. The tube is evacuated and then partially filled with a working fluid. The liquid and its vapor will become distributed throughout the pipe as liquid slugs and vapor bubbles. As the evaporator section of the PHP is heated, the vapor pressure of the bubbles located in that section will increase. This forces the liquid slug toward the condenser section of the heat pipe. When the vapor bubbles reach the condenser, it will begin to condense. As the vapor changes phase, the vapor pressure decreases, and the liquid flows back toward the condenser end. In this way, a steady oscillating flow is set up in the PHP. Boiling the working fluid will also cause new vapor bubbles to form. Research on PHPs can be categorized as either experimental or theoretical. While experimental studies have focused on either visualizing the flow pattern in PHPs or characterizing the heat transfer.

Capability of PHPs, theoretical examinations attempt to analytically and numerically model the fluid dynamics and/or heat transfer associated with oscillating two-phase flow. A PHP is a complex heat transfer device with a strong thermo-hydraulic coupling governing its performance. It is essentially a non-equilibrium heat transfer device. The performance success of the device primarily depends on the continuous maintenance or sustenance of these non-equilibrium conditions within the system. The liquid and vapor slug transport results because of the pressure pulsations caused in the system. Since these pressure pulsations are fully thermally driven, because of the inherent constructions of the device, there is no external mechanical power source required for the fluid transport.

2.2.2 Evolutions of PHP

True development of conventional heat pipes (CHP) began in the 1960s; since then, various geometries, working fluids, and wick structures have been proposed [8]. In the last 20 years, new types of heat pipes—such as capillary pumped loops and loop heat pipes—were introduced, seeking to separate the liquid and vapor flows to overcome certain limitations inherent in conventional heat pipes.

In the 1990s, Akachi et al. [11] invented a new type of heat pipe known as the pulsating or oscillating heat pipe (PHP or OHP). The most popular applications of PHP are found in electronics cooling because it may be capable of dissipating the high heat fluxes required by next generation electronics. Other proposed applications include using PHPs to preheat air or pump water. This review article will describe the operation of pulsating heat pipes, summarize the research and development over the past decade, and discuss the issues surrounding them that have yet to be resolved.

Miyazaki and Akachi [12] derived the wave equation of pressure oscillation in a PHP based on self- excited oscillation, in which reciprocal excitation between pressure oscillation and void fraction is assumed. They also obtained a closed-form solution of wave propagation velocity by solving the wave equation.

Miyazaki and Arikawa [13] presented an experimental investigation on the oscillatory flow in the PHP, and they measured wave velocity, which agreed reasonably well with the prediction of Akachi et al. [11].

Lee et al. [14] reported that the oscillations of bubbles are caused by nucleate boiling and vapor oscillation, and the departure of small bubbles is considered to be the representative flow pattern at the evaporator and adiabatic section, respectively.

Khandekar [3] conducted a large number of experiments for various PHP configurations. He performed an analysis of the impact of several parameters on their behavior (filling ratio, heat input, number of turns, orientation). He gained from his experiments an improved understanding of the heat and fluid flow mechanisms in PHPs. He discussed to effect of the tube diameter that should be small enough to ensure the flow oscillations.

Khandekar et. al. [15] also performed some flow visualizations during the operation of a PHP. They distinguished four regimes that can be related to the PHP operating curve (overall thermal resistance of the heat pipe as a function of the input power): at low heat input, the oscillations amplitude remains limited, and the thermal resistance slightly decreases with the increase of the heat input. At higher heat input, the decrease of the thermal resistance is more noticeable, and this corresponds to a slug flow pattern. Nevertheless, when increasing the heat input, a preferred flow direction progressively appears. When this preferred flow direction is clearly established, and when the flow pattern is annular rather than of slug type, the thermal resistance is minimum and exhibits a plateau. Finally, at high heat flux, the thermal resistance strongly increases with the increase of the heat input; this regime corresponds to a dry out of the evaporator.

Additional information was provided by Khandekar et. Al. [16] in their experiments with three different fluids (ethanol, water, R-123). For ethanol and water, the critical diameter was much larger than the tube diameter, while for the latter, the critical diameter was of the order of (or even slightly lower than) the tube diameter. According to their experiments, the effect of bubbles on the two-phase oscillating flow that develops out of the extreme operational limits of PHPs (i.e. PHP completely empty or completely filled with liquid) depends on the filling ratio and on the PHP orientation. At high filling ratio (e.g. 95% of liquid) and favorable orientation (evaporator at bottom, condenser at top), the bubbles tend to limit the two-phase fluid motion. For a moderate filling ratio (about 20 % - 70%, which actually gives birth to oscillations), gravity was shown to play a role even for water, i.e. even for a critical diameter noticeably greater than the tube diameter (highly confined situation), while with R-123, the PHP was found to operate, in spite of a critical diameter slightly lower than the tube diameter. All these observations were interpreted through the effect of bubbles on the two-phase flow too.

P. Charoensawan et. al. [17] has a work on effect to CLPHP thermal performance depends on various parameters like internal diameter of tube, number of turns, working fluid and inclination angle of the device and experimentally studied. The conclusion of this experimentation were, gravity has a great influence on the performance on the CLPHP, internal diameter must be specified with critical Bond number within the limit, the performance can be increased by increasing the ID and/or no. of meandering turns, the buoyancy forces effect bubble shape. Different fluids are beneficial under different operating conditions and the relative share of latent heat and sensible heat, flow behavior**.**

Zhang and Faghri [18] numerically investigated oscillatory flow and heat transfer in a U- shaped miniature channel. The two sealed ends of the U-shaped channel were the heating sections. The condenser section was located in the middle of the U-shaped channel. The U-shaped channel was placed vertically with two sealed ends (heating sections) at the top. The effects of various non- dimensional parameters on the performance of the PHP were also investigated. The empirical correlations of amplitude and circular frequency of oscillation were obtained.

2.2.3 Parameters affect the performance of CLPHP

There are various parameters which affect the performance of closed loop pulsating heat pipe directly or indirectly. Basically the affecting parameters can be broadly divided into three parts, which are given below [9]:

(a) Design/Geometrical Parameters:

i. Tube diameter and material,

ii. Orientation of PHP,

iii. Number of turns,

iv. Design of evaporator and condenser section,

v. Bend effect.

(b) Operating Parameters:

i. Filling ratio,

ii. Dry out condition,

(c) Properties of working fluids:

i. Operating temperature range,

ii. Sensible heat and latent heat

In our experiment, we have worked with operating parameters and different working fluid with continual variation of heat input.

2.2.3.1 Design/Geometric Parameters: Diameter and material of tube

The diameter of heat pipe plays vital role in the selection of the heat pipe, because it affects the performance of PHP. The internal diameter directly affects the PHP. A large hydraulic diameter results in a lower wall thermal resistance and increases the effective thermal conductivity. The capillary tube inside diameter must be small enough such that:

$$D_{max}= 2[\sigma/g\ (\rho_{liq} - \rho_{vap})]^{1/2}$$

Where, σ = working fluid surface tension (N/m);

G =gravitational acceleration (m/s2);

ρ_{liq} = liquid density (Kg/m3);

ρ_{vap} = vapor density (Kg/m3)

If D <D_{max}, surface tension forces dominate and stable liquid plugs are formed. However, if D >D_{max}, the surface tension is reduced and the working fluid will stratify by gravity and oscillations will cease. Also the selection of tube material is important; the different type materials have their own coefficient of heat transfer.

2.2.3.2 Orientation of PHP

Orientation of PHP has small effect on the performance of heat pipe. Researcher has shown that the different inclination angle with respect to horizontal with evaporator at bottom gives the different results. The optimum angle of inclination is between 50-65 where the PHP gives its optimum performance.

2.2.3.3 Number of turns

As the number of turn of PHP increases it provides flexibility to the PHP to operating at any orientation (i.e. at various angle of inclination with horizontal). Researchers have shown that if the number of turns is less then it operates in vertical position only, not in horizontal position. Mamelli [31] also concluded that nine turns CLPHP has many advantages with respect to the one with three turns:

i. It is able to work also in the horizontal heat mode.

ii. Its thermal resistance is lower,

iii. There are less evident differences between different fluids in terms of overall efficiency.

2.2.3.4 Design of evaporator and condenser section:

Design of evaporator and condenser plays important role, which affects the performance of heat pipe. It is thumb rule that the condenser should have the larger area than the evaporator in order to avoid the dry out condition. The evaporator section lengths affected on critical heat flux in this range. When the evaporator section lengths increased the critical heat transfer flux decreased. The heat pipe is assumed to be operating at an adiabatic temperature of T_1 with heat input of Q_1, very close to the dry out power Q_{dry-1} corresponding to the operating temperature. If, under such operating conditions the condenser capacity is increased, by either lowering the coolant temperature or increasing the coolant mass flow, there is a risk of a dry out to occur. This will happen since the operating temperature drops to T_2 for which the heat input Q_1 is too high. Thus, increasing the condenser capacity need not necessarily improve the heat transfer for conventional heat pipes. Although there is no well-defined adiabatic operating temperature for pulsating heat pipes, a similar trend regarding the effect of condenser capacity may be observed. Increasing the condenser capacity affects not only the thermo-physical properties of the working fluid but as a side effect alters the slug-annular flow pattern transitions, thereby altering the final performance. This aspect has to be addressed while practical designing.

2.2.3.5 Bend Effect:

In PHP geometry three numbers of U-terns are present. Mamelli[31] explained the effect of bend on the performance of PHP. Due to the 180° and 90° bent pressure loss occurs in heat pipe. Mamelli also have developed the numerical model to account for the local pressure loss taking place in the PHP. He concluded that Local pressure losses due to bends and turns affect the device operation especially in the horizontal mode and for high heat input levels.

2.2.3.6 Operating Parameters: Filling ratio:

The filling ratio is defined as the fraction by volume of the heat pipe, which is initially filled with the liquid. The optimal filling ratio is determined experimentally when the maximum heat transfer rate is achieved at a given temperature.

2.2.3.7 Dry out condition:

This factor restrains the operation of heat pipe. At the point when the total working liquid vaporized and there is no any fluid in the evaporator segment then we can state dry out condition is happened. This condition happens when there is low filling proportion and high heat input is given to the pipe. At the point when dry out condition achieves the heat exchange happen totally because of conduction.

2.2.3.8 Properties of Working Fluid:

The selection of working fluid is also important parameter which affects the performance of PHP. Selection of working fluid is directly linked to the properties of the fluid. The properties are going to affect both the ability to transfer heat and the comparability with the tube material. The working fluid should be selected such that it supports the PHP operating temperature range. The temperature range of different fluids is shown in table 2.1.

When selecting a working fluid, the following working fluid characteristics should be examined:

i. Compatibility with the OHP material(s),

ii. Thermal stability,

iii. Acceptable freezing point.

iv. Reasonable vapor pressure,

v. High latent heat and thermal conductivity,

vi. Low liquid and vapor viscosities,

For most applications, the thermodynamic characteristics of water make it a good choice for PHP applications, as it has high latent heat, which spreads more heat with less fluid flow, and high thermal conductivity which minimizes dT. However, water does have high surface tension and may have adverse effects on the PHP as it may cause additional friction and limit the two phase flow oscillations of the PHP. Methanol is a good substitution for water, especially for sub-zero applications, as it has approximately one third the surface tensions.

