CHAPTER - 1

INTRODUCTION

1.1 History

The advancement of modern society, the need for miniaturization and compactness has increased. Entire human civilization now opts for smart and convenient devices that are easy to carry and user friendly. Everyday latest versions of existing electronics are being launched and new designs are being fabricated. This has brought the present society face to face with problems of high-power dissipation and heat density. Market demand for efficient microelectronics has posed the challenge of thermal management of increased power levels coupled with high heat fluxes.

To mitigate and solve this problem of power electronics, the use of liquid-vapor phase change cooling devices such as the heat pipes, have been introduced. Although the conventional heat pipes (e.g. mini or micro) are one of the proven technologies, the manufacturing of the complex, miniaturized wick structure/geometry of these heat pipes could become the most cost intensive factor. Another common limitation is the capillary limit, which occurs when the wick structure cannot return an adequate amount of liquid back to the evaporator.

With a view to overcome these difficulties researchers have come up with pulsating heat pipes (PHP) which work on the principle of oscillation of the working fluid and phase change phenomenon in a capillary tube. PHP is a meandering tube of capillary dimensions with many turns filled partially with a suitable working fluid with no wick structure. PHPs are passive two-phase thermal control devices first introduced by Akashi et al [1-4]. In this application, reduced diameter channels are used, which are directly influenced by the selected working fluid. The vapor plugs generated by the evaporation of the working fluid push the liquid slugs toward the condensation section and this motion causes flow oscillations that guide the device operation [5].
Performance of a PHP depends upon many factors like the geometrical parameters of flow channel, the working fluid, the filling ratio, and number of turns, PHP configuration and the inclination angle [5]. The purposes of this investigation are to study the heat transfer characteristics of a CLPHP and evaluate several issues related to its performance.

There are many engineering practical situations where heat is being transferred under conditions of pulsating and reciprocating flow such as the operation of modern power producing facilities and industrial equipment used in metallurgy, aviation, chemical and food technology. Cavitation's in hydraulic pipelines, pressure surges and flow of blood are also some of familiar instance of such flows. The performance of this equipment in thermal engineering applications is affected by the pulsating flow parameters (Al-Had-dad and Al- Binally, 1989). During the past few decades, numerous studies have been devoted to this pulsating flow and its associated heat transfer problems. A review of these studies with emphases on the onset of turbulence, velocity distribution and pipe flow as well as the heat transfer characteristics including axial heat transfer enhancement and convective heat transfer are presented in the following section.

1.2 Block Diagram

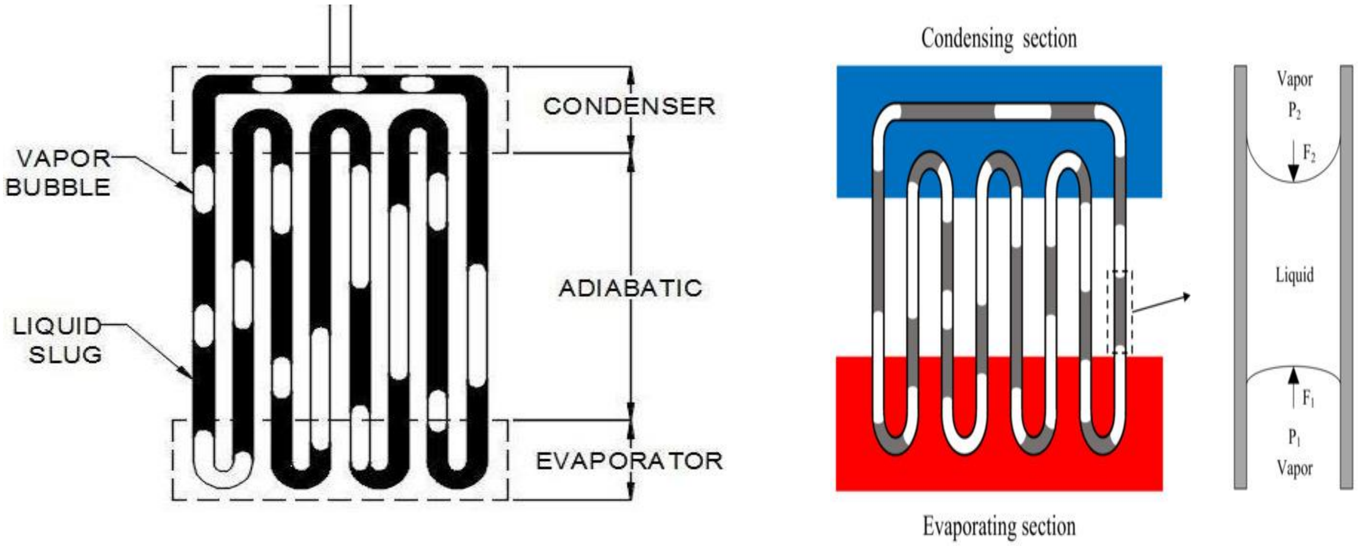


Fig 1.1: Block diagram of CLPHP

1.3 Objectives

This thesis work is designed with an aim with following objectives:

- To analysis the performance of the normal device.
- To compare the thermal resistances of the system with different working fluid with different filling ratios.
- To understand the different operational regimes of closed loop pulsating heat pipe.
- To determine optimum condition for the working fluid to be used in commercial basis in heat pipes for heat transfer and cooling applications.
- To determine the most efficient and beneficial working range of the device for which fluid and which inclination, maximum possible desired results can be obtained.

CHAPTER - 2

LITERATURE REVIEW

2.1 Heat Pipe

Heat pipes are hollow metal pipes filled with a liquid coolant that moves heat by evaporating and condensing in an endless cycle. It combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces.

As the lower end of the Heat pipe is exposed to heat, the coolant within it starts to evaporate, absorbing heat. As the coolant turns into vapor, it, and its heat load, convection within the heat pipe. The reduced molecular density forces the vaporized coolant upwards, where it is exposed to the cold end of the Heat pipe. The coolant then condenses back into a liquid state, releasing the latent heat. Since the rate of condensation increases with increased delta temperatures between the vapor and Heat pipe surface, the gaseous coolant automatically streams towards the coldest spot within the Heat pipe. As the coolant condenses, and its molecular density increases once more, gravitational forces pull the coolant towards the lower end of the Heat pipe. To aid this coolant cycle, improve its performance, and make it less dependent on the orientation of the Heat pipe towards earth gravitational center, modern Heat pipes feature inner walls with a fine, capillary structure. The capillary surfaces within the Heat pipe break the coolants surface tension, distributing it evenly throughout the structure. As soon as coolant evaporates on one end, the coolants surface tension automatically pulls in fresh coolant from the surrounding area. As a result of the self-organizing streams of the coolant in both phases, heat is actively convection through Heat pipes throughout the entire coolant cycle, at a rate unmatched by solid Heat spreaders and Heat sinks.

Heat pipes enable passive cooling solutions for high heat load and high temperature equipment, lacking moving parts and boasting extraordinary lifetimes as a result. The idea of heat pipe was given by Gaugler [6] from General Motors. 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 [6] 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.

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.

2.2 Closed Loop Pulsating Heat Pipe

Closed pulsating is a new addition to the heat pipe family. The principle difference is that CLPHP has no wick structure. This enable the working fluid to transfer heat by formation and collapse of vapor bubbles. The vapor formed at the evaporator is pushed towards the condenser in the form of discrete vapor bubbles among packets of fluid at the condenser. At the condenser the vapor gets condensed and releases the latent heat of vaporization and returns to the evaporator to complete the cycle. The entire essence of thermo-mechanical physics lies in the closed (constant volume), two- phase, and bubble–liquid slug system formed inside the tube-bundle due to the dominance of surface tension forces.

These can be divided into 3 groups at least: (a) closed loop PHP (CLPHP); (b) CLPHP with check valves; (c) open loop PHP (OLPHP), also called closed end PHP (CEPHP). It is simple in structure with a coil of capillary tubes filled with certain working fluid in it and extended from the heat source to sink. Unlike a conventional heat pipe, PHP having no wick structure prevents the condensate from returning to the evaporator section. PHP works on the principle of fluid pressure oscillations created by means of differential pressure across vapor plugs from evaporator to condenser and back [7].

2.3 Operation features

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.

Consider a case when a PHP is kept isothermal throughout, say at room temperature. In this case, the liquid and vapor phases inside the device must exist in equilibrium at the saturated pressure corresponding to the fixed isothermal temperature. Referring to the pressure- enthalpy diagram, the thermodynamic state of all the liquid plugs, irrespective of their size and position, can be represented by point A. Similarly point B represents the thermodynamic state of all the vapor bubbles present in the PHP.

Suppose the temperature of the entire PHP structure is now quasi-statically increased to a new constant value. Then the system will again come to a new equilibrium temperature and corresponding saturation pressure, point A" and point B". In doing so, there will be some evaporation mass transfer from the liquid until equilibrium is reached again. A similar phenomenon will be observed if the system is quasi-statically cooled to a new equilibrium condition A" and B" (exaggerated representation for clarity).

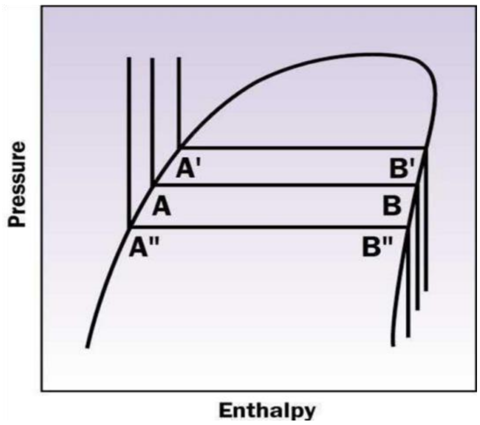


Fig 2.1: Pressure Vs Enthalpy Graph

In an actual working PHP, there exists a temperature gradient between the evaporator and the condenser section. Further, inherent perturbations are always present in real systems as a result of:

- Pressure fluctuations within the evaporator and condenser sections due to the local non uniform heat transfer always expected in real systems.
- Unsymmetrical liquid-vapor distributions causing uneven void fraction in the tubes.
- The presence of an approximately triangular or saw-tooth alternating component of pressure drop superimposed on the average pressure gradient in a capillary slug flow due to the presence of vapor bubbles.

The net effect of all these temperature gradients within the system is to cause non-equilibrium pressure condition which, as stated earlier, is the primary driving force for thermo-fluidic transport. As shown in upper figure, heating at the evaporator continuously tries to push point

2.4 Evolution of PHP

Pulsating Heat Pipes (PHPs) has been the subject of research in an increasing number of laboratories in the recent times. PHPs were presented in 1971 by Smyrnov in a Russian Patent and in 2003 in a U.S. patent. PHP in the form as they are investigated today have been first proposed by Akachi [1-4] in the 1990.

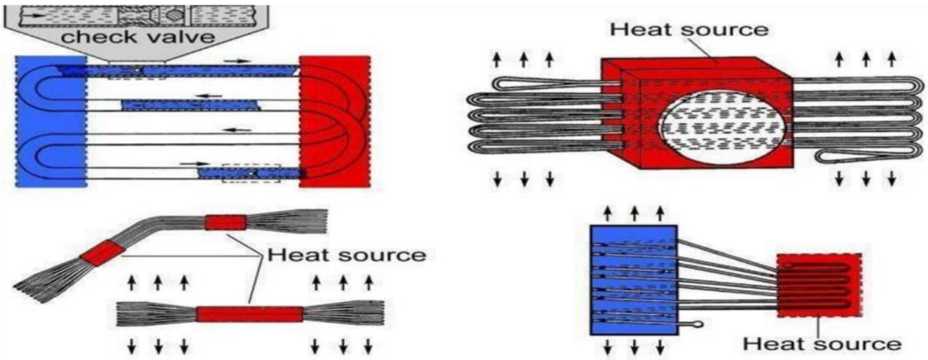


Fig 2.2: Earlier versions presented of heat pipe by Akachi

P. Charoensawan et.al [8]; has a work on effect to CLPHP thermal performance depends on various parameter like internal diameter of tube, number of turns, working fluid and inclination angle of the device and experimentally studied. The conclusion of P. Charoensawan's 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.