Table: 2.1 *Temperature Range of Working Fluid*

Working Fluid	Melting Point (°C)	Boiling Point (°C)	Useful Range (°C)
Methanol	-98	64	10 to 120
Ethanol	-112	78	10 to 120
Acetone	-95	56	10 to 100
Water	0	100	30 to 200

2.3 Limitations of CLPHP

The rate of heat transfer through the heat pipe is solely dependent on the rate of evaporation and condensation.

- **Capillary Limit:** It occurs when the capillary pressure is too low to provide enough liquid to the evaporator from the condenser. Leads to dry out in the evaporator. Dry out prevents the thermodynamic cycle from continuing and the heat pipe no longer functions properly.
- **Boiling Limit:** occurs when the radial heat flux into the heat pipe causes the liquid in the wick to boil and evaporate causing dry out.

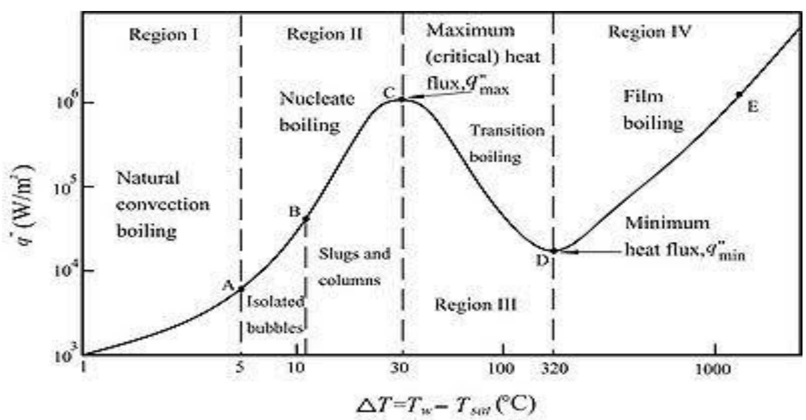

Figure 2.3: *Pool Boiling Curve*

- **Viscous Limit*:*** at low temperatures the vapor pressure difference between the condenser and the evaporator may not be enough to overcome viscous forces. The vapor from the evaporator doesn't move to the condenser and the thermodynamic cycle doesn't occur.
- **Speed of sound limit**: It is important for high temperature heat pipes, where the vapor could possibly reach the speed of sound when leaving the evaporation.
- **Interaction limit:** This limit is connected with open channels, where the vapor can be carried away by the vapor, due to high velocity differences**.**
- **Melting temperature:** One cannot use a heat pipe below the melting temperature of the fluid.
- Most manufacturers cannot make a traditional heat pipe smaller than 2 mm due to material limitation. Heat pipes are excellent heat transfer devices but their sphere of application is mainly confined to transferring relatively small heat loads over relatively short distances when the evaporator and condenser are at same horizontal level.
- Each limit has its own particular range in which it is important. However, in practical operation, the capillary and boiling limits are the most important. The figure below is an example of these ranges.
- To judge about the efficiency of a heat pipe the Merit-number 'Me' is introduced This number shows that the main influence factors for the heat pipe are the surface tension, evaporation enthalpy and the viscosity of the liquid, as higher Me as better is the heat pipe.

2.4 Heat Transfer by convection

Convective heat transfer is one of the major types of heat transfer, and convection is also a major mode of mass transfer in fluids. Convective heat and mass transfer take place both by diffusion – the random Brownian motion of individual particles in the fluid – and by advection, in which matter or heat is transported by the larger-scale motion of currents in the fluid. In the context of heat and mass transfer, the term "convection" is used to refer to the sum of advective and diffusive transfer. In common use the term "convection" may refer loosely to heat transfer by convection, as opposed to mass transfer by convection, or the convection process in general. Sometimes "convection" is even used to refer specifically to "free heat convection" (natural heat convection) which is due to temperature-induced differences in buoyancy, as opposed to "forced heat convection" where forces other than buoyancy (such as pump or fan) move the fluid. However, in mechanics the correct use of the word "convection" is the general sense, and different types of convection should be qualified for clarity. There are two types of convection based on driving force:

- **Natural/free/Passive convection**: It occurs due to temperature differences which affect the density, and thus relative buoyancy of the fluid. Heavier (denser) components will fall, while lighter (less dense) components rise, leading to bulk fluid movement. Natural convection can only occur, therefore, in a gravitational field. The onset of natural convection can be determined by the Rayleigh number (Ra).

- **Forced/Active convection**: It is also called heat advection, fluid movement results from external surface forces such as a fan or pump. Forced convection is typically used to increase the rate of heat exchange. The ratio of Convective to conductive heat transfer across the boundary can be evaluated by Nusselt Number (Nu).

CHAPTER 3

EXPERIMENTATION

3.1 Experimental setup

An experimental facility has been designed, fabricated and installed for studying the heat transfer characteristics of a closed loop pulsating heat pipe (CLPHP). The detailed description of experimental apparatus and experimental procedure are presented in this chapter.

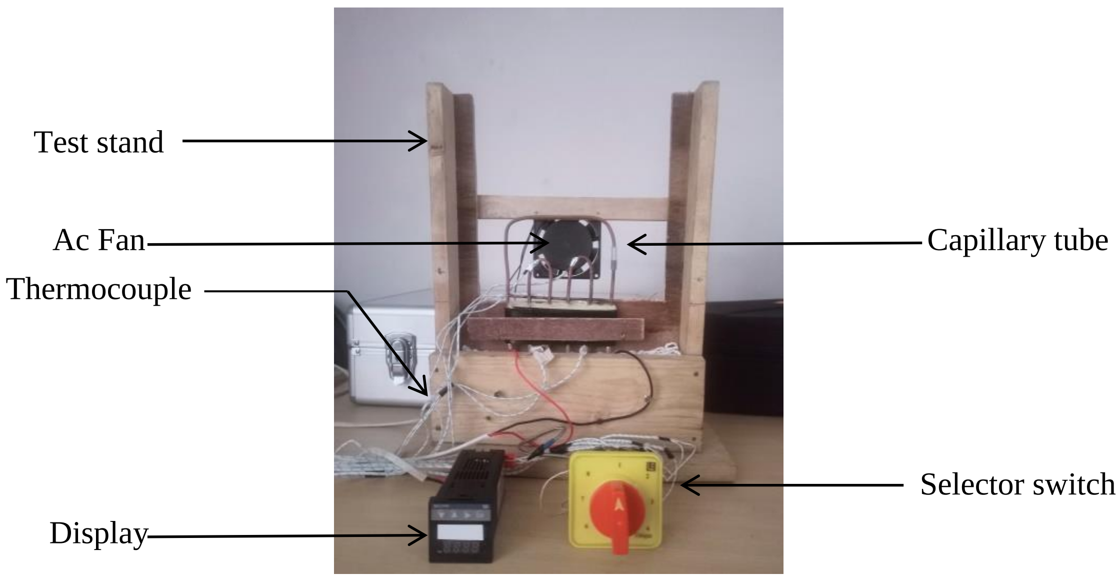

Fig 3.1: *Experimental Setup of CLPHP*

3.1.1 Apparatus:

- Working fluid
    - Methanol
    - Ethanol
    - Distilled Water
    - Acetone
- Test stand
- Heating apparatus

- Variac
- Power Supply Unit
- Ni-chrome Thermal Wire

- Insulating apparatus
  - Mica tape/ Heat tape
  - Glass wool
  - Foam tape
  - Asbestos tape
- Measuring apparatus
  - K-Type Thermocouple
  - Wattmeter
- Other Equipment
  - AC fan
  - Glue Gun
  - Electric Wire

3.2 Description of Different types of Apparatus

3.2.1 Pulsating Heat Pipe

A closed loop pulsating heat pipe (CLPHP) or oscillating heat pipe consists of a metallic tube of capillary dimensions wound in a serpentine manner & joined end to end. It consists of 3 sections:

3.2.2 Evaporator Section:

It is the section of the heat pipe where the working fluid absorbs heat & evaporates. It is located on the bottom section of the heat pipe. The heat is supplied on the heat pipe by Ni-chrome wire which is connected to the variac. As the copper tube is a good conductor of electricity, it is not directly connected with Ni-chrome wire because it can cause short circuit connection. So, the Ni-chrome wire is surrounded to a mica sheet & kept in a distance of copper tube. So, heat is transferred to the copper tube through the mica tape. In our experiment, the evaporative side was also thermally insulated with asbestos tape to ensure better sealing of heat. In this way, the heat loss was reduced.

3.2.3 Condenser Section:

It is the section of heat pipe where heat is rejected from the working fluid. In this section, the working fluid condenses & rejects little bit of less amount of heat which is absorbed from the evaporator section. In this experiment, this section is located on upper section of the heat pipe.

3.2.4 Adiabatic Section:

It is located between the evaporator section & condenser section. In here the liquid & vapor phases of the fluid flow in opposite directions and no significant heat transfer occurs between the fluid & surrounding medium. Glass wool and foam tape are used for the section insulated.

Parameters	**Condition**
Inner diameter	2.0 mm
Outer diameter	4.0 mm
Total length	130.0 mm
Length of evaporator section	30mm
Length of adiabatic section	40mm
Length of condenser section	60mm
Material	Copper

Table 3.1*: Experimental Component Parameter and Dimensions*

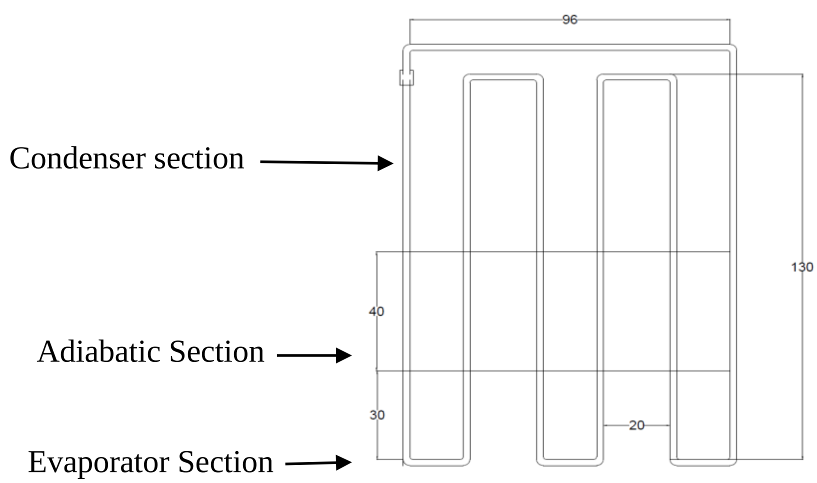

Fig 3.2: *Diagram of CLPHP*

3.3 Working Fluid:

3.3.1 Methanol

Methanol, also known as methyl alcohol, wood alcohol, wood naphtha or wood spirits, is a chemical with the formula CH_3OH (often abbreviated MeOH). Methanol acquired the name "wood alcohol" because it was once produced chiefly as a byproduct of the destructive distillation of wood. Modern methanol is produced in a catalytic industrial process directly from carbon monoxide, carbon dioxide, and hydrogen.

Methanol is the simplest alcohol, and is a light, volatile, colorless, flammable liquid with a distinctive odor very similar to that of ethanol (drinking alcohol). However, unlike ethanol, methanol is highly toxic and unfit for consumption. At room temperature, it is a polar liquid, and is used as an antifreeze, solvent, fuel, and as a denaturant for ethanol. It is also used for producing biodiesel via trans esterification reaction.

Methanol is produced naturally in the anaerobic metabolism of many varieties of bacteria, and is commonly present in small amounts in the environment. As a result, there is a small fraction of methanol vapor in the atmosphere. Over the course of several days, atmospheric methanol is oxidized with the help of sunlight to carbon dioxide and water.

Methanol burns in oxygen, including open air, forming carbon dioxide and water: 2
$CH_3OH + 3 O_2 \rightarrow 2 CO_2 + 4 H_2O$

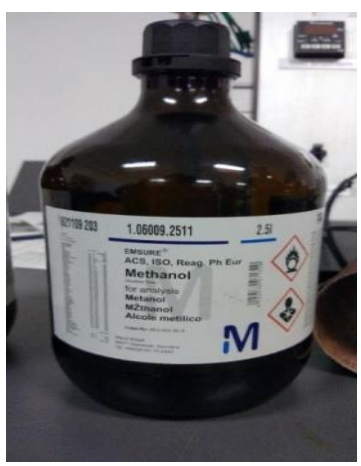

Fig 3.3: *Methanol*

3.3.2 Ethanol

Commonly referred to simply as alcohol or spirits, ethanol is also called ethyl alcohol, and drinking alcohol. It is the principal type of alcohol found in alcoholic beverages produced by the fermentation of sugars by yeasts. It is a neurotoxic psychoactive drug and one of the oldest recreational drugs used by humans. It can cause alcohol intoxication when consumed in sufficient quantity. Ethanol is used as a solvent, an antiseptic, a fuel and the active fluid in modern (post-mercury) thermometers. It is a volatile, flammable, colorless liquid with a strong chemical odor. Its structural formula CH_3CH_2OH, is often abbreviated as C_2H_5OH or C_2H_6O.

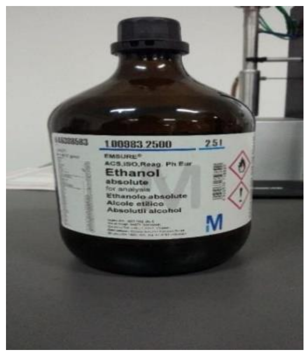

Fig 3.4: *Ethanol*

3.3.3 Acetone

Acetone is an organic compound with the formula $(CH_3)_2CO$. It is the simplest and smallest ketone. It is a colorless, highly volatile and flammable liquid with a characteristic pungent odour. Acetone is miscible with water and serves as an important organic solvent in its own right, in industry, home, and laboratory.

Fig 3.5: Acetone

3.3.4 Distilled Water

Distilled water is water that has been boiled into vapor and condensed back into liquid in a separate container. Impurities in the original water that do not boil below or near the boiling point of water remain in the original container. Thus, distilled water is a type of purified water

Fig 3.6: *Distilled Water*

3.4 Test Stand

A wooden frame is used as the base structure where all other equipment are set upon. The frame made with kerosene wood is capable of holding all weights with required stability. The test stand is a wooden structure which holds the heat pipe. It has a base where a box has been set. It contains the evaporator section of the heat pipe. The evaporator section is connected to Ni-C thermal wire (Ni-chrome Wire) which is connected with the variac.

Fig 3.7: *Test Stand*

3.5 Heating apparatus

3.5.1 Power Supply Unit

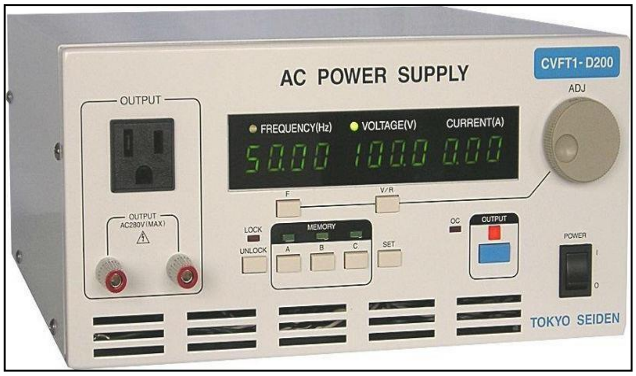

Fig 3.8: *Power supply unit*

Type	:	A.C
Voltage	:	Up to 220 volt
Frequency	:	50 Hz

3.5.2 Ni-chrome Wire

Ni-chrome wire is an alloy typically made of 80% nickel and 20% chrome. Because of Ni-chrome wire's high internal resistance, it heats up rapidly when applying electricity and also cools rapidly when shut off or removed from a heat source. It maintains its strength as the temperature rises and has a higher melting point than other wire. It does not oxidize or corrode, and is non-magnetic and highly flexible. We had used Ni-chrome wire in our experiment for heating up the test section whose internal resistance was about 18 m. Its' resistivity is 1.0 x 10^{-6} to 1.5 x 10^{-6} Ωm and specific heat is 450 $JKg^{-1}K^{-1}$.

Fig 3.9*: Ni-chrome Wire*

3.5.3 VARIAC

Variac provides variable voltage to run different types of operations or the operation that requires different voltage in times. We used voltages ranges from 10-40 volts by this power source. It is connected to the power supply unit to provide variable power (heat input) by varying voltage output

***Fig 3.10**: Variac*

3.6 Apparatus

3.6.1 Mica Tape (Electric Insulation)

This was used for electric insulation in evaporator as the Ni-chrome wire was winded throughout the evaporator. The term "mica" is used for a group of minerals that show perfect cleavage. Actually, they are sheets of silicate. The name comes from the Latin word ‘micare’, meaning to shine, in reference to the brilliant appearance of this material. Von Roll's commitment to mica starts with mining, followed by the very specialized field of producing paper from a mineral and finishing with the production of special mica tapes as well as mica ancillary parts.

Von Roll uses two types of mica, phlogopite and muscovite, for a variety of applications and depending on the needed electrical characteristic, mainly in:

- Electrical and thermal insulation of electrical machines.
- Insulation of cable for fire resistance.

***Fg 3.11:** Mica Tape*

3.6.2 Silicone Tube

Fig 3.12: *Silicone Tube*

3.6.3 Glass Wool (thermal Insulation)

Glass wool is an insulating material made from fiber of glass arranged using a binder into a texture similar to wool. This was used surrounding the adiabatic section so that the heat can be kept trapped in desired section. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties. Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. It may also be produced as a material that can be sprayed or applied in place, on the surface to be insulated. The modern method for producing glass wool is the invention of Games Slayter working at the Owens-Illinois Glass Co. (Toledo, Ohio). He first applied for a patent for a new process to make glass wool in 1933.

Fig 3.13: *Glass wool*

3.6.4 Foam tape

foam tape provides heat and sound insulation. Foam tape also finds use in cabling and wiring systems, where a few wraps can provide both distance and adhesion between multiple cables. It plays a variety of important roles in the construction of robots, and is useful in robot drive trains and other functions. Foam tape is manufactured in a number of different shapes, and in roll form. There are also various adhesives used on the tape itself, including rubber and acrylic adhesives, all of which provide different advantages and drawbacks. This was used surrounding glass wool in adiabatic section.

Fig 3.14: *Foam tape*

3.6.5 Asbestos tape

It is usually used for thermal insulation. Sticky gray tape that everyone has come to know and love got its name from its very practical function; Duct tape was intended to be used for taping various kinds of ducts, especially those used for heating. The tape keeps excess heat from escaping, making it a money-saving and useful product. Duct tape has gone on to become a trendy home product with thousands of uses. It comes in all colors, sizes, and different levels of quality. In our experiment, we used Asbestos tape of 2” width and .25” in thickness.

Fig 3.15: *Asbestos Tape*

3.7 Cooling Apparatus

3.7.1 Fan

For the cooling process, we used axial dc fan. An axial fan in general, whether AC axial fans or otherwise, is the most commonly used variety of cooling fan, as well as the most cost effective. Also called 'box fan' on occasion, they move air on a straight axis through the fan. This kind of fan functions best under a low pressure or low system impedance environment. With reduced fan speed the noise produced by an axial fan can be kept at a minimum. Because of this low level of audible noise, as well as their economical price range.

Fig 3.16*: Fan*

3.8 Measuring Apparatus

3.8.1 K- Type Thermocouple

A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the See beck effect, and this voltage can be interpreted to measure temperature. Thermocouples are widely used as temperature sensors. Type K (chromel–alumel) is the most common general-purpose thermocouple with a sensitivity of approximately 41 µV/°C. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C (−330 °F to +2460 °F) range.

Fig 3.17: *K-Type Thermocouple*

3.8.2 Wattmeter

Wattmeter's measure how much electricity is being used by an electrical circuit. A typical wattmeter can measure voltage, current resistance.

The wattmeter is used in various like:

- Laboratories
- Industries
- Measurements of power in distribution and transmission power.

Fig 3.18: *Wattmeter*

3.9 Other Equipment

3.9.1 Electric Wire

To conduct the flow of electricity, we used electric wire of negligible diameter. this wire used to connected electric equipment.

Fig 3.19: *Electric Wire*

3.9.2 Glue gun

Fig 3.20: *Glue gun*

3.10 Mathematical Equations and Calculations

3.10.1 Calculation of filling Ratio

Let, V = Internal volume of the heat pipe
= 100% Fill Ratio

Volume, V = $\frac{\pi D^2}{4}\ x\ L$

Now, V $= \frac{3.1416\ x\ 2^2}{4}$ x 1040 mm^3
= 3267.264 mm^3

≈ 3.267 ml
= 3.3 ml

As there is no additional container for working fluid in the test setup, the total internal volume of the pipe is considered to be the maximum capacity of the system. For example, to study the heat transfer characteristics **0.66ml, 1.65ml and 2.31ml** of working fluids were used which yielded **30%, 50% and 70%** filling ratio respectively.

3.10.2 Calculation of Thermal Resistance

Let, R_{th} = Thermal resistance
T_e = Evaporator Temperature
T_c = Condenser Temperature

$R_{th} = (T_e - T_c) / Q$ C°/W

3.11 Experimental Procedure

- Firstly the construction has been made and the flowing sets were carried out. To complete the experiment.
- Filling the working fluid inside the heat pipe.
- First the heat pipe was filled 30% by working fluid Distilled Water (injecting by syringe) and the heat pipes were kept in vertical position.

- Then different heat inputs were provided to the system and temperature reading of evaporator, adiabatic and condenser sections was measured the steady point.
- The filling ratio was changed 50%, 70% on; keeping same fluid and above procedure was carried on.
- The above were carried out systematically for the working fluid Acetone, (50% ethanol +50% methanol) and acetone respectively.

3.12 Safety Measured

The following this were considered while performing the experiment:

- During the entire experiment, all other source that can effect heat transfer process, kept off.
- The sensor (K- type thermocouple sensors) used in the experiment must be checked properly before taking temperature measurement.
- The injection of fluid has to be precise as the fill ratio has an impact on performance of heat pipe

CHAPTER 4

RESULT AND DISCUSSION

4.1 Effect of Evaporator and Condenser Temperature:

The effect of evaporator temperature (Te) and condenser temperature (Tc) different working fluid of close loop pulsing heat pipe in different heat input .The detailed description of in this chapter.