Honghai Yang et.al. [9] Presented a paper on experimental study on the operational limitation of closed loop pulsating heat pipes (CLPHPs). Investigated, viz. vertical bottom

Flux on thermal performance and performance limitation were investigated. The CLPHPs were operated till a performance limit characterized by serious evaporator overheating (dry- out) occurred. Rather high heat loads could be accommodated. An experimental study was performed on two closed loop pulsating heat pipes (CLPHPs) to investigate the effects of inner diameter, filling ratio, operational orientation and heat load on thermal performance and occurrence of performance limitation in the form of evaporator dry-out. In general, the CLPHPs obtain the best thermal performance and maximum performance limitation when they operate in the vertical bottom heat mode with 50% filling ratio. As the inner diameter decreases, performance differences due to the different heat modes (i.e. the effect of gravity) become relatively small and even insignificant. The effect of inner diameter and inclination angles on operation limit of a closed loop oscillating heat pipes with check valves (CLOHP/CV) were studied in this paper. Copper tubes of ID 1.77 and 2.03 mm with 4 turn, with R123 was used as the working fluid. The inclination angles were 0°.

P. Meena et al. [10] were concluded that when the inner diameter changed from 1.77-2.03 mm the critical temperature increased. And when increase the inclination angles from 0 until to 90° the critical temperature increased.

S. Rittidech et.al. [11] a visualization study of the internal flow patterns of a closed–loop oscillating heat-pipe with check valves (CLOHP/CV) at normal operating condition for several evaporator lengths (Le), and ratio of check valves to number of turns (Rcv) has been conducted. This article describes the effects of varying Le, and Rcv on flow patterns. It was found that the internal flow patterns could be classified according to the Le and Rcv as follows: At the high heat source when the Le decreases the main flow changes from the bubble flow with slug flow to disperse bubble flow. The Rcv decreases the main flow changes from the disperse bubble flow with bubble flow to disperse bubble When the velocity of slug increases, the length of vapor bubbles rapidly decreases and the heat flux rapidly increases. The ratio of check valves to number of turns decreases the main flow changes from the dispersed bubble flow with bubble flow to disperse bubble flow for the high heat source.

P. Meena, et.al. [12] Has aims to study the effect of evaporator section lengths and working fluids on operational limit of closed loop oscillating heat pipes with check valves (CLOHP/CV). It is experimentally concluded when the evaporator lengths increased the critical heat transfer flux decreased. There was working fluids change from R123 to Ethanol and water the critical heat flux decreased. The latent heat of vaporization affects the critical heat flux. The working fluid with the lower latent heat of vaporization exhibits a higher critical heat flux.

Stéphane Lips Ahlem Bensalem et al. [13] various experiments were conducted on two fullsize pulsating heat pipes (PHP) which differed from their diameter, number of turns, and working fluid. The analysis of the experimental results for low heat fluxes the PHP performance is sensitive to the orientation and for high heat fluxes, it is independent from the orientation. The experiments were conducted at the scale of a single branch of a PHP. The test section was either adiabatic or heated. The adiabatic experiments brought to therefore the importance of dynamic contact angles in the flow and the dissymmetry between the

N. Panyoya et al. [14] the purpose of this research was to determine the effects of aspect r ratios (ratio of evaporator length to the inner diameter of tube) and number of meandering turns on performance limit of an inclined closed-loop oscillating heat pipe. The geometrical sizes, which were the variable parameters were the internal diameter, the evaporator section length of, the adiabatic and condenser section length of each set was equaled to the evaporator length and the numbers of meandering turn and also variable inclination angles adjusted by 10°.The result indicated that the aspect ratio, the ratio of evaporator length by internal diameter and number of meandering turns significantly affect the maximum heat flux and inclination angle. The effects of aspect ratios and number of meandering turns on maximum heat flux of an inclined CLOHP have been thoroughly investigated in this study. In the case of aspect ratio, it can be seen that, the highest maximum heat flux occurs at inclination angle about 70-90° and lower value of aspect ratio. In the case of number of meandering turns, it can be seen that, when number of meandering turns increases, number of meandering turns does not affect to the maximum heat flux. In the case of inclination angle, it can be seen that, when the inclination angle increases from 0-90°, the maximum heat flux increases with respect to increasing numbers of tubes. Moreover, the highest maximum heat flux occurs at vertical position to about 70°. P. Sakulchangsatjatai et al. [15] this research studies the effect of length ratios on heat transfer characteristic of Closed Loop Oscillating Heat Pipe with Non-Uniform Diameter (CLOHP/NUD) i.e. inner diameter of capillary tube were alternated connection and bent into several numbers of turns and both ends were connected to form of loop. It was found that, the CLOHP/NUD transferred higher heat than the conventional Closed Loop Oscillating Heat Pipe (CLOHP) with the same heat transfer area because the working fluid flowed in only one direction. Working fluid moved to condenser section in larger inner diameter and returned to evaporator section in smaller inner diameter. The heat transfer performance of CLOHP/NUD can be improved if one directional circulation of working fluid can be induced. The effects of length ratios and working fluids on the heat performance of CLOHP/NUD have been experimentally investigated and conclude heat flux increased when the length ratio decreased.

2.5 Heat Pipe Materials and Working Fluids

Heat pipes have an envelope, a wick, and a working fluid. Heat pipes are designed for very long-term operation with no maintenance, so the heat pipe wall and wick must be compatible with the working fluid. Some material/working fluids pairs that appear to be compatible are not. For example, water in an aluminum envelope will develop large amounts of non- condensable gas over a few hours or days, preventing normal operation of the heat pipe.

Since heat pipes were rediscovered by George Grover in 1963, extensive life tests have been conducted to determine compatible envelope/pairs, some going on for decades. In a heat pipe life test, heat pipes are operated for long periods of time, and monitored for problems such as non- condensable gas generation, material transport, and corrosion. The most commonly used envelope (and wick)/fluid pairs include:

- Copper envelope/Water working fluid for electronics cooling. This is by far the most common type of heat pipe.
- Copper or Steel envelope/Refrigerant R134a working fluid for energy recovery in HVAC systems

- Aluminum envelope/Ammonia working fluid for Spacecraft Thermal Control
- Super alloy envelope/Alkali Metal (Cesium, Potassium, Sodium) working fluid for high temperature heat pipes, most commonly used for calibrating primary temperature measurement devices

Other pairs include stainless steel envelopes with nitrogen, oxygen, neon, hydrogen, or helium working fluids at temperatures below 100 K, copper/methanol heat pipes for electronics cooling when the heat pipe must operate below the water range, aluminum/ethane heat pipes for spacecraft thermal control in environments when ammonia can freeze, and refractory metal envelope/lithium working fluid for high temperature (above 1050 °C) applications.

CHAPTER 3

METHODOLOGY

3.1 General Aspect

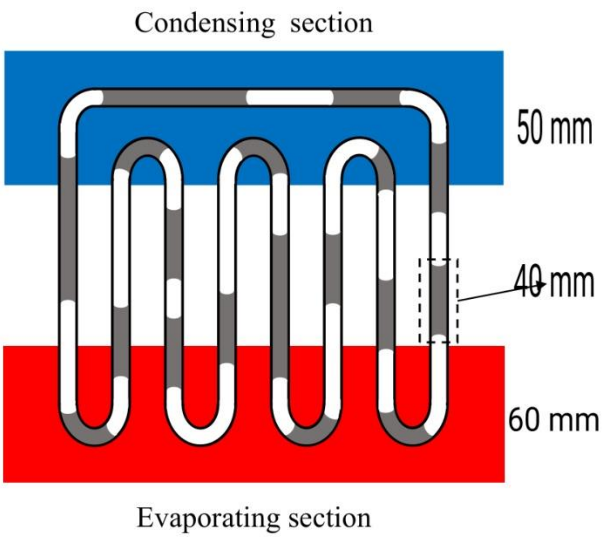
An experimental facility has been designed, fabricated and installed to collected data for this research. The detailed description of experimental apparatus and experimental procedure are presented in this chapter.

Thus, apparatus used in this experiment are-

- Normal structure
- Propanol
- Ethanol
- Butanol
- Aceton
- Test stand (Chassis)
- Variable power supply (Variac)
- Nichrome Wire
- Thermocouple (LM35)
- Watt Meter
- Digital Thermometer Display
- Selector Switch
- Mica tape
- Aluminum foil
- Glass wool
- Foam tape
- Silicon Tube
- Soldering Iron
- Filler Metal
- Inserted wire (Copper)
- AC fan (220V)
- Glue Gun
- Electric Wire
- Syringe 5ml

3.2 View of experimental setup

Fig 3.1: Experimental set-up



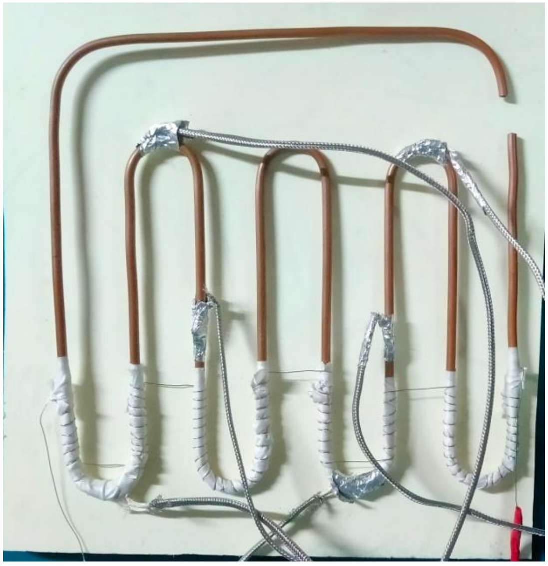


Fig 3.2: Experiment Design/ Normal Structure

Fig 3.3: Actual experimental structure.

3.3 Pulsating Heat Pipe

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

- Evaporator section
- Adiabatic section
- Condenser section

In this research was conducted taking normal structure, and structure with fin. The fin was attached to the outer surface of the adiabatic section. This has increased the heat transfer surface.

For this experiment heat pipe with insert of copper wire was also done. The insert was tested and new result was found out. Shows the different cross sections of the heat pipe with insert.