4.1.1 Working Fluid: DI Water (Fill Ratio: 30%)

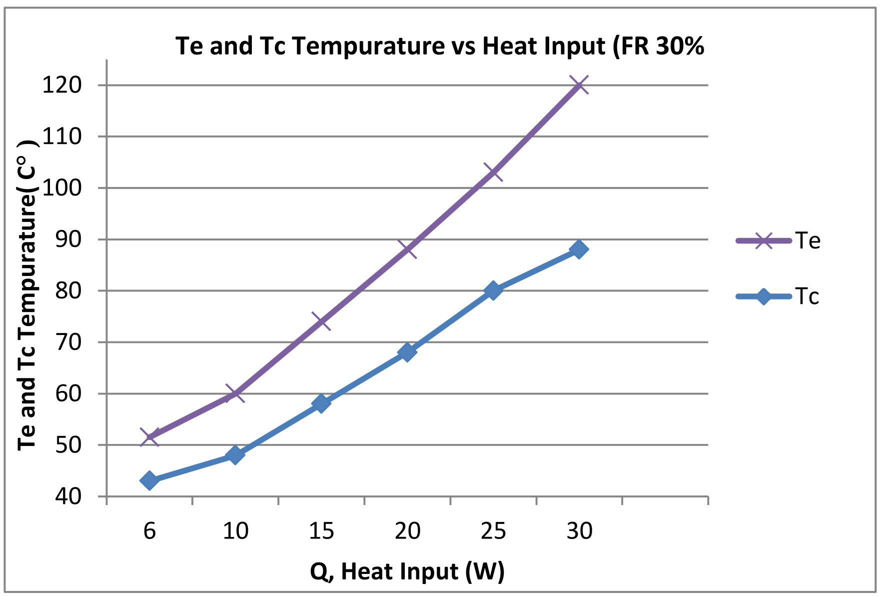

Fig: 4.1: *Evaporator temperature and Condenser temperature vs with heat input of DI water fill ratio 3o%*

Figure 4.1 shows the effect of Evaporator and Condenser temperature vs heat input of water at filling ratio 30%.As we increase the heat, the temperature of the evaporator increases. At the same time condenser temperature is increasing. But it can be observed that the initial temperature rate rise is low, The evaporator temperature does not rise at the same rate as the condenser temperature.

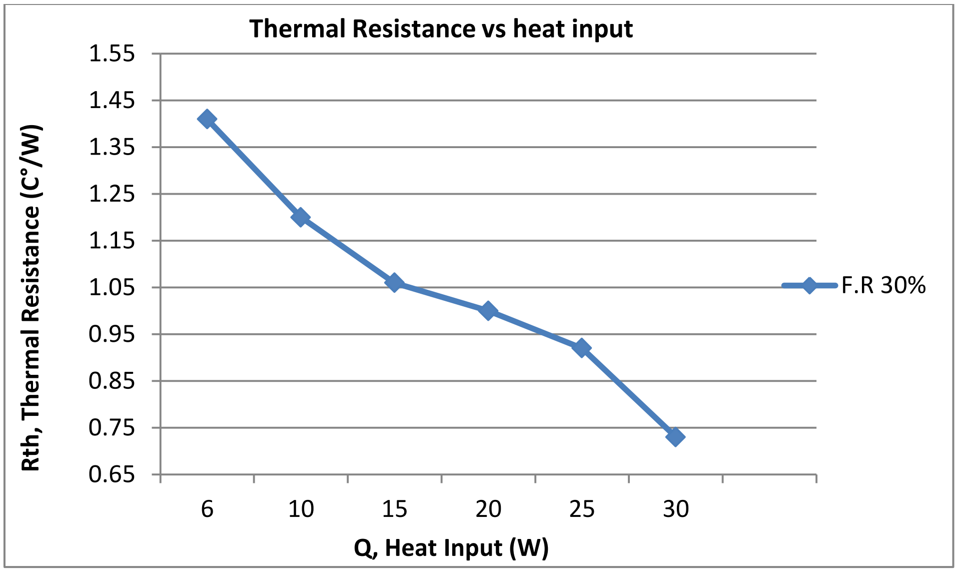

Fig: 4.2: Effect of thermal resistance vs with heat input of water at fill ratio 30%

Figure 4.2 shows the effect of the thermal resistance input for with heat distilled water. It shows the effect of different fill ratio on thermal resistance change. From this figure we can understand, the thermal resistance decreases with the increment of heat input. In case of distilled water, it can be observed that the thermal resistance decreases at a constant rate from 6 W to 15 W. From 15 W to 20 W, thermal resistance decreases at slower rate.

4.1.2 Working Fluid: DI Water (Fill Ratio: 50%)

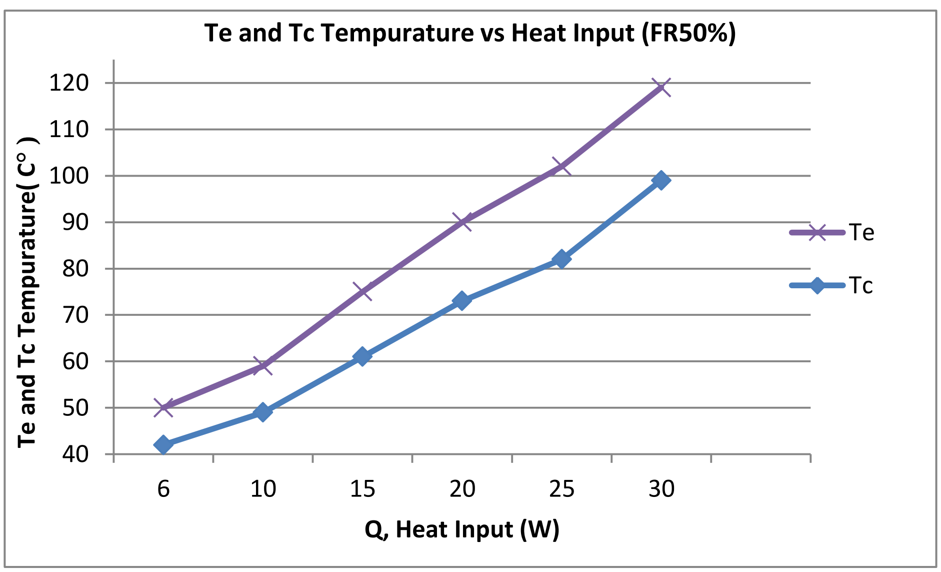

Fig: 4.3: *Evaporator temperature and Condenser temperature vs with heat input of DI water fill ratio 5o%*

Figure 4.3 shows the effect of Evaporator and Condenser temperature vs heat input of water at filling ratio 50%. As we increase the heat, the temperature of the evaporator increases. At the same time condenser temperature is increasing. But it can be observed that the evaporator and condenser temperature difference rate almost same from 6w to 15 w, From 15w to 30 w temperature difference rate increase.

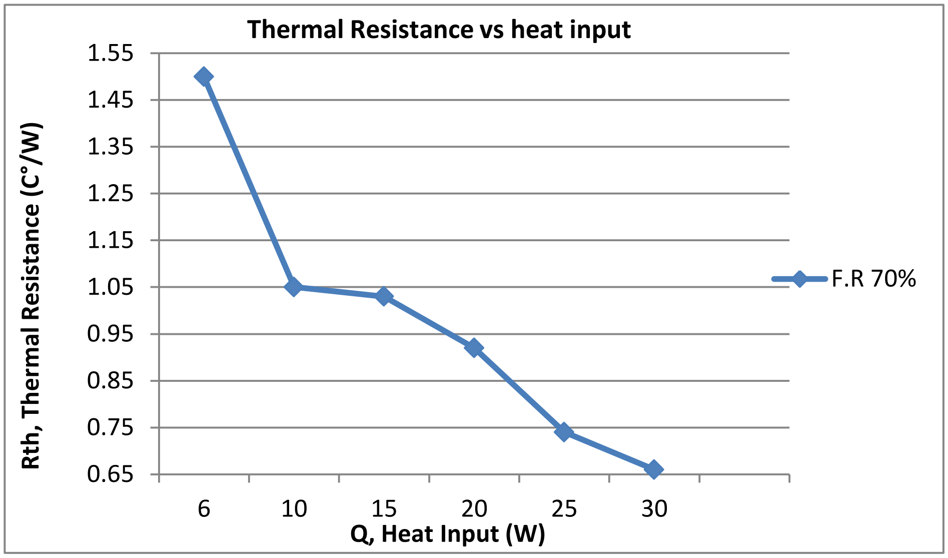

Fig: 4.4: *Effect of thermal resistance vs with heat input of water at fill ratio 50%*

Figure 4.4 shows the effect of the thermal resistance input for with heat distilled water. It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 10w , From 10w to 25w almost same ,but 25w to30w, thermal resistance again decreases.

4.1.3 Working Fluid: DI Water (Fill Ratio: 70%)

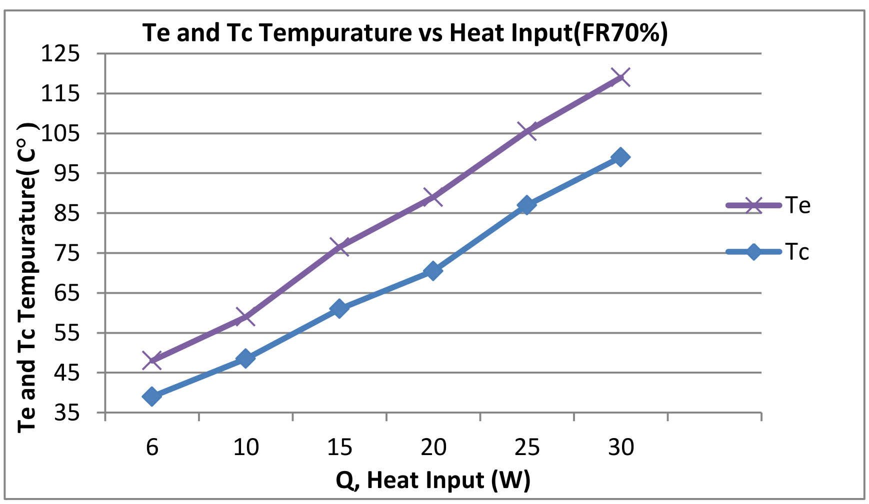

Fig: 4.5: *Evaporator temperature and Condenser temperature vs with heat input of DI water fill ratio 70%*

Figure 4.5 shows the effect of different heat input on evaporation and condenser temperature taking distilled water at fill ratio 70%. it can be observed that the evaporation and condenser temperature increases at a constant rate from 6 W to 15 W. From 15 W to 30 W, temperature increases at higher rate.