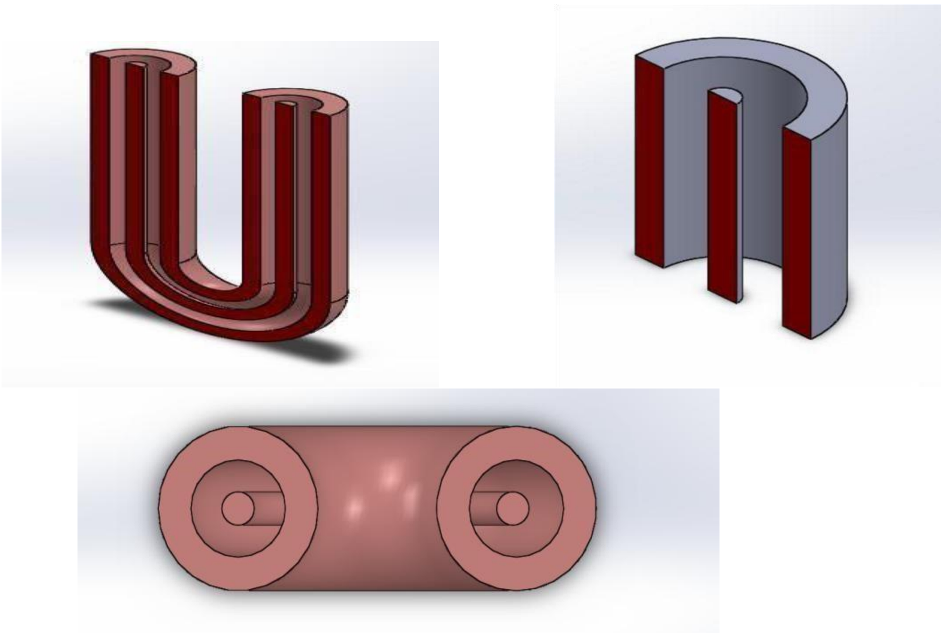


Fig 3.4: Different cross section of CLPHP with insert fin

3.3.1 Evaporator Section

In the evaporator section of the heat pipe the working fluid absorbs heat from the heat source. It is located on the bottom section of the heat pipe. Heat is supplied to the heat pipe using Nichrome wire connected to a variable power supply. The Nichrome wire is wound around the pipes in the evaporator section on top of a layer of mica tape. The mica sheet prevents direct contact of copper tube with Nichrome wire to prevent any possibility of short circuitconnection. The evaporator section is further enveloped by asbestos sheet to reduce heat loss to the environment.

3.3.2 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. The part of the tube in adiabatic section is wound with aluminum foil, glass wool and finally covered with heat insulating tape to prevent heat transfer to the surrounding environment.

3.3.3 Condenser Section

It is the section of the heat pipe where heat is rejected from the working fluid to the surrounding. In this section, the working fluid condenses & rejects the same amount of heat which is absorbed from the evaporator section. In this experiment, this section is located on upper section of the heat pipe and a DC fan help dissipation of heat continually.

Parameters	Condition
Inner diameter (without insert)	2.0 mm
Outer diameter (without insert)	3.0 mm
Inner diameter (with insert)	2.5 mm
Outer diameter (with insert)	3.5 mm
Insert wire diameter	0.5 mm
Length of evaporator section	50 mm
Length of adiabatic section	40/120 mm
Length of condenser section	60/80 mm
Total length	150/250 mm
Material	Copper

TABLE 3.1: EXPERIMENTAL COMPONENT PARAMETER AND DIMENSIONS

3.4 Working Fluid

Here is the use of Propanol, Ethanol, Butanol & Acetone as a working fluid.

3.4.1 Propanol

Fig 3.5: Propanol

Propan-1-ol (also **propanol**, **n-propyl alcohol**) is a primary alcohol with the formula $CH_3CH_2CH_2OH$ and sometimes represented as **PrOH** or ***n*-PrOH**. It is a colorless liquid and an isomer of 2-propanol. It is formed naturally in small amounts during many fermentation processes and used as a solvent in the pharmaceutical industry, mainly for resins and cellulose esters, and, sometimes, as a disinfecting agent..

Sl. No.	Parameters	Symbol	Quantity	Unit
1.	Freezing temperature	T_{freeze}	-88.33	°C
2.	Boiling temperature	T_{boil}	82.6	°C
3.	Density (at 20°C)	P	786	kg/m^3
4.	Specific heat (at 20°C)	C_p	2.47	kj/kg-K
5.	Vapor pressure	Pv	2.7	kpa
6.	Molar mass	Ms	58.08	g/mol

TABLE 3.2: PROPERTIES OF ETHANOL

3.4.2 Ethanol

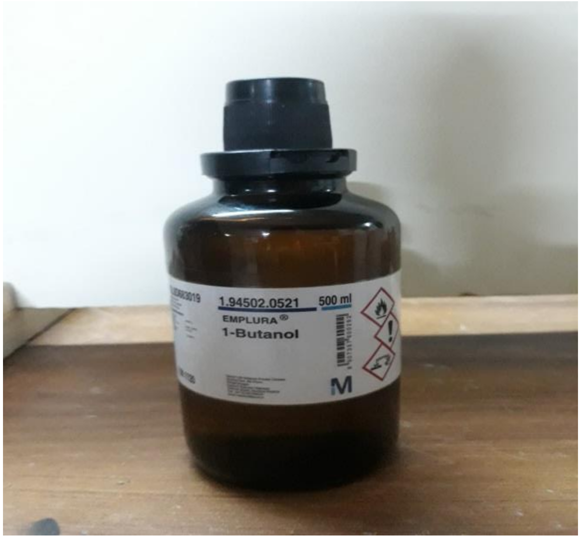
Fig 3.6: Ethanol

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 CH3CH2OH, is often abbreviated as C2H5OH or C2H6O.

Sl. No.	**Parameters**	**Symbol**	**Quantity**	**Unit**
1.	Freezing temperature	T_{freeze}	-114.1	°C
2.	Boiling temperature	T_{boil}	78.37	°C
3.	Density	P	789	kg/m^3
4.	Specific heat (at 20°C)	C_p	2.47	kj/kg-K
5.	Vapor pressure	Pv	5.95	kpa
6.	Molar mass	Ms	46.07	g/kg

TABLE 3.2: PROPERTIES OF ETHANOL

3.4.3 Butanol



3.7: Butanol

1-Butanol, also known as butan-1-ol or *n*-butanol, is a primary alcohol with the chemical formula C_4H_9OH and a linear structure. Isomers of 1-butanol are isobutanol, butan-2-ol and *tert*-butanol. The unmodified term butanol usually refers to the straight chain isomer.

Sl. No.	**Parameters**	**Symbol**	**Quantity**	**Unit**
1.	Freezing temperature	T_{freeze}	25.82	°C
2.	Boiling temperature	T_{boil}	118	°C
3.	Density	P	810	kg/m^3
4.	Specific heat (at 25°C)	C_p	2.351	kj/kg-K
5.	Vapor pressure	Pv	6.5	Kpa
6.	Molar mass	Ms	74.122	g/mol

TABLE 3.2: PROPERTIES OF ACETONE

3.4.4 Acetone

Acetone is an organic compound with the formula (CH3)2CO. It is the simplest and smallest ketene. It is a colorless, highly volatile and flammable liquid with a characteristic pungent odor. Also a colorless volatile flammable pungent liquid, miscible with water, used in the manufacture of chemicals and as a solvent and thinner for paints, varnishes, and lacquers. Formula: CH_3COCH_3

Fig 3.8: Acetone

Sl. No.	**Parameters**	**Symbol**	**Quantity**	**Unit**
1.	Freezing temperature	T_{freeze}	0	°C
2.	Boiling temperature	T_{boil}	9.97	°C
3.	Density	P	1000	kg/m^3
4.	Specific heat (at 25°C)	C_p	4.184	kj/kg-K
5.	Vapor pressure	Pv	1	kpa
6.	Molar mass	Ms	18.02	g/mol

TABLE 3.2: PROPERTIES OF DI WATERE

3.5 Test Stand

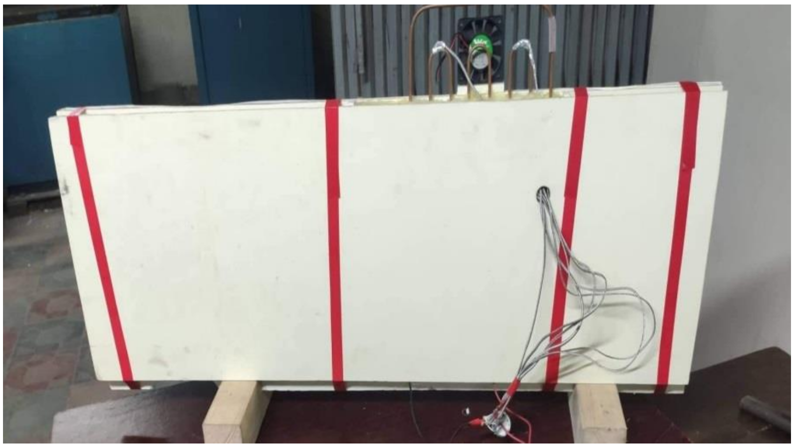


Fig 3.9: Test Stand

The test stand is a steel structure. The whole structure is supported by two columns which is situated in a large PVC base.

3.6 Heating Apparatus

Heating apparatus can be used to transfer heat. It is used for heat transfer from one place to another

3.6.1 Variable power supply

3.10: Variable power supply

Variable power supply provides variable voltage to run different types of operations or the operation that requires different voltage in times. We used voltages ranges from 20-60 volts by this power source. It is connected to the power supply unit to provide variable power (heat input) by varying voltage output.

Phase	3ϕ
Rated capacity	300 volt
Rated frequency	60 Hz
Input voltage	220 volt

TABLE 3.4: VARIABLE POWER SUPPLY SPECIFICATION

3.6.2 Nichrome wire

Fig 3.11: Nichrome Wire

Nichrome wire is an alloy typically made of 80 percent nickel and 20 percent chrome. Because of Nichromewire‟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.

3.6.3 K Type Thermocouple (LM35)

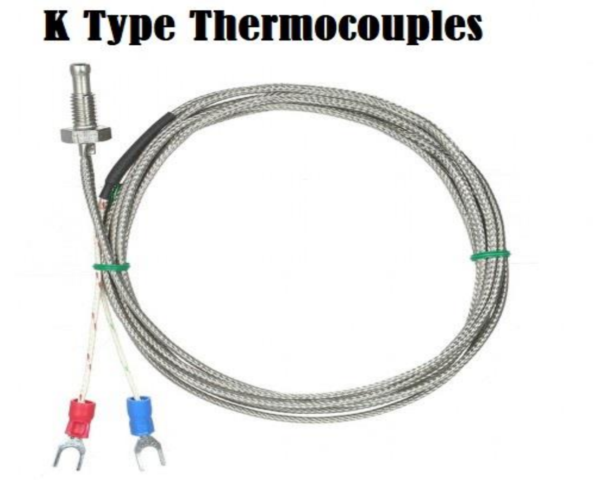


Fig 3.16: LM35

The LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature.

A total number of 6 thermocouples are glued to the wall of pulsating heat pipe; 2 for evaporator section 2 for adiabatic and the rest 2 for condenser section. They are calibrated and connected to different sections of heat pipe for measuring temperature. These thermocouples are Type K (Chromel/Alumel). It is General purpose thermocouple. It is low cost and, owing to its popularity, available in a wide of probes.

We used lm35 as our preferred temperature sensor as-

- It can measure temperature more accurately than a using a thermistor.
- The sensor circuitry is sealed and not subject to oxidation, etc.
- The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified.
- From overall perspective, we thought about lm 35 as it is cheap in price and effective.
- It has an output voltage that is proportional to the Celsius temperature. The scale factor is .01V/°C

- The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4 °C at room temperature and +/- 0.8 °C over a range of 0 °C to +100 °C.
- Another important characteristic of the LM35DZ is that it draws only 60 micro amps from its supply and possesses a low self-heating capability. The sensor self-heating causes less than 0.1 °C temperature rise in still air.

3.7 Insulating Materials

Material that is used to stop the passage of electricity, heat, or sound from one conductor to another

3.7.1 Mica Tape

Fig 3.12: Mica Tape

The term "mica" is used for a group of minerals that show perfect cleavage. Mineralogically speaking, 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 thermal and electrical characteristic, mainly in:

- Electrical and thermal insulation of electrical machines
- Thermal insulation of equipment that is subject to extremely high temperatures, such as induction ovens
- Insulation of cable for fire resistance

3.7.2 Aluminum Foil

Fig 3.13: Aluminum Foil

For the insulation of pulsating heat pipe, aluminum foil tape is used. It resists flame, moisture, temperature extremes, UV exposure and most chemicals with a backing that withstands harsh environments. We used metal-backed foil tapes with the conformability to wrap tightly around virtually any shape or contour. With the used of this aluminum foil tape, we managed to resist heat loss during temperature measurement in different voltage was in run.

3.7.3 Glass wool

Fig 3.14: Glass wool

Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties. It reduces the heat loss and is used as insulator

3.7.4 Heat insulating Foam Tape

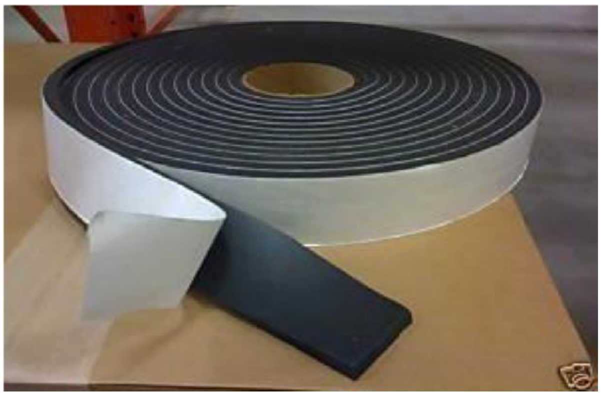


Fig 3.15: Foam tape

This is used as a heat insulator and the adhesive side of the tape helps to bind the glass wool in the adiabatic section

3.7.5 Silicon Tube

Silicone tubing is a very tough elastomer that exhibits high strength, flexibility, and resistance. Silicone tubing can be stretched without tearing and is highly versatile. It cannot be weakened with repeated bending and twisting due to its significant flexibility. Because silicone tubing is very hygienic and non-toxic, it can be produced as a medical-grade material, making it a popular choice for healthcare and medical applications.

Fig 3.7.5: Silicon Tube

3.8 Measuring Apparatus

One of the most common devices for measuring temperature is the Temperature controller relay and many more measuring instruments are used such as digital watt meter and Selector Switch .

3.8.1 Watt Meter

Fig 3.6.4 Watt Meter

The wattmeter is a very sensitive instrument and can be damaged by excessive current. All wattmeter’s are rated for a safe maximum current rating. In many devices, the maximum allowable current is limited to 16 A. This means 3,680 W of power at 230 V AC mains voltage. In order to prevent damaging the wattmeter, this current and power value should be observed. Some devices also have overload protection.

3.8.2 Temperature controller relay

A thermal relay works depending upon the above mentioned property of metals. The basic working principle of thermal relay is that, when a bimetallic strip is heated up by a heating coil carrying over current of the system, it bends and makes normally open contact**.**

Fig 3.6.4 Watt Meter

Fig 3.6.4 Temperature controller relay

3.8.3 Selector Switch

We know that an electrical switch is used to control the electrical current flow in a circuit and it can also be used to both initiate and inhibit the current flow. There are different types of switches available in the market which are used based on the requirement. Toggle, pushbutton, limit, joystick, proximity, speed, pressure, temperature, liquid level, and selector switch. So this article discusses one of the types of electric switch like a **selector switch**

Fig 3.6.6

Selector Switch

3.9 Other Equipment's

Soldering iron, Filler metal, inserted wire (Copper), Fan, Arduino Mega, Arduino 1.5.2 Compiler, Glue Gun, Electric Wire is used as other equipment.

3.9.1Soldering Iron

Fig 3.19: Soldering iron

This has been used to solder the LM35. It uses the filler metal to complete the soldering process.

3.9.2 Filler Metal

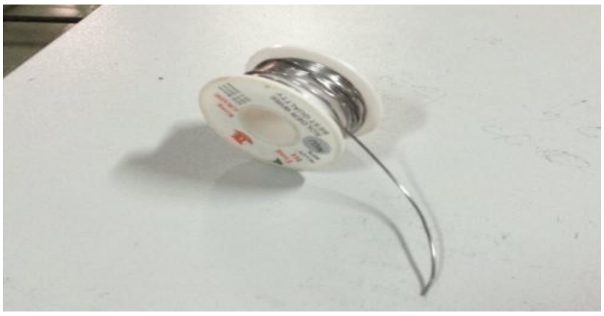


Fig 3.20: Filler Metal

Filler metals are generally made by Lead. It is used in soldering. Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal (solder) into the joint, the filler metal having a lower melting point than the adjoining metal. Soldering differs from welding in that soldering does not involve melting the work pieces. In brazing, the filler metal melts at a higher temperature, but the work piece metal does not melt. In the past, nearly all solders contained lead, but environmental concerns have increasingly dictated use of lead-free error for electronics and plumbing purposes.

3.9.3 Inserted wire (Copper)

Fig 3.21: Copper Wire

As the inserted wire, here we used copper wire with a negligible diameter. As copper has a good conductivity, we have thought of using copper as our selected one. The thermal Conductivity of copper is 231 Btu with a density of 0.322 lbs/in. The specific heat of this wire is .095 Btu/lb/F. Its melting point is 1976 F. The strength of metallic bonds for copper reaches a maximum around the center of the transition metal series, as those elements have large.

3.9.4 AC Fan

Fig 3.22: AC Fan

For the cooling process, we used axial dc fan. An axial fan in general, whether AC(220V) 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

3.9.5 Glue Gun

Fig 3.25: Glue Gun

Hot glue guns are portable devices that utilize and dispense hot melt adhesives. It uses glue sticks as It has been used to glue the LM and for miscellaneous purposes.

3.9.6 Electrical wire

- Keep the length of the wire to a minimum to avoid an unnecessary voltage drop on the conductor.
- Connect wires solidly to panels and switchboards.
- Size and select the type of wires to match the current-carrying requirements of… To view this content... Request subscription information.

3.9.7 Syringe 5ml

While experimenting, Pascal invented the syringe and created the hydraulic press, an instrument based upon the principle that became known as Pascal's principle: pressure applied to a confined liquid is transmitted undiminished through the liquid in all directions regardless of the area to which the pressure is applied

.

Fig 3.9 Syringe

3.10 Experimental Procedure

After the construction of the whole setup the experiments were carried out. The construction included

- PVC base and frame
- PVC stage for placing the whole setup
- Rotating mechanism of stage to gain vertical angles
- Evaporator, adiabatic and condensation section with nichrome wire winding Installation of heat pipe
- Setting the thermocouple connections at desired locations on the heat pipe
- Electrical connection via variable power supply
- Electrical connection to the cooling fan
- Electrical connection to the Arduino mega to run the program to take desired data readings.

The experiment was carried out for ethanol as working fluids, four different filling ratio and four different angular orientations of the heat pipe.

3.10.1 Normal Structure

- First the inner volume of the heat pipe was checked and then vacuum was created using a vacuum pump.
- Next it was filled 60% of the volume with working fluid Ethanol and methanol (injecting by syringe) and the heat pipes were sealed to make a closed loop.
- The set-up was kept at vertical (0) position.
- Different heat inputs were provided to the system and temperature reading of different sections was measured through computer program with the help of Arduino.
- The above three steps were carried out systematically for filling ratio 20%,60%,and 80% respectively.
- Temperature vs time graphs were plotted for all the experimental data set.

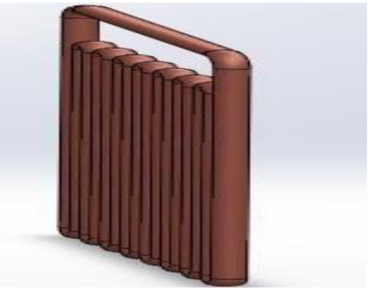


Fig: 3.27: Position of PHP in Angles (a) Vertical

3.10.2 Precautions

The following precautions were considered while performing the experiment:

3.10.2 During the entire experiment, all other source that can affect heat transfer process, were kept off.

3.10.3 The sensor (LM35 sensors) used in the experiment must be checked properly before taking temperature measurement.

3.10.4 Temperature readings must be taken only when that particular temperature is reached at steady state or a constant value.

3.10.5 All the angles must be measured carefully as it has greater effect on output temperatures.

3.10.6 While attaching the fin care must be taken not to press the copper tube.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Calculation

1. We know that , V=AL

Volume= Area×Length

$$=\frac{\pi d^2}{4} \times 1480mm$$

$$= \pi \times 1480mm$$

$$=4649.55m\boldsymbol{m^3}$$

=4.65ml

Thermal Resistance

Rt = Thermal Resistance

Teva $=\frac{T1+T4}{2}$ Tcon $=\frac{T2+T6}{2}$

ΔT = Teva – Tcon

$$= \frac{\Delta t}{Q}$$

$$= \frac{Te - Tc}{Q} \quad ℃/w$$

4.2 Inclination Compare and Filling Ratio Compare

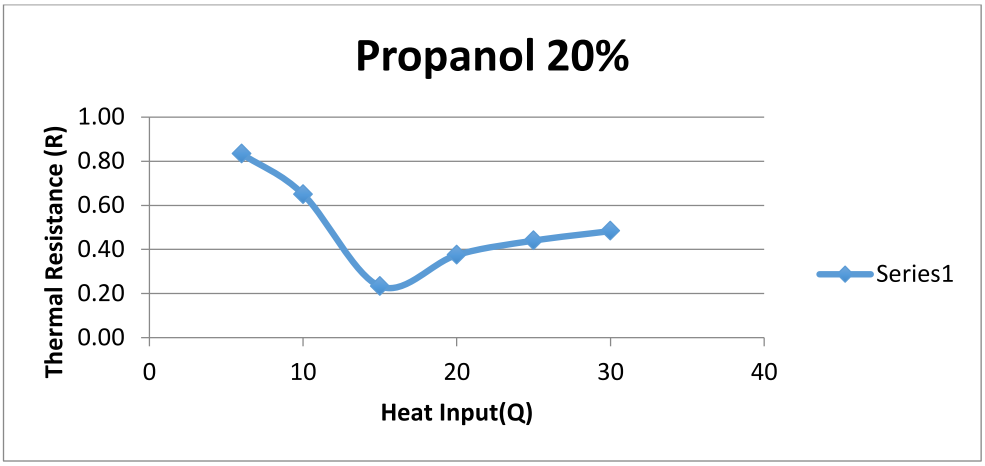
Working fluid: Propanol, Ethanol, Butanol, Aceton

Filling ratio: 20%, 60%, 80%

Position: 0^{o}(Vertical)