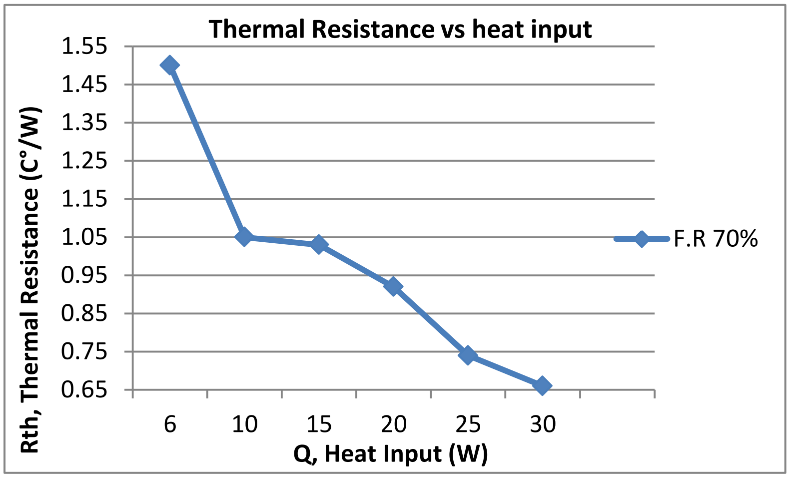

Fig: 4.6: *Effect of thermal resistance vs with heat input of water at fill ratio 70%*

Figure 4.6 shows the effect of the thermal resistance input for with heat distilled water. It shows the effect of different fill ratio on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 10w , From 10 w to 30 w the thermal resistance decreases rate almost same.

4.1.4 Working Fluid: Acetone (Fill Ratio: 30%)

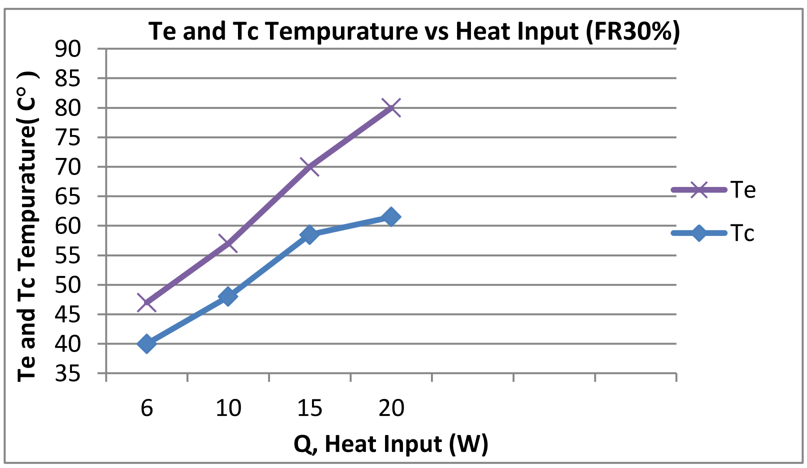

Fig: 4.7: *Evaporator temperature and Condenser temperature vs with heat input of acetone fill ratio 30%*

Figure 4.7 shows the effect of different heat input on evaporation and condenser temperature taking distilled water at fill ratio 30%. it can be observed that the evaporation and condenser temperature difference at a constant rate from 6 W to 15 W. From 15 W to 20 W, temperature difference at higher rate.

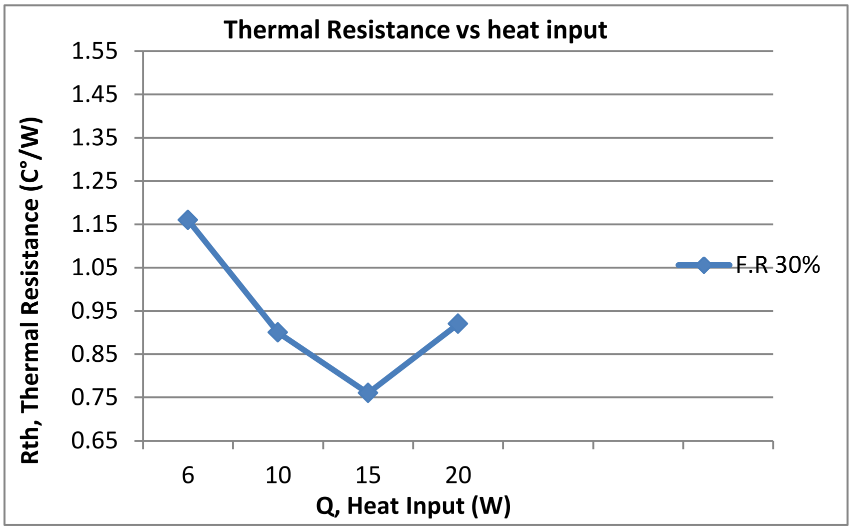

Fig: 4.8: *Effect of thermal resistance vs with heat input of acetone at fill ratio 30%*

Figure 4.8 shows the effect of the thermal resistance input for with heat acetone . It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 15 w , From 15 w to 20 w the thermal resistance increases the reason may be that the condenser temperature exceeds the boiling temperature of acetone

4.1.5 Working Fluid: Acetone (Fill Ratio: 50%)

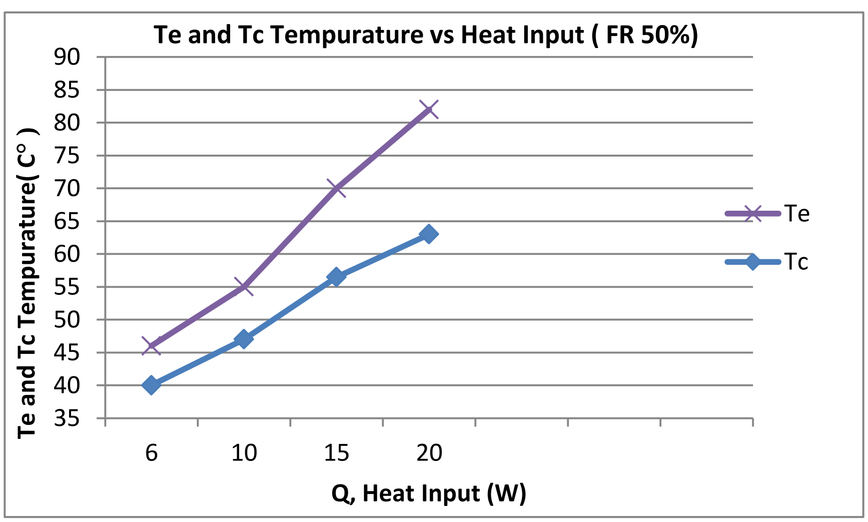

Fig: 4.9: *Evaporator temperature and Condenser temperature vs with heat input of acetone fill ratio 50%*

Figure 4.9 shows the effect of different heat input on evaporation and condenser temperature taking distilled water at fill ratio 50%. it can be observed that the evaporation and condenser temperature increases at a constant rate from 6 W to 10 W. From 10 W to 20 W, temperature increases at higher rate.

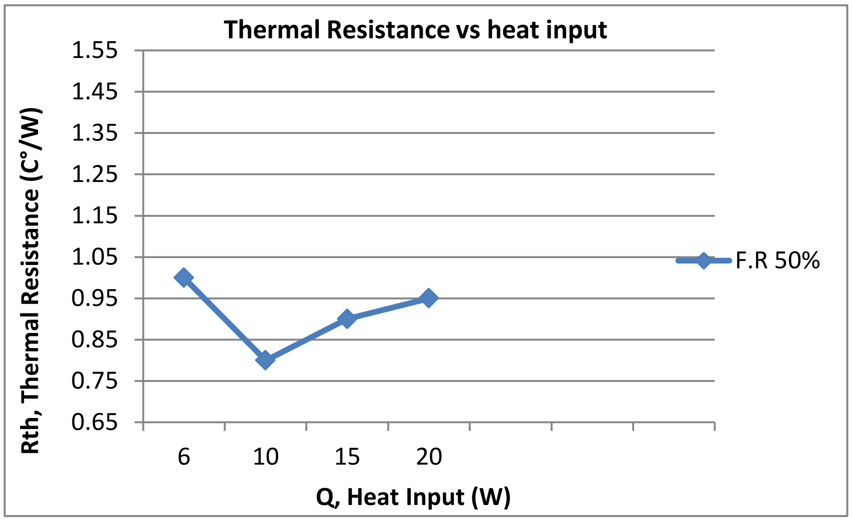

Fig: 4.10: *Effect of thermal resistance vs with heat input of acetone at fill ratio 50%.*

Figure 4.10 shows the effect of the thermal resistance input for with heat acetone. It shows the effect of different heat on thermal resistance change. From this figure we can Understand , the thermal resistance decreases rate high from 6w to 10 w , From 10 w to 20 w the thermal resistance increases the reason may be that the condenser temperature exceeds the boiling temperature of acetone.

4.1.6 Working Fluid: Acetone (Fill Ratio: 70%)

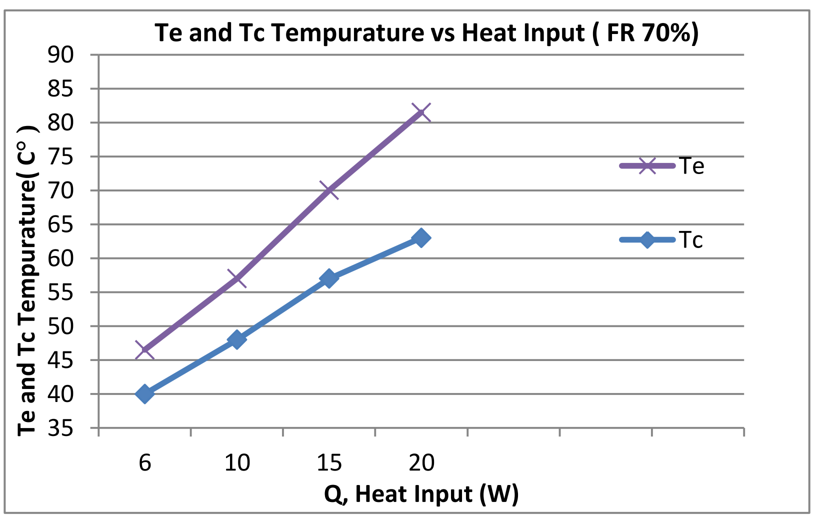

Fig: 4.11: *Evaporator temperature and Condenser temperature vs with heat input of acetone*

70%

Figure 4.11 shows the effect of different heat input on evaporation and condenser temperature taking distilled water at fill ratio 70%. it can be observed that the evaporation and condenser temperature increases at a constant rate from 6 W to 10 W. From 10 W to 20 W, temperature increases at higher rate.

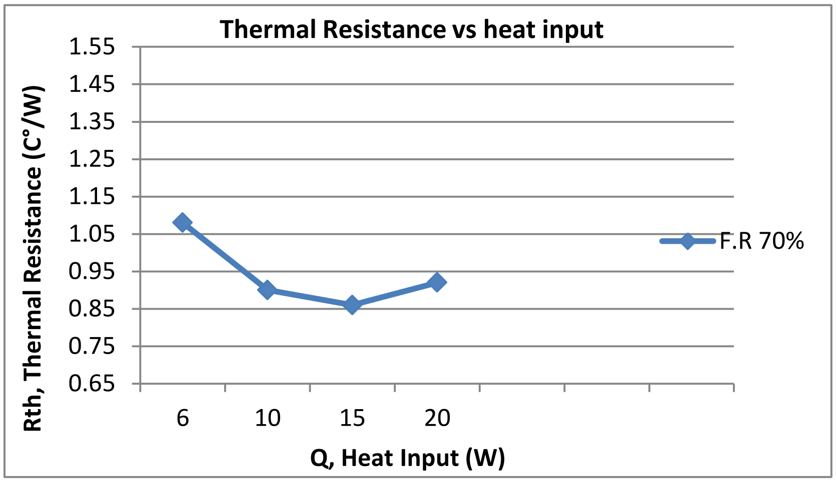

Fig: 4.12: *Effect of thermal resistance vs with heat input of acetone at fill ratio 70%*

Figure 4.12 shows the effect of the thermal resistance input for with heat acetone . It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 10 w , From 10 w to 20 w the thermal resistance increases, the reason may be that the condenser temperature exceeds the boiling temperature of acetone.