Structure: Forced Convection

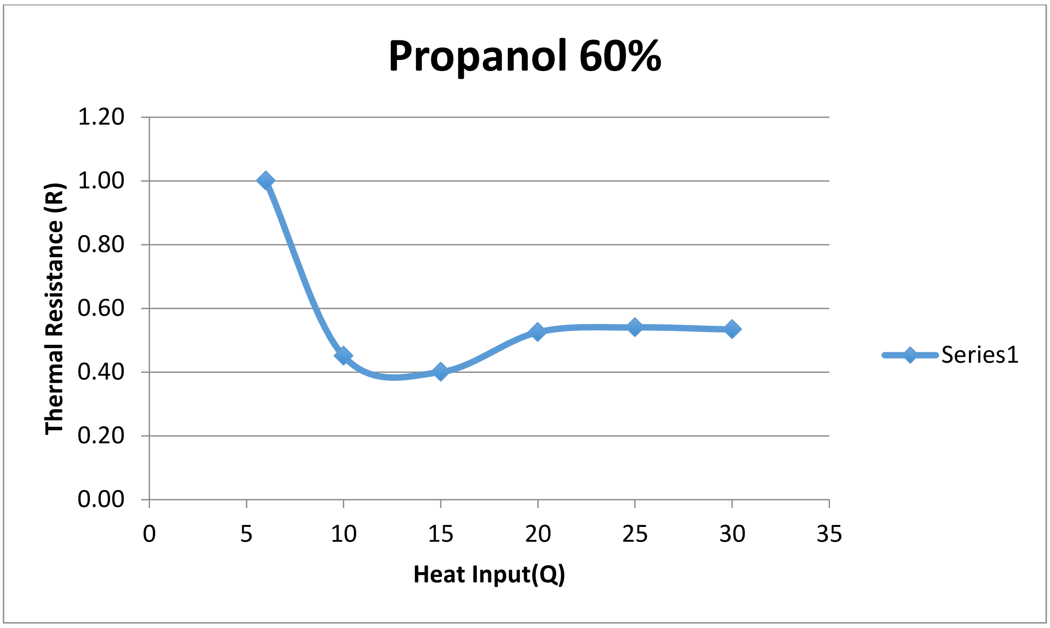
Liquid:	Propanol			Filling Ratio:20%						
		Eva		Adi		Con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	34	33	31	32	28	29	33.5	28.5	0.83
2	10	36	38	34	36	30	31	37	30.5	0.65
3	15	41	43	36	40	39	38	42	38.5	0.23
4	20	47	51	38	46	41	42	49	41.5	0.38
5	25	56	59	40	53	45	48	57.5	46.5	0.44
6	30	64	69	42	62	49	55	66.5	52	0.48



The figure shows that when the volt is 6watt its resistance is high. Then increases the watt that time the resistance going down the resistance. . When volts 15watt, then the resistance value is lower. Again increase the volt that time increases the resistance value again

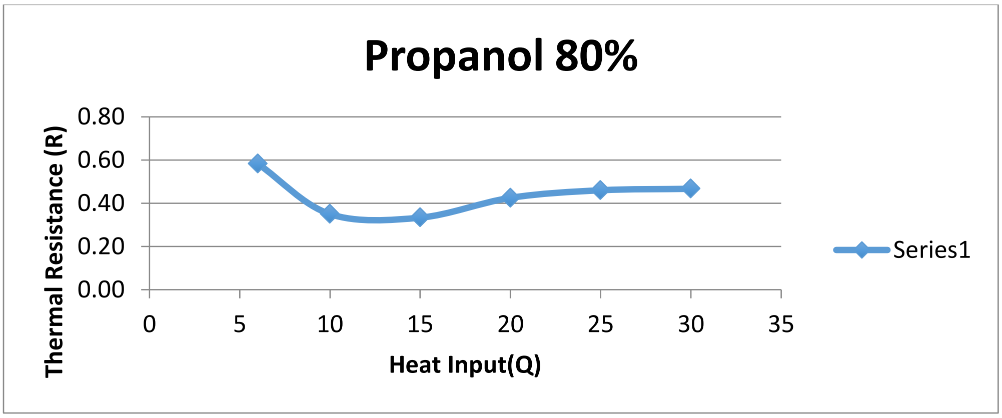
When time 1000 second then thermal resistance 0.7761 (°C/W)

Chart -2										
Liquid:	Propanol			Filling Ratio:		60%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	44	45	39	41	38	39	44.5	38.5	1.00
2	10	41	42	35	39	37	37	41.5	37	0.45
3	15	45	46	37	44	39	40	45.5	39.5	0.40
4	20	55	56	42	51	44	46	55.5	45	0.53
5	25	62	64	44	59	48	51	63	49.5	0.54
6	30	72	73	47	68	54	59	72.5	56.5	0.53



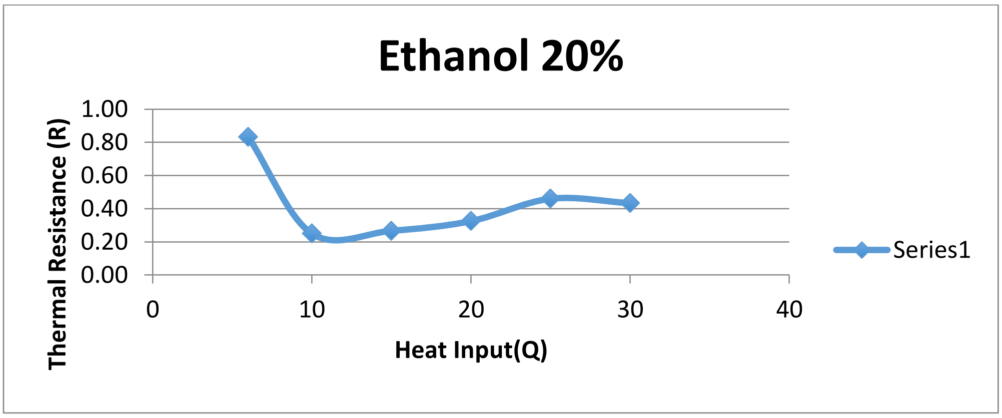
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 15watt, then the resistance value is lower. Again increase volts After 20-30watt its make a steady line

Chart -3										
Liquid:	Propanol			Filling Ratio:		80%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	39	40	35	37	37	35	39.5	36	0.58
2	10	40	41	35	39	37	37	40.5	37	0.35
3	15	42	43	37	40	37	38	42.5	37.5	0.33
4	20	48	49	37	44	40	40	48.5	40	0.43
5	25	54	54	39	50	41	44	54	42.5	0.46
6	30	65	63	43	59	47	53	64	50	0.47



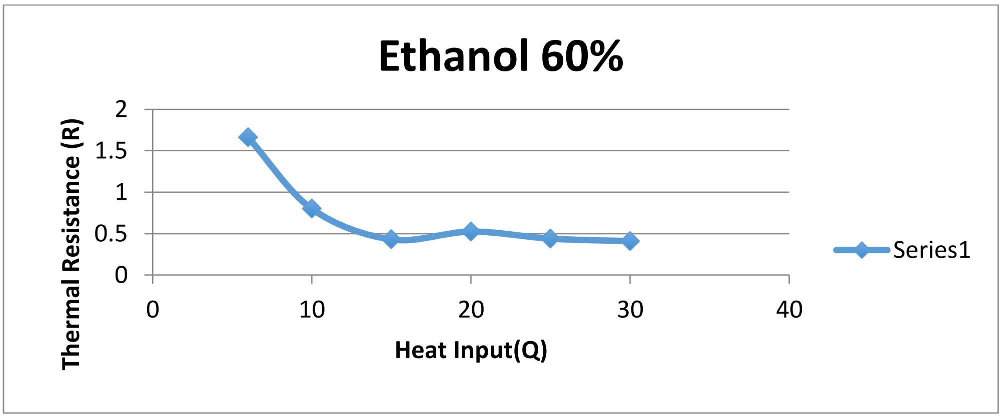
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 10-15watt, then the resistance value is lower. Again increase the volt that time slowly increases the resistance steady line.

Chart -4										
Liquid:	Ethanol			Filling Ratio:		20%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	35	34	33	35	29	30	34.5	29.5	0.83
2	10	37	38	35	37	35	35	37.5	35	0.25
3	15	42	43	36	41	38	39	42.5	38.5	0.27
4	20	46	47	37	44	40	40	46.5	40	0.33
5	25	54	55	38	50	42	44	54.5	43	0.46
6	30	65	66	40	61	50	55	65.5	52.5	0.43



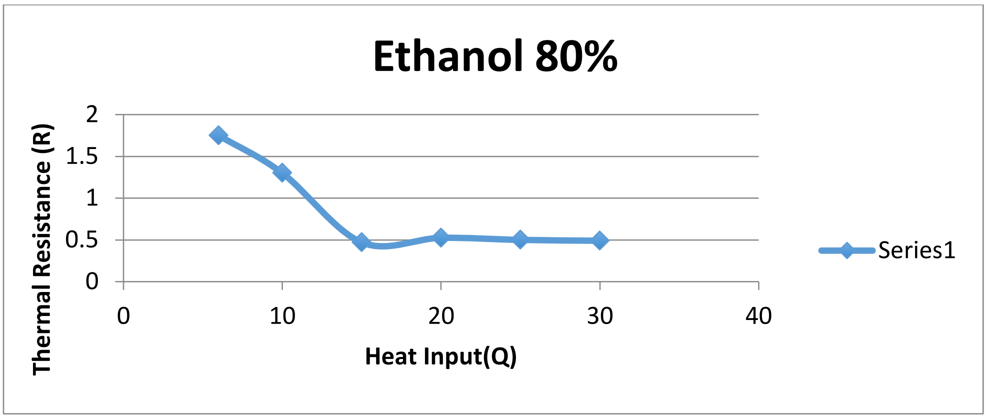
The figure shows that when the volt is 6watt its resistance is high. Then increases the watt that time the resistance going down to fast the resistance. When volts 10watt, then the resistance value is lower. And in 15-25watt make a curve . Again 25-30 volts are increase the Resistance is low down.

Chart -5										
Liquid:	Ethanol			Filling Ratio:		60%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	35	36	32	33	28	29	35.5	28.5	1.66
2	10	37	38	33	34	29	30	37.5	29.5	0.8
3	15	42	44	35	36	36	37	43	36.5	0.43
4	20	52	55	40	44	42	44	53.5	43	0.525
5	25	54	60	42	45	45	47	57	46	0.44
6	30	62	70	46	52	52	55	66	53.5	0.41



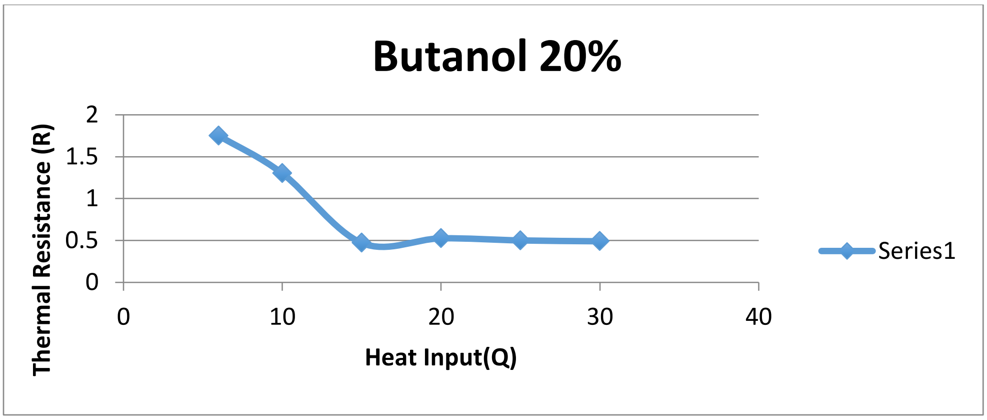
The figure shows that when the volt is 6watt its resistance is high .then increases the watt that time the resistance going down to fast the resistance. When volts 15 watt , then the resistance value is lower. Again increase the volt that time decreases the resistance value again.

Chart -6										
Liquid:	Ethanol			Filling Ratio:		80%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	38	40	33	35	28	29	39	28.5	1.75
2	10	42	43	34	35	29	30	42.5	29.5	1.3
3	15	46	45	36	39	38	39	45.5	38.5	0.47
4	20	51	54	39	42	42	42	52.5	42	0.525
5	25	58	60	41	46	46	47	59	46.5	0.5
6	30	65	68	40	47	52	52	66.5	52	0.49



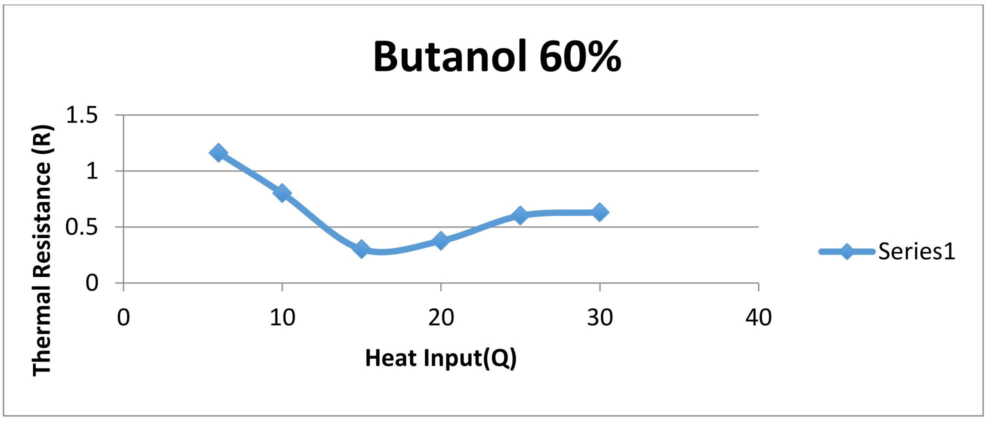
The figure shows that when the volt is 6watt its resistance is high. Then increases the watt that time the resistance going down to fast the resistance. When volts 15watt, then the resistance value is lower. And in 20-30watt make a steady line.

Chart -7										
Liquid:	Butanol			Filling Ratio: 20%						
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	34	37	33	35	28	29	35.5	28.5	1.16
2	10	37	38	32	35	29	30	37.5	29.5	0.8
3	15	42	44	35	38	36	37	43	36.5	0.43
4	20	52	64	50	55	42	55	58	48.5	0.475
5	25	70	72	45	55	55	57	71	56	0.6
6	30	73	72	50	60	55	62	72.5	58.5	0.47



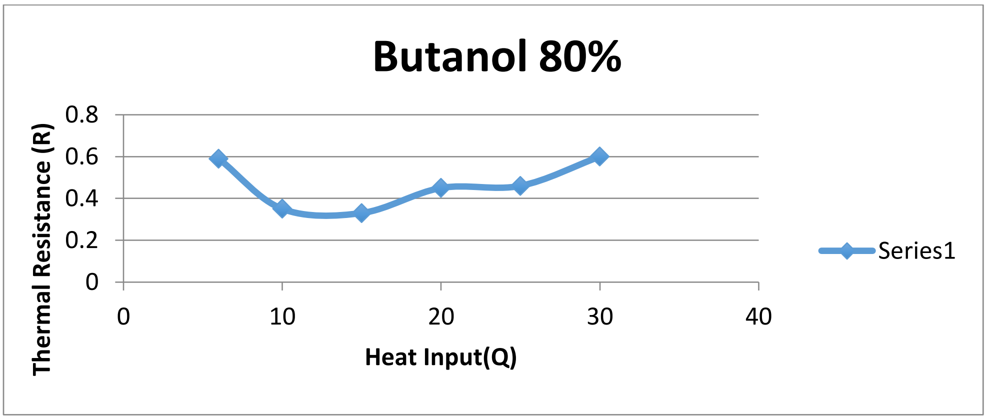
The figure shows that when the volt is 6watt its resistance is high. Then increases the watt that time the resistance going down to fast the resistance. When volts 10 watt, then the resistance value is lower. And in 20-30watt make a steady line.

Chart -8										
Liquid:	Butanol			Filling Ratio: 60%						
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	35	36	35	36	28	29	35.5	28.5	1.16
2	10	36	39	37	36	29	30	37.5	29.5	0.8
3	15	40	43	40	40	38	36	41.5	37	0.3
4	20	45	52	47	47	40	42	48.5	41	0.375
5	25	54	60	33	54	38	46	57	42	0.6
6	30	64	68	70	65	40	54	66	47	0.63



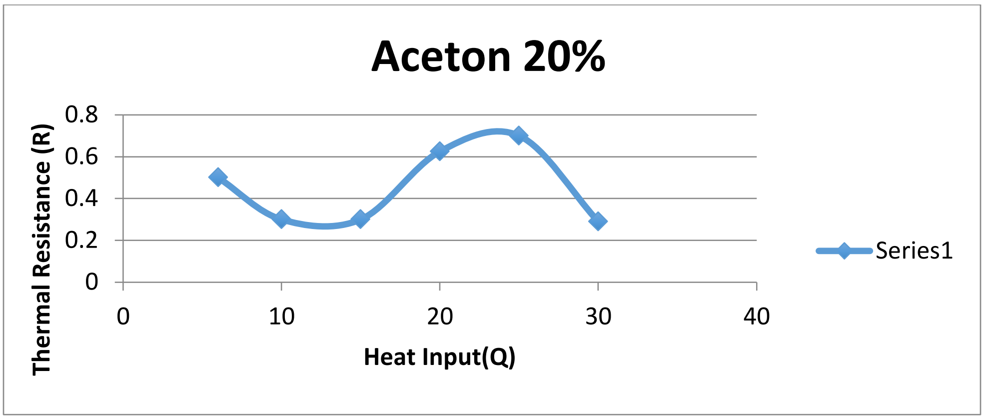
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 15watt, then the resistance value is lower. Again increase the volt that time increases the resistance value again. But when The volt is 30watt then resistance steady line .

Chart -9										
Liquid:	Butanol			filling ratio		80%				
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	34	36	34	32	33	30	35	31.5	0.59
2	10	36	38	36	35	33	34	37	33.5	0.35
3	15	40	44	42	41	36	38	42	37	0.33
4	20	51	53	53	50	42	44	52	43	0.45
5	25	60	57	58	60	48	46	58.5	47	0.46
6	30	70	70	70	65	50	54	70	52	0.6



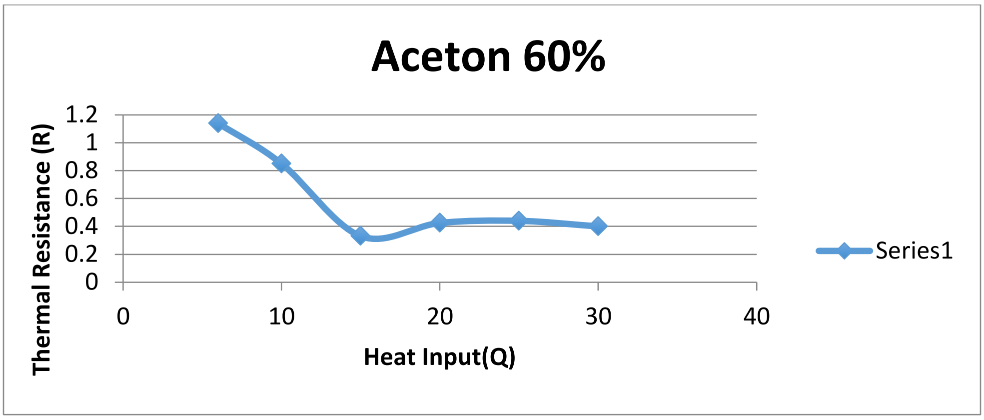
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 10-15watt, then the resistance value is lower. Again increase the volt that time increases the resistance value again.

Chart -10										
Liquid:	Aceton			Filling Ratio: 20%						
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	36	37	36	35	34	33	36.5	33.5	0.5
2	10	37	38	36	36	34	35	37.5	34.5	0.3
3	15	43	47	47	45	40	41	45	40.5	0.3
4	20	57	60	58	55	45	47	58.5	46	0.625
5	25	66	68	66	62	51	48	67	49.5	0.7
6	30	63	61	68	61	52	55	62	53.5	0.29



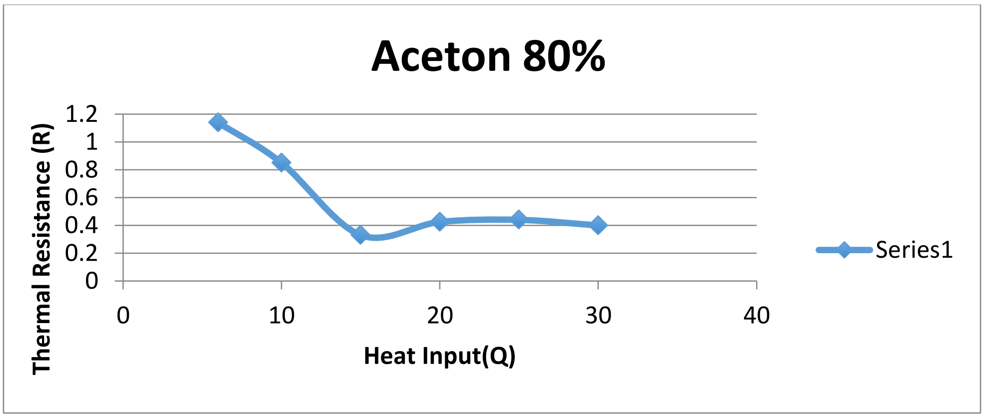
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance is same in 10-15 watt. When volts 15watt, then the resistance value is higher coming to 25 watt . Again increase the volt that time decreases the resistance value again. But when The volt is 30watt then resistance is down.

Chart -11										
Liquid:	Aceton			Filling Ratio: 60%						
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	36	38	37	37	28	29	37	28.5	1.14
2	10	38	38	38	37	29	30	38	29.5	0.85
3	15	45	47	47	45	40	42	46	41	0.33
4	20	55	55	58	53	45	48	55	46.5	0.425
5	25	60	62	61	59	49	51	61	50	0.44
6	30	66	66	72	64	52	56	66	54	0.4