4.1.7 Working Fluid: 50% Ethanol + 50%Methanol (FR: 30%)

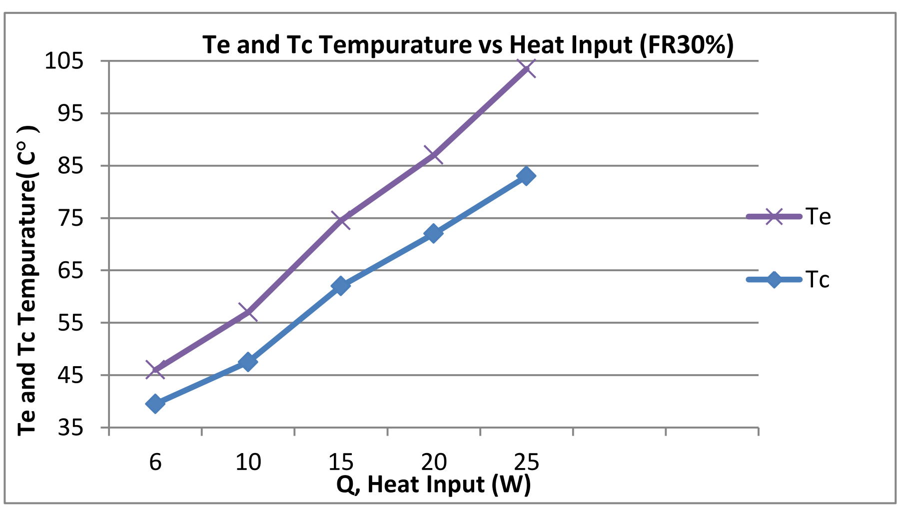

Fig: 4.13: *Evaporator temperature and Condenser temperature vs with heat input of (50% Ethanol+50% Methanol) fill ratio 30%*

Figure 4.13 shows the effect of Evaporator and Condenser temperature vs heat input of (50% Ethanol+50% Methanol) fill ratio 30% at filling ratio 30%. As we increase the heat, the temperature of the evaporator increases. At the same time condenser temperature is increasing. But it can be observed that the initial temperature rate rise is low, The evaporator temperature does not rise at the same rate as the condenser temperature. (50% Ethanol+50% Methanol), we can see, the highest temperature is acquired from 25w heat input whereas the lowest temperature is acquired from 06 w heat input.

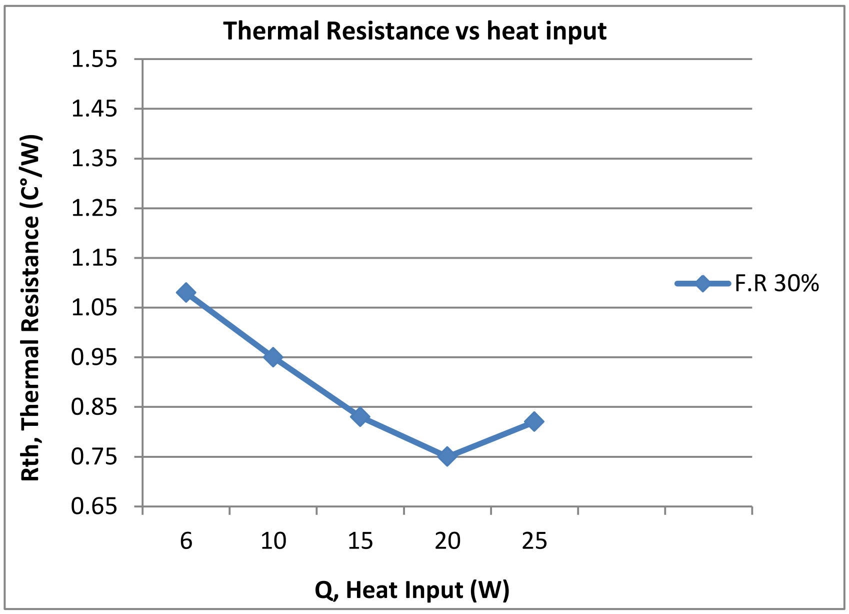

Fig: 4.14: *Effect of thermal resistance vs with heat input (50% Ethanol+50% Methanol) fill ratio 50%*

Figure 4.14 shows the effect of the thermal resistance input for with heat (50% Ethanol+50% Methanol),. It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 20w , From 20w to 25w thermal resistance again increases. the reason may be that the condenser temperature exceeds the boiling temperature of acetone. (50% Ethanol+50% Methanol), we can see, the highest thermal resistance is acquired from 06 w heat input whereas the lowest thermal resistance is acquired from 25 w heat input.

4.1.8 Working Fluid: 50% Ethanol + 50%Methanol (FR: 50%)

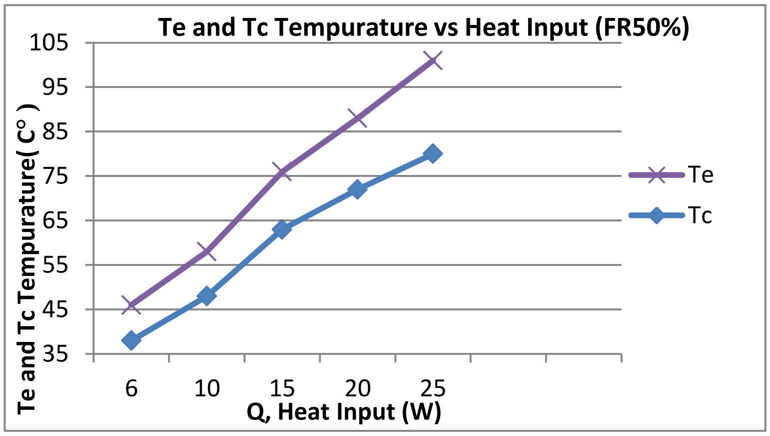

Fig: 4.15: *Evaporator temperature and Condenser temperature vs with heat input of (50% Ethanol+50% Methanol) fill ratio 50%*

Figure 4.15 shows the effect of Evaporator and Condenser temperature vs heat input of (50% Ethanol+50% Methanol) fill ratio 50% at filling ratio 50%. As we increase the heat, the temperature of the evaporator increases. At the same time condenser temperature is increasing. But it can be observed that the initial temperature rate rise is low, The evaporator temperature does not rise at the same rate as the condenser temperature. (50% Ethanol+50% Methanol), we can see, the highest temperature is acquired from 25w heat input whereas the lowest temperature is acquired from 06 w heat input.

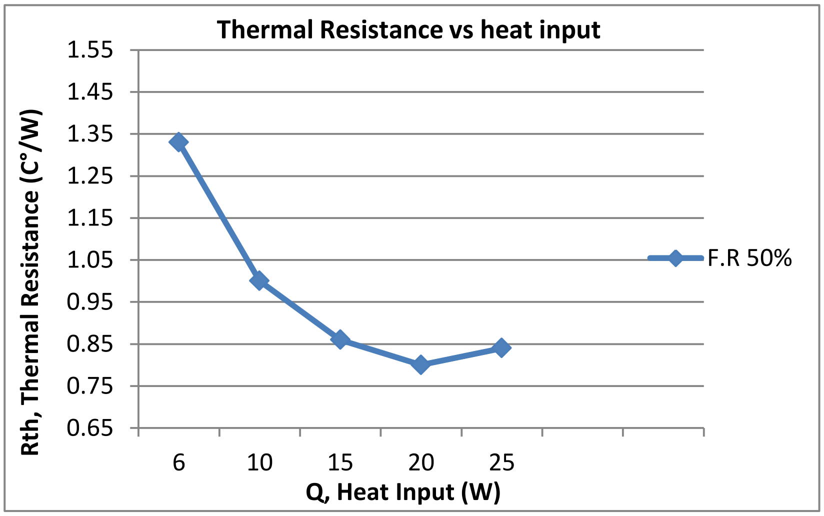

Fig: 4.16: *Effect of thermal resistance vs with heat input (50% Ethanol+50% Methanol) at fill ratio 50%.*

Figure 4.16 shows the effect of the thermal resistance input for with heat (50% Ethanol+50% Methanol) . It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 20 w , From 20 w to 25 w the thermal resistance increases, the reason may be that the condenser temperature exceeds the boiling temperature of (50% Ethanol+50% Methanol).

4.1.9 Working Fluid: 50% Ethanol + 50%Methanol (FR: 70%)

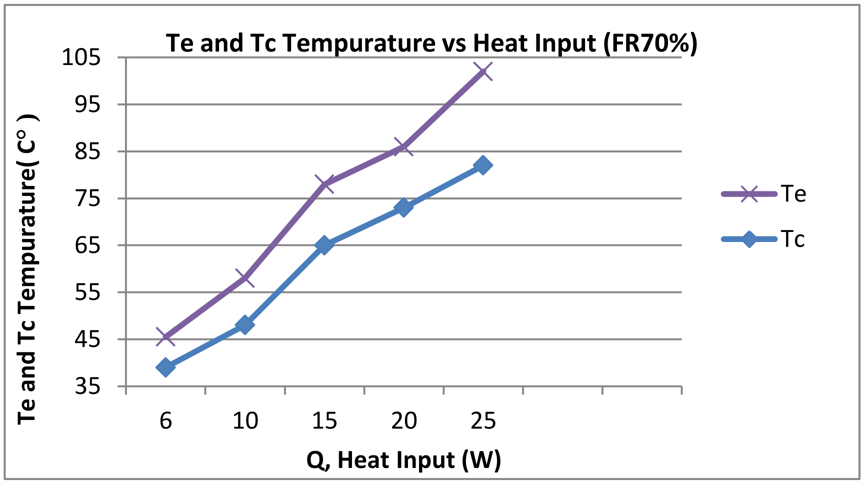

Fig: 4.17: *Evaporator temperature and Condenser temperature vs with heat input of (50% Ethanol+50% Methanol) fill ratio 70%*

Figure 4.17 shows the effect of different heat input on evaporation and condenser temperature taking (50% Ethanol+50% Methanol) at fill ratio 70%. it can be observed that the evaporation and condenser temperature increases highest rate from at 10 W to 15 W.