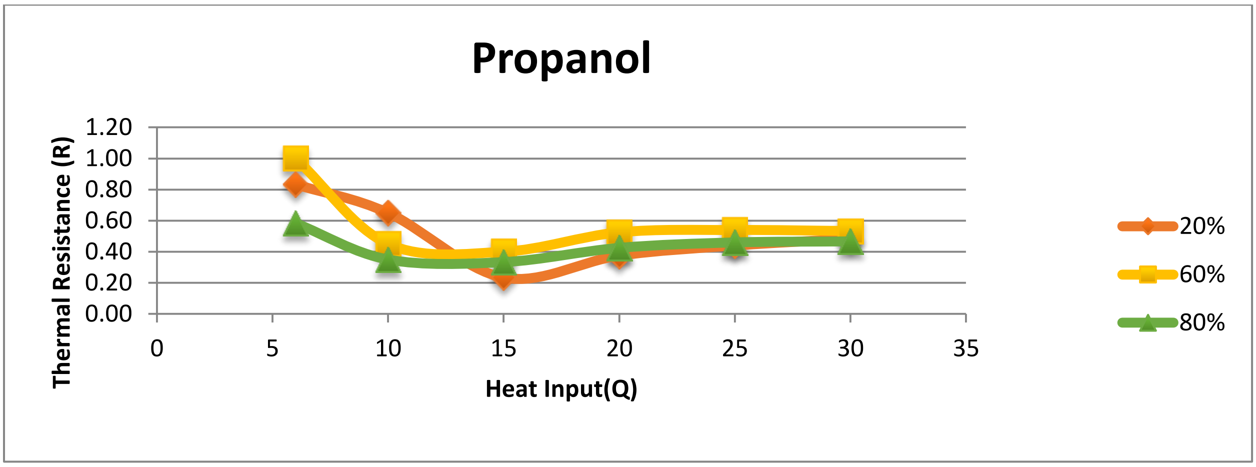


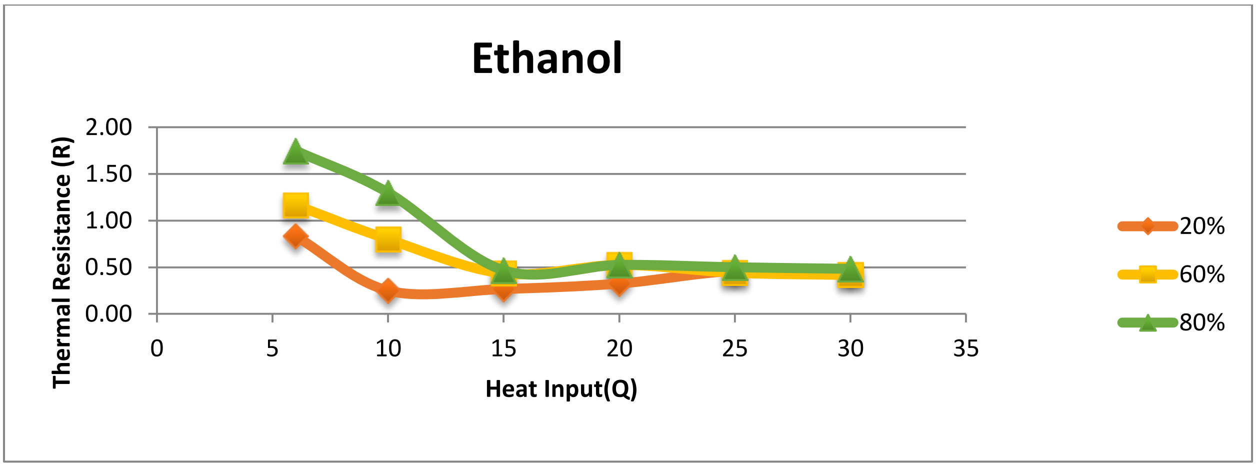
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 15watt, then the resistance value is lower. Again increase the volt that time increases the resistance value again. But when The volt is 25-30watt then resistance steady line .

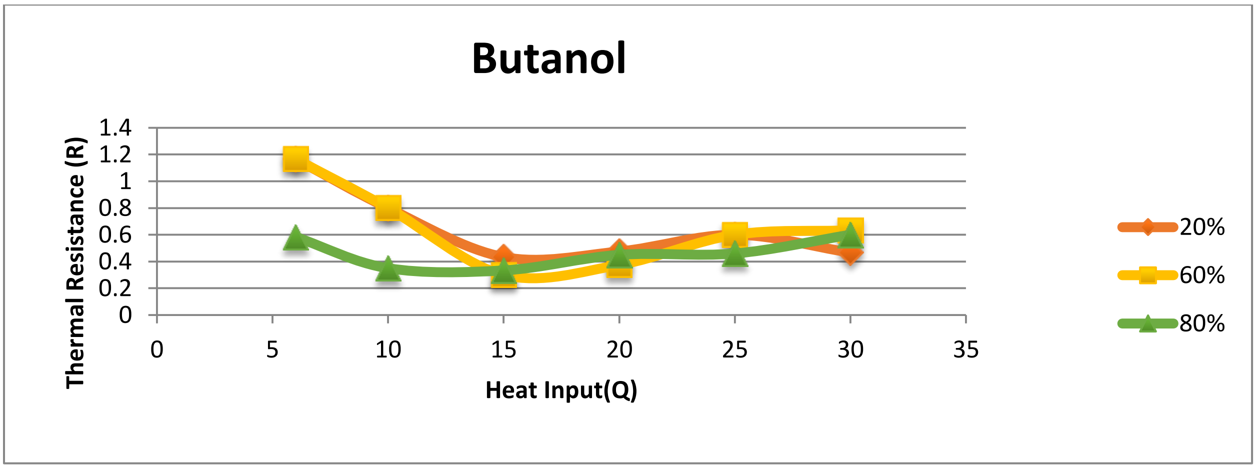
Chart -12										
Liquid:	Aceton			Filling Ratio:80%						
		Eva		Adi		con				
S/N	Q(W)	T1	T4	T3	T5	T2	T6	T Eva(avg)	T Con(avg)	R
1	6	36	38	37	36	28	29	37	28.5	1.41
2	10	38	40	40	38	30	31	39	30.5	0.85
3	15	44	45	45	44	38	40	44.5	39	0.37
4	20	54	53	55	51	43	46	53.5	44.5	0.45
5	25	59	61	63	59	48	52	60	50	0.4
6	30	65	68	70	65	54	57	66.5	55.5	0.37

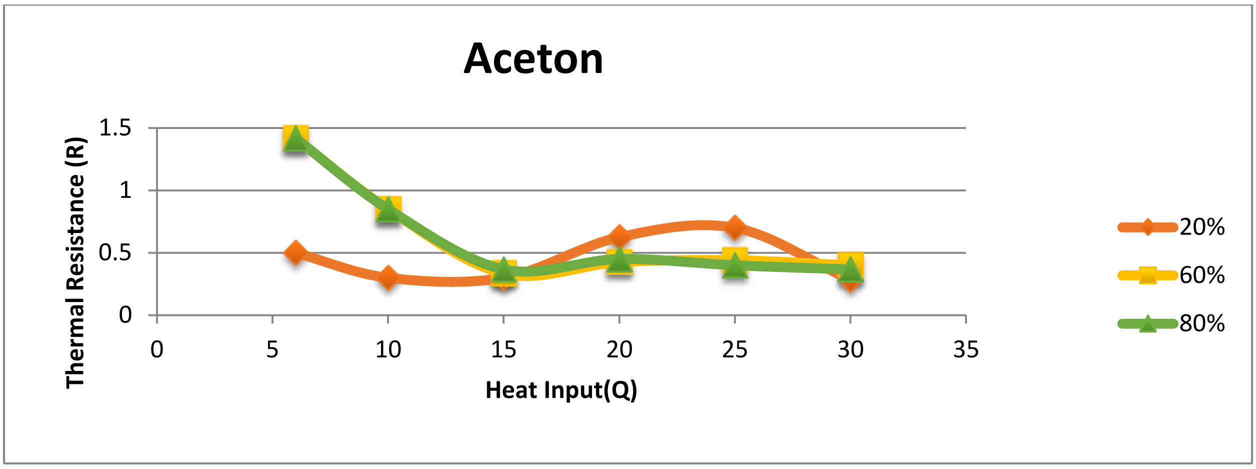


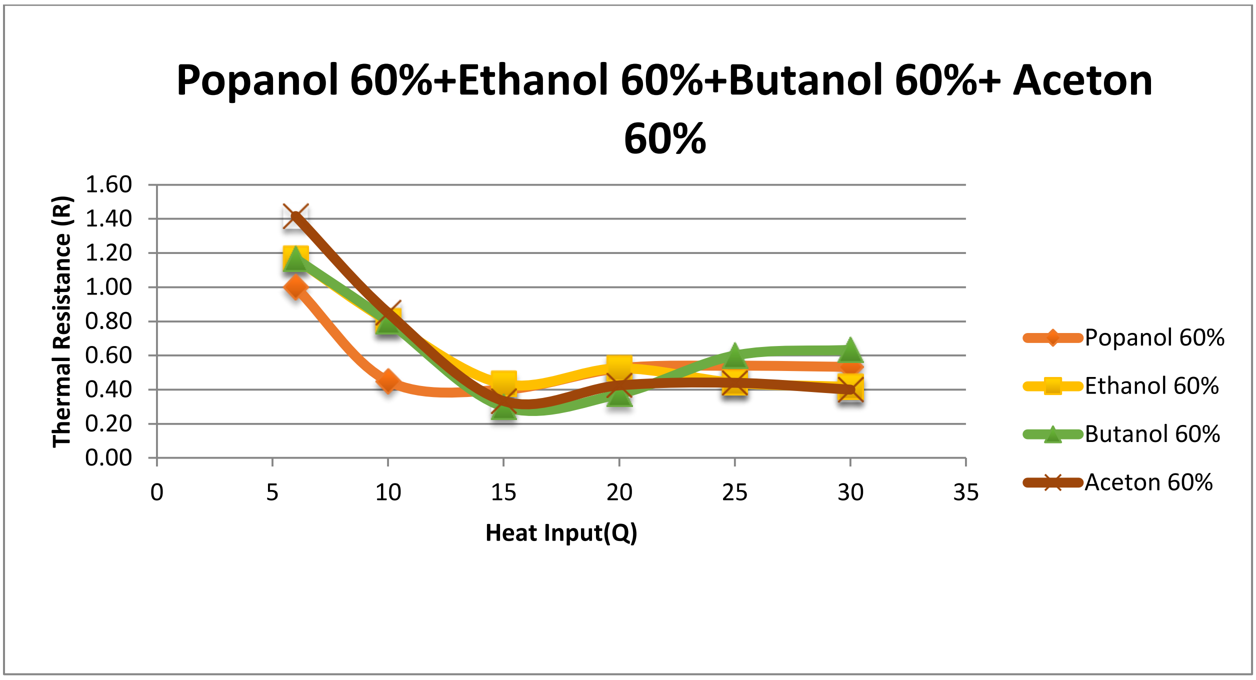
The figure shows that when the volt is 5watt its resistance is high .then increases the watt that time falls down the resistance. When volts 15watt, then the resistance value is lower. Again increase the volt that time increases the resistance value again. But when The volt is 30watt then resistance down.











4.3 General findings and outcomes

- Heat transfer characteristics of CLPHP are studied for ethanol and methanol as working fluid using normal type of CLPHP structures. The structures used are normal CLPHP on the condenser section. Among these structures normal structures show the best performance. The normal structure with fin incorporated at the condenser section shows the worst performance. Wire inserted CLPHP shows comparatively better result that finned structures and in some cases it works just as good as the normal structure.
- Five different filling ratio of working fluid is used for each type of structures. Filling ratios are 20%, 60% and 80% a of the total volume of the CLPHP. The optimum filling ratio is accounted based on the heat transfer characteristics and start up characteristics. Filling ratio

good performance of 30% FR for Ethanol. Optimum filling ratio good performance at most of the cases. 50%FR and 70%FR also show close performances.

- The experiment is carried out for vertical angles taking vertical orientation as 0º inclination of the CLPHP. The best performance is observed at vertical condition for all cases.
- The minimum starts up power required for pulsating effect to activate is about 40W. This may vary depending on the working fluid used in the CLPHP. For normal structures the minimum starts up time is observed for 50%FR.
- Three different parameters are considered in this work for evaluating the performance of CLPHP using ethanol as working fluid. These parameters are thermal resistance, heat transfer coefficient and minimum start up condition i.e. time and power.
- The performance of CLPHP is affected by the working fluid used, saturation temperature of the working fluid, wall temperature, bubble formation, buoyancy, surface tension, inside geometry, vapor pressure and transient conditions.
- The temperature distribution curves show almost similar pattern in all cases.
- The condenser temperature remains nearly the same for all FR except 70%FR. At 70%FR the condenser temperature shows unstable fluctuation. The cooling range hence decreases so it renders bad performance.
- The adiabatic section considered is assumed to be completely adiabatic. But in practical there is always a very little heat loss from the section which cannot be stopped.
- The evaporator section must be wrapped up by heat insulating materials to stop heat loss to environment while giving heat input to the CLPHP. This is very important as heat losses result in variation in the performance of the CLPHP.