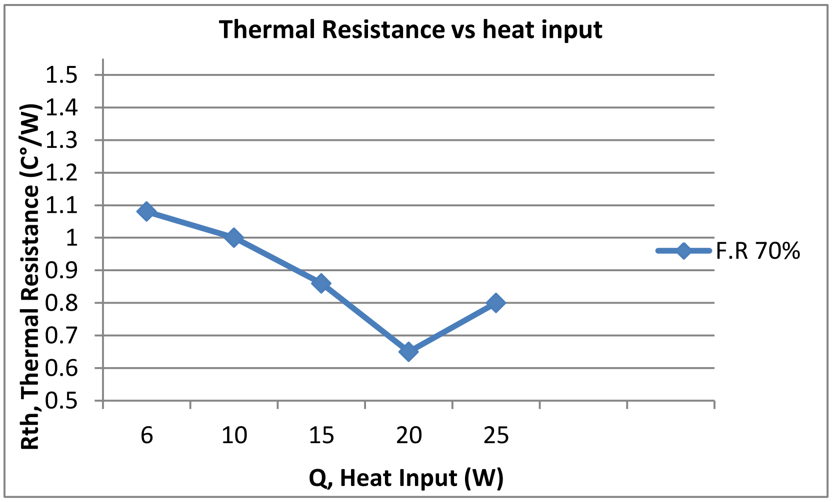

Fig: 4.18: *Effect of thermal resistance vs with heat input (50% Ethanol+50% Methanol) at filling ratio70%*

Figure 4.18 shows the effect of the thermal resistance input for with heat (50% Ethanol+50% Methanol) . It shows the effect of different heat on thermal resistance change. From this figure we can understand, the thermal resistance decreases rate high from 6w to 20 w , From 20 w to 25 w the thermal resistance increases, the reason may be that the condenser temperature exceeds the boiling temperature of (50% Ethanol+50% Methanol).

4.2 Effect of Mixture Liquid of Thermal Performance of CLPHP:

The effect of Mixture liquid (DI water, acetone and 50%Ethanol+50%Methanol) of thermal performance of different fill ratio (30%,50%and 70%) of close loop pulsing heat pipe in different heat input .The detailed description of in this chapter.

4.2.1 Filling Ratio:30%:

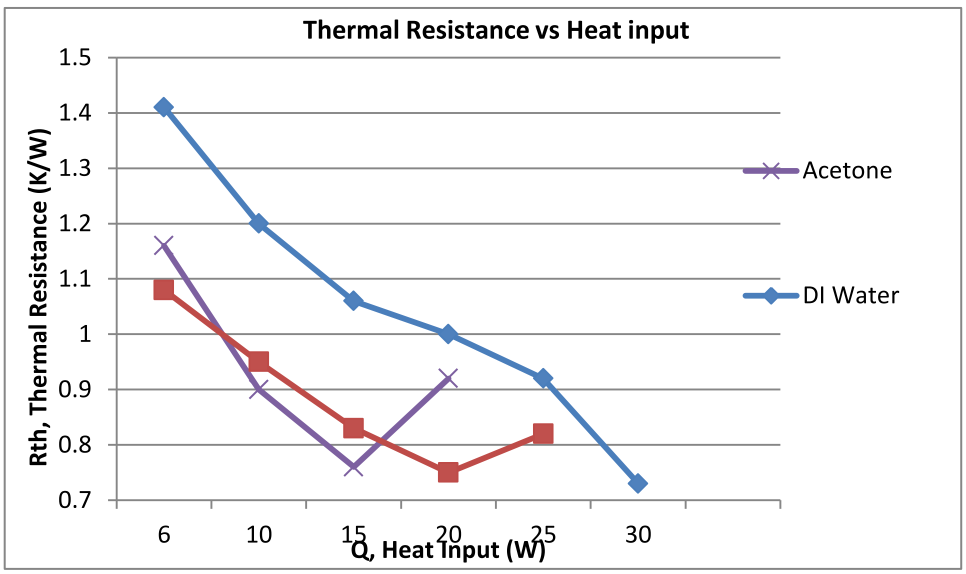

Fig: 4.19: *Effect of Acetone, DI water and (50%Ethanol +50%Methanol) Thermal Resistance vs with Heat Input at FR 30%.*

Figure 4.19 shows the effect of thermal resistance of acetone (50%ethanol+50%methanol) and distilled water with the increment of heat input each at fill ratio of 30%. We can see, for different fluids at 30% fill ratio, thermal resistance decreases with the increment of heat input. But, acetone and (50%ethanol+50%methanol) thermal resistance increases 15w and 20w ,the reason may be that the condenser temperature exceeds the boiling temperature this liquid.

4.2.2 Filling Ratio:50%

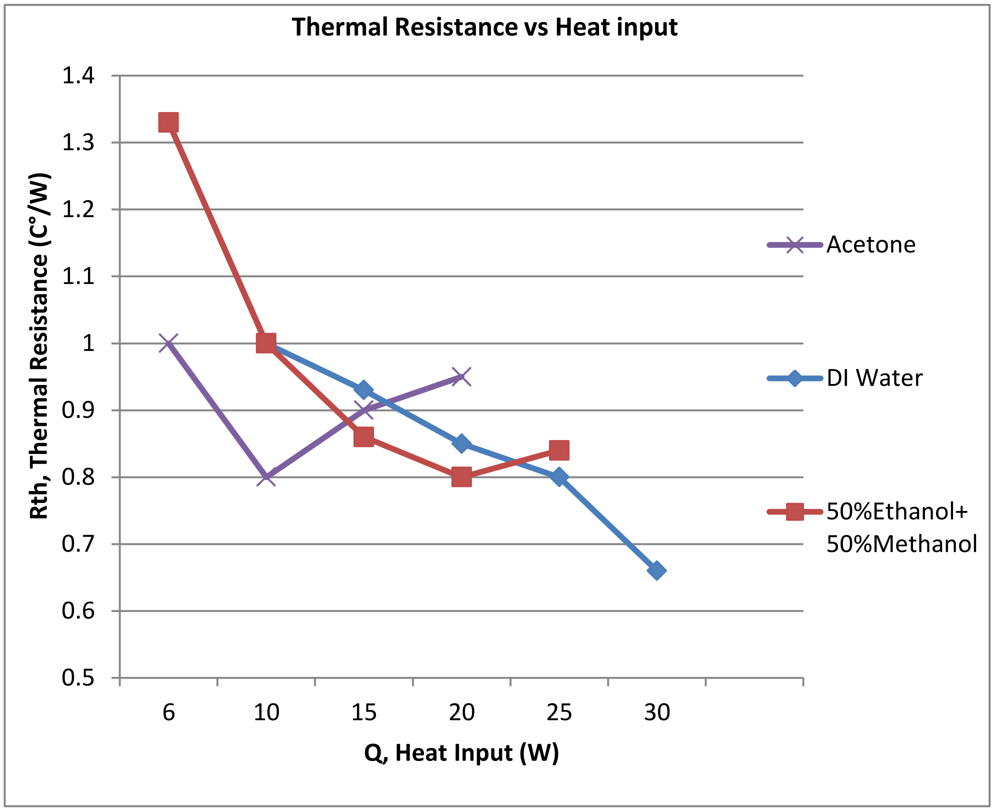

Fig: 4.20: *Effect of Acetone, DI water and (50%Ethanol +50%Methanol) Thermal Resistance vs with Heat Input at FR 50%.*

Figure 4.20 shows effect of thermal resistance of Acetone, DI water and (50%Ethanol +50%Methanol) at 50% fill ratio with the increment of heat input. At 50% fill ratio, acetone showed thermal resistances decreases from 6w to 10w,and after 10w, increases the thermal resistance. than that of (50%ethanol +50%methanol) thermal resistance decreases rate almost same from 10 W to 20 W and after that,(50%Ethanol +50%Methanol) showed more thermal resistance increases from 20 W to 30 W. the reason may be that the condenser temperature exceeds the boiling temperature (50%Ethanol +50%Methanol) .

4.2.3 Filling Ratio:70%

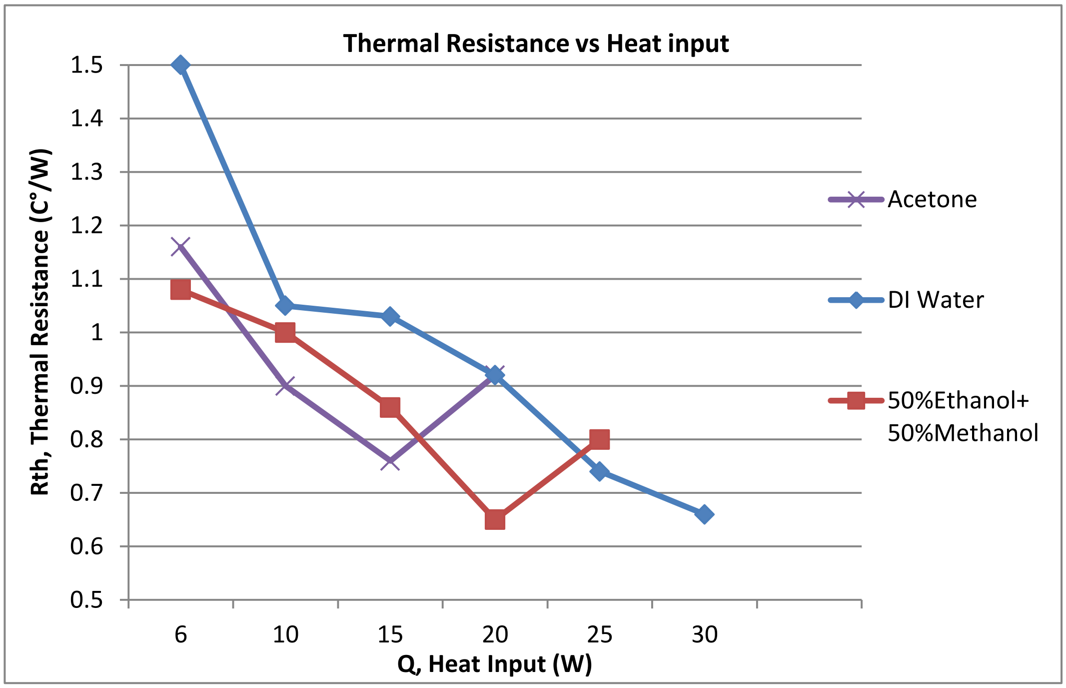

Fig: 4.21: *Effect of Acetone, DI water and (50%Ethanol +50%Methanol) Thermal Resistance vs with Heat Input at FR 70%.*

Figure 4.21 shows effect of thermal resistance of Acetone, DI water and (50%Ethanol +50%Methanol) at 70% fill ratio with the increment of heat input . this figure we can understand, the thermal resistance decreases rate high from 6w to 20 w , From 20 w to 25 w the thermal resistance increases, the reason may be that the condenser temperature exceeds the boiling temperature of (50% Ethanol+50% Methanol). From this figure we can understand, the thermal resistance decreases rate high from 6w to 10w , From 10 w to 30 w the thermal resistance decreases rate almost same of DI water. From this figure we can understand, the thermal resistance decreases rate high from 6w to 10 w , From 10 w to 20 w the thermal resistance increases , the reason may be that the condenser temperature exceeds the boiling temperature of acetone.

4.3 Applications of Heat pipe

Pulsating heat pipe is gaining more and more popularity, which due to their simple design, cost effectiveness and excellent thermal performance may find wide applications. a great deal of experimental studies indicated that the visualization technique combining the scrutiny investigated images of the flow patterns and the experimental data of heat transfer performance, contributed a lot to further understanding of the thermos-hydrodynamic mechanism within the PHPs. The characteristics of the start-up procedure and dry-out phenomena are presently the main research topics.

Heat pipes are one of the most effective procedures to transport thermal energy from one point to another. The idea behind is to create a flow field which transports heat energy from one spot to another by means of convection, because convective heat transfer is much faster than heat transfer due to conduction. Main application field of PHP might be:

- Electronics cooling
- Heat exchangers
- production tools
- medicine and human body temperature control
- engines and automotive industry
- Humidity control require
- Air reheated after cooling in traditional HVAC system
- Large quantities of ventilation air needed
- Laptop heat solution
- Solar thermal
- Pipeline over permafrost
- Cooking
- Nuclear power conversion
- Humidity control

CHAPTER 5
CONCLUSION

5.1 Conclusion

This study presents the new experimental data on heat transfer characteristics using close loop pulsating heat pipe (CLPHP). These works make use of the concept of heat enhancement to develop a design methodology. The application of the approach results in a simple quick and easy implementation of the methodology. The study on three working fluids at a wide range of filling ratio was promising and helped to understand ins and outs of the working principle of CLPHP. Although, this method helped us to understand the significance of positioning of heat pipe and working fluid used that govern the heat transfer characteristics, there is still need of further research to conclude the systems behavior with response to its effectiveness.

The following conclusions can be given from our experimental results:

a. Thermal resistance is the key to find the effectiveness of working fluids. Thermal resistance decreases with the increment of heat input. At lower heat input, decrement rate is higher and at higher heat input, decrement rate is lower. According to our experiment, $R_{th,\ \mathbf{acetone}} < R_{th,\ \mathbf{(50\%ethanol=50\%methanol)}} < R_{th,\ \mathbf{dw}}$. This condition is occurs up to 15 w and above the 15 w the thermal resistance of acetone is increased.

b. Evaporation temperature increases with the increment of heat input. According to our experiment.$T_{e,\mathbf{dw}} > T_{e,\mathbf{(50\%ethanol=50\%methanol)}} > T_{e,\mathbf{acetone}}$. Water has achieved higher evaporation temperature for higher specific heat. The lower is evaporation temperature, the more bubble formation at lower temperature which results in higher heat transfer. So methanol is better choice than the other two fluids.

c. The filling ratio is critical parameter ,which need to be optimized to achieve max. thermal performance and min. thermal resistance for operating condition. From this experimental set up we are conclude that at 70% filling of PHP give the optimum result.

5.2 Recommendations

Many practical and sophisticated mathematical models of the PHPs are expected to be proposed for theoretical analyses, in particular of the nonlinear behavior analytical method. Owing to the limitations of the two-phase flow theories, the mundane of the pulsating or oscillating flow behaviors and heat transfer mechanisms are required further development. Moreover, numerical simulations will definitely attract extensive attention with the fast development of supercomputers. Focusing our experiment, there are some recommendations for future development on CLPHP:

- Different working fluids, binary fluids and Nano fluids can be incorporated in this study for more effective and variable results. That will ensure the very best finding as a variety of fluids

- We used heat pipes made with copper. A more comprehensive thesis can be done using other materials to make the heat pipe i.e. stainless steel for more flexibility. In addition to that several alloys can be used and Biot number can be considered for more accurate result.

- Different angular orientation should be tested to get the results in various orientation.

- Our experiment was executed throughout the year. So different seasons affected room temperature. Room temperature should be controlled and atmospheric properties should be uniform for standard reading.

- A Computational Fluid Dynamics(CFD) analysis can be done to investigate the reasons of difference in thermal resistance and further improvement.

- Some more parameters like insert/wick structure as parameter, air velocity, heat pipe's pulsation orientation, number of loops etc can be applied in further research.

- The working environment should make more adiabatic to excessive avoid heat loss.

- Dry out mechanism is still unexplored at wide range which is required for further acceptance of this technology to be established more firmly.

- No experiments have been done with life-lasting of a CLPHP. So, continuous experiment should be run for years to understand the life cycle and working capabilities of a CLPHP.

REFERENCES

1. Azar K., The History of Power Dissipation, Electronics Cooling, Vol. 6, No. 1, 2000. Available at http://electronics-cooling.com/html/articles.html.

2. 'HEAT TRANSFER DEVICE' Patented in June 6, 1944 by Richard S. Gaugler, Dayton, Ohio; Patent No. US2350348 A.

3. S. Khandekar, Thermo-hydrodynamics of closed loop pulsating heat pipe, PhD thesis, Univ. of Stuttgart, Germany (2004).

4. Lin S., Sefiane K. and Christy J., Prospects of Confined Flow Boiling in Thermal Management of Microsystems, Applied Thermal Engg. Vol. 22, pp. 825-837, 2002.

5. 'Experimental Investigation On the Characteristics of a Closed Loop Pulsating Heat Pipe for Methanol On Different Conditions' by Zaimaa Salsabil, Nusrat Yasmin, Farah Nazifa Nourin.

6. Gi, K., Maezawa, K. Y., and Yamazaki, N., "CPU Cooling of Notebook PC by Oscillating Heat Pipe," Proceedings of the 11th International Heat Pipe Conference, Japan Association for Heat Pipes, Tokyo, Japan, 1999, pp.166–169.

7. Zuo, Z. J., North, M. T., and Ray, L., Combined Pulsating and Capillary Heat Pipe Mechanism for Cooling of High Heat Flux Electronics, Proc. ASME Heat Transfer Device Conference, pp.2237–2243, Nashville, Tennessee, USA, 1999.

8. Zuo, Z. J., North, M. T., and Wert, K. L., High Heat Flux Heat Pipes for Cooling of Electronics, IEEE Transactions on Components and Packaging Technologies, vol. 24, no. 2, pp. 220–225,2001.

9. Holley, B., and Faghri, A., Analysis of Pulsating Heat Pipe with Capillary Wick and Varying Channel Diameter, International Journal of Heat and Mass Transfer, vol. 48, pp. 2635– 2651,2005.

10. Akachi, H., Polasek, F., and Stulc, P., Pulsating Heat Pipes, Proc. 5th International Heat Pipe Symposium, pp. 208–217, published in a conference held in Melbourne, Australia, 1996.

11. Miyazaki, Y., and Akachi, H., "Self Excited Oscillation of Slug Flowin a Micro Channel," Proceedings of the 3rd International Conference on Multiphase Flow, Lyon, France, 1998.

12. Miyazaki, Y., and Arikawa, M., "Oscillatory Flow in the Oscillating Heat Pipe," Proceedings of the 11th International Heat Pipe Conference, Japan Association for Heat Pipes, Tokyo, Japan, 1999, the identification number for the paper is: pp. 131– 136.

13. Lee,W. H., Jung,H. S., Kim, J. H., and Kim, J. S., "Flow Visualization of Oscillating Capillary Tube Heat Pipe," Proceedings of the 11th International Heat Pipe Conference, Japan Association for Heat Pipes, Tokyo, Japan, 1999, pp. 131–136.

14. S. Khandekar, P. Charoensawan, M. Groll, P. Terdtoon, Closed loop pulsating heat pipes, Part. B: visualization and semi-empirical modelling, Appl. Therm. Eng. 23 (2003) 2021- 2033.

15. P. Charoensawan, S. Khandekar, Manfred Groll, and PraditTerdtoon "Closed loop pulsating heat pipes Part A: parametric experimental investigations". The paper was published in Applied Thermal Engineering 23 (2003) 2009–2020.

16. Zhang, Y., Faghri, A. and Shaffi, M. B., "Analysis of Liquid–Vapor Pulsating Flow in a U Shaped Miniature Tube," International Journal of Heat and Mass Transfer, Vol. 45, No. 12,2002, pp. 2501–2508.

17. Mamelli M., Marengo M. and Zinna S., Numerical model of a multi-turn Closed Loop Pulsating Heat Pipe: Effects of the local pressure losses due to meanderings, Journal of Heat and Mass Transfer, 55, 1036–1047, (2011).

Appendix: A

Distilled Water

Table A.1: *Variation of Thermal Resistance with Power Input (Distilled Water)*

Q (W)	0%	30%	50%	70%
6	1.08	1.41	1.33	1.5
10	1	1.2	1	1.05
15	0.93	1.06	0.93	1.03
20	0.7	1	0.85	0.92
25	0.6	0.92	0.8	0.74
30	0.56	0.73	0.66	0.66

Table A.2: *Variation of Evaporation Temperature with Power Input (Distilled Water)*

Q (W)	0%	30%	50%	70%
6	40	51.5	50	48
10	50	60	59	59
15	70	74	75	76.5
20	79	88	90	89
25	82	103	102	105.5
30	94	110	119	119

Table A.3: *Variation of Condensation Temperature with Power Input (Distilled Water)*

Q (W)	0%	30%	50%	70%
6	33.5	43	42	39
10	40	48	49	48.5
15	56	58	61	61
20	65	68	73	70.5
25	67	80	82	87
30	77	88	99	99

Table A.4: *Variation of Adiabatic Temperature with Power Input (Distilled Water)*

Q (W)	0%	30%	50%	70%
6	37.5	46.5	46.5	44.5
10	49	55.5	55.5	51.5
15	64	68.5	68.5	66.5
20	73	77	77	82
25	81	90	90	92
30	95.5	100	100	103

50%Ethanol+ 50%Methanol

Table A.5: *Variation of Thermal Resistance with Power Input (50%Ethanol+50%Methanol)*

Q (W)	0%	30%	50%	70%
6	1.08	1.08	1.33	1.08
10	1	0.95	1	1
15	0.93	0.83	0.86	0.86
20	0.7	0.75	0.8	0.65
25	0.6	0.82	0.84	0.80
30	0.56			

Table A.6: *Variation of Evaporation Temperature with Power Input (50%E+50%M)*

Q (W)	0%	30%	50%	70%
6	40	46	46	45.5
10	50	57	58	58
15	70	74.5	76	78
20	79	87	88	86
25	82	103.5	104	106

Table A.7: *Variation of Condensation Temperature with Power Input (50%E+ 50%M)*

Q (W)	0%	30%	50%	70%
6	33.5	39.5	40	40.5
10	40	47.5	48	48
15	56	62	63	65
20	65	72	72	73
25	67	95	96	98

Table A.8: *Variation of Adiabatic Temperature with Power Input (50%E+50% M)*

Q (W)	0%	30%	50%	70%
6	37.5	43.5	45.5	42.5
10	49	50.5	52	54
15	64	64.5	66.5	67
20	73	75	74.5	75
25	81	89	90	91
30	95.5			

Acetone

Table A.9*: Variation of Thermal Resistance with Power (Acetone)*

Q (W)	0%	30%	50%	70%
6	1.08	1.16	1	1.08
10	1	0.9	0.8	0.9
15	0.93	0.76	0.9	0.86
20	0.7	0.92	0.95	0.92
25	0.6			
30	0.56			

Table A.10: *Variation of Evaporation Temperature with Power (Acetone)*

Q (W)	0%	30%	50%	70%
6	40	47	46	46.5
10	50	57	55	57
15	70	71	70	70
20	79	85	84	85.5

Table A.11: *Variation of Condensation Temperature with Power Input (Acetone)*

Q (W)	0%	30%	50%	70%
6	33.5	40	40	40
10	40	48	47	48
15	56	56.5	56.5	57
20	65	75	75	76

Table A.12: *Variation of Adiabatic Temperature with Power Input (Acetone)*

Q (W)	0%	30%	50%	70%
6	37.5	44.5	43.5	43.5
10	49	50	49	51.5
15	64	67	64	68
20	73	74	75	77
25	81			
30	95.5			