4.4 Characteristics of temperature distribution

The temperature distribution curves show the evaporator wall temperature and condenser wall temperature plotted against time. These curves show almost similar pattern in all cases. The curves are somewhat exponential in nature.

The temperature distribution curves are used to find out the startup time for the CLPHP. These curves are governed by the saturation temperature of the working fluid used as well as its surface tension, buoyancy and gravity. For all the experimental cases, the curves at first increase rapidly with time and then the rate of increase become slow to some extent. This is same for all the evaporator temperature data. But, certainly, the rate of increase is different for different regions.

After reaching the boiling point, the temperature increase in evaporator slows down due to the heat required in phase transfer. Then it starts acting on pulsating effect. The pulsating effect is when the liquid starts to boil in the evaporator section it takes the latent heat from the evaporator wall then bubble formation Begins. These bubbles with liquid slugs inside due to buoyancy and low surface tension of ethanol starts to go up. The liquid slugs inside want to come down due to gravitational force. When the bubble reaches the condenser section the force convection takes away the heat, so the bubble collapses and the relatively less hot liquid goes down again and gets heat from the evaporator wall. As this is a continuous process so at every instance the temperature fluctuates due to this bubble formation and collapsing. The heat transfer is carried out by this fluctuation of temperature, this is the pulsating effect.

The saturation temperature of ethanol is 78ºC, meaning ethanol starts boiling at 78ºC. Depending on the pressure inside the CLPHP and the heat transfer from the heating arrangement to the liquid ethanol inside the CLPHP via the evaporator wall the saturation temperature may vary to a slight extent. Again a thumb rule of heat transfer, about 8-20ºC temperature difference is required for good amount of heat transfer between bodies. In most cases this pulsating effect occurs at about 95-100ºC, meaning the when the evaporator wall temperature reaches this temperature the ethanol inside the CLPHP starts to boil hence reaches it boiling temperature and starts the pulsating effect.

The temperature distribution curves along with thermal resistance and heat transfer coefficient curves are shown. The temperature distribution curves on this section focus on the changes in temperature curve due to changes on the inclination or orientation of the heat pipe. Temperature distribution curves for 30%FR, 40%FR, 50%FR, 60%FR and 70%FR respectively of normal CLPHP at different inclinations for 50W heat input. The evaporator temperature curves at different inclinations are of similar trend. Usually the evaporator temperature curves show maximum value at 60º inclination. This is because when the CLPHP is tilted 60º the bubbles formed collapses before reaching the condenser section due to gravity. These bubbles actually collapse at the heat pipe walls and hot liquid slugs come down again so temperature increases. The condenser temperatures remain nearly the same in all cases except for cases 70%FR. From it is seen that the condenser temperature fluctuates vigorously for 70%FR at all orientations. This is because at 70%FR the CLPHP has very little unoccupied space or free space. When the heat input is given the liquid expands, hence the free space reduces to almost zero. This results in very little space for bubble to collapse and also the warm liquid in this case avails in the condenser section also. As a result, condenser temperature increases. Due to force convection by fan the condenser section is constantly cooled so when the liquid cooled goes down the temperature goes down and, in an instance, warm liquid takes up the condenser section again. As the condenser temperature increases the difference between evaporator temperature and condenser temperature decreases resulting in low thermal resistance but low cooling range which renders it ineffective.

Show the temperature distribution curves for finned normal structures for different filling ratios at different inclinations. These figures show similar evaporator temperatures as normal structure but a reduced condenser temperature than normal structures. This happens because the fin takes some portion of the heat away from the condenser section making the CLPHP to achieve lower condenser temperature.

Show the temperature distribution curves for wire insert structures. The wire inserts structures show higher evaporator temperature curves than normal structures though the curve trend is similar. The possible explanation to this is that the wire inserted inside also heats up by taking heat from liquid and as solids have better heat conductivity, so it increases the temperature by getting hotter and hotter. This also accounts for a slight condenser temperature increase.

The finned wire insert temperature curves for different inclinations also show similar trend and outcomes as the other three structures. At all cases 70% FR show high condenser temperature of fluctuating nature.

In section temperature distribution curves show comparison for different filling ratios. In this section the figures also show the similar trend. The interesting finding from these figures is that the evaporator temperature distribution decreases with filling ratio. At 40%FR there is less amount of fluid inside the CLPHP. As the heat input is increased the pulsating starts and liquid vaporizes and liquefies consistently. Now if high heat input is given then the amount of liquid vaporizing increases And there remains little amount of liquid to take the huge amount of heat. This condition is called dry up. When dry up occurs the evaporator wall gets heated up as it cannot pass the heat to liquid due to lack of adequate amount of liquid present inside. As filling ratio increases the amount of liquid available increases so temperature of evaporator walls decreases. Again at 70%FR the evaporator and condenser temperature increase due to the reasons explained in above the section.

4.5 Minimum Start up Conditions

Mainly three parameters are used to evaluate the performance of PHP, start-up time and power, thermal resistance and heat transfer coefficient. The startup power is the minimum power needed by the PHP to get started. When the PHP reaches the required startup condition, the oscillating motion in the PHP starts. The time required for this is minimum start up time. When the required superheat or input power meets the required condition, the stable oscillating motion can be self-sustained. The startup condition is very important for the stable oscillating motion or pulsating motion occurring in a PHP. The startup depends on many factors like the filling ratio, tube geometry, wall temperature variation, heat flux level, physical properties of working fluid, heating and cooling modes, transient heat transfer process, initial temperature, and so on.

The minimum starts up condition refers to both the minimum start up power and minimum start up time. The startup condition for normal and wire insert structures are shown for all filling ratios. As the finned normal structure and finned wire insert structure are the same as normal and wire insert structure respectively, no change in heating media, only fin is used at the condenser section so the startup curves will be more or less same.

Show start up curve for normal structure and wire insert structure respectively for different filling ratio at different heat inputs. From Figs. it can be seen that at different heat inputs the temperature of evaporator increases and then becomes constant after which the device starts working in pulsating mode. This is the startup condition when the device starts working. Before the start up condition has reached, the pressure in the vapor bubble is not sufficient to drive the train of liquid plug and vapor bubble above it. After the achievement of startup condition, nucleate boiling starts in the heating section and the size of vapor bubbles grow, increasing its instant pressure and thus the pressure difference between the evaporator and the condenser section, which is the driving force for the oscillatory motion inside [16]. It is seen that for higher filling ratio the startup time is less than lower filling ratios. Again, at higher filling ratios start up power required is higher than lower filling ratios. The minimum starts up power required is about 40W for both normal and wire insert structure. Based on the startup condition the optimum filling ratio is 50% for normal structures.

4.6 Variation of Thermal Resistance

Thermal resistance is considered in this paper as an indicator of heat pipe effectiveness. It is defined as the ratio of difference in average temperature of evaporator section and average temperature of condenser section for any instance to the heat input at that time. The thermal resistance of CLPHP is given by

$$\square\,\square_{h} = \underline{\square\square}\,\square\,\underline{-\,\square\square}$$

We know, Rth= Thermal resistance (°C/W), Q= Heat input (W), $T_{e=}$ Evaporator Temperature (°C), $T_{C=}$ Condensation Section Temperature (°C)

The equation indicates how much resistance does heat experiences in the system. Thermal resistance has an inverse relationship with heat input *i.e.* thermal resistance decreases with increasing heat input. These curves follow an exponential pattern. Thermal resistance decreases with increasing power. At low heat inputs the thermal resistance is high. This is because at low heat inputs the liquid slug movement is very low and there is little bubble formation resulting in low heat transfer. As heat input is increased liquids inside the CLPHP gets exposed to adequate amount of heat and slowly pulsating

Action starts. At first the decrease rate of thermal resistance is high this is because there is a vast amount of liquid present to pulsating action. As heat input increases more i.e. to high heat input range the decrease rate of thermal resistance becomes low. This results in slowly flattening out of the thermal resistance curve. This is due to high amount of pulsating movement occurring inside the PHP, so amount of ethanol available in liquid form for pulsating movement decreases. The thermal resistance curve decreases up to an optimum value after which the thermal resistance starts to increase. At this point dry out occurs inside the PHP. Dry out means almost all the liquid available is in pulsating action i.e. in bubble form and there is very little liquid available which does not have the ability to compensate the high amount of heat input. In the experiment we carried out up to 60W heat input is applied in the PHP. In our experiment dry out did not occur. This implies that ethanol works well up to 60W heat input. The curves also have not flattened out as much so more heat input can be applied to find out the optimum value of thermal resistance. Thermal resistance is closely governed by filling ratio, inclination of the PHP and structural differences also.

4.7 Variation of Heat Transfer Coefficient

The convective heat transfer coefficient of PHP is given by

As area of the heat transfer is constant so heat transfer coefficient is inversely proportional to thermal resistance. Lower the thermal resistance, higher will be heat transfer coefficient resulting in high amount of heat transfer. So high heat transfer coefficient is desirable.

4.8 Effect of Inclination

The inclination comparison for different structures and different filling ratios are shown in section. The best performance is obtained at vertical condition for all type of structures.

The inclination comparison at different filling ratios for normal structures. The thermal resistance is lowest at vertical condition and heat transfer coefficient is high at vertical condition. At vertical condition the vapor bubbles grow in size and their buoyancy helps them lift up. High amount of vapor bubble formation occurs at this case. These vapor bubbles can go straight up to the condenser section and collapse. So, the performance is adequate. When the PHP is inclined these bubbles cannot go up to condenser section due to buoyancy. They rise up by temperature and pressure difference, hence the pulsating movement is not up to the mark. So, the performance hinders due to inclination. The inclined positions give close performance i.e. at 30º, 45º and 60º.

The comparison for inclination of normal structures with fin. At 40%FR and 50%FR the performance is almost similar up to 30W. Beyond 30W they work slightly better. This is because due to incorporation of the fin at the condenser section the condenser temperature reduces as more amount of heat is carried out from the condenser section. At 60% FR and 70%FR vertical condition gives best results likewise.

Gives comparison of thermal resistance for inclination of wire insert structures. They give similar performance as normal structures with best outcome at vertical condition.

The insert fin structure's inclination comparison is shown in figures. The thermal resistance curves here show almost same performance at any inclination.

4.9 Effect of Filling Ratio

Shows the Effect of filling ratio for different structures.

Referred to show the comparison for normal structures. At low filling ratios, as the heat input is increased, the entire surface is covered by the vapor space which leads to dry-out situation. As the filling ratio increases further, the device starts acting in pulsating mode. For ethanol minimum resistance is offered at a filling ratio of 50% whose value is 0.98°C/W. As the filling ratio increase beyond 70%, the thermal resistance decreases slowly for ethanol. At FR 70% few bubbles are present in the PHP at high heat input, thus satisfactory performance is not observed. Moreover, due to high condenser temperature this filling ratio is not desirable. In PHP vapor bubbles are supposed to pulse And promote the liquid slug and dispel the heat from evaporator to the condensation section. In the PHP high

Fill ratio is responsible to hinder the pulsation of the bubble and hence the efficiency of heat transfer will not be very good. The low filling ratios are expected to favor the pulsation of the bubble, but it is extremely easy to dry out. The lowest thermal resistance for ethanol 0.98ºC/W is obtained at 50%FR and it is the optimum filling ratio. At 60%FR ethanol shows almost a similar performance as 50%FR and is just as effective.

Shows finned normal structure comparisons. This structures also give best performance for 50FR similarly, in case of wire insert structures and insert finned structures the best performance is observed for 50%FR and 60%FR.

It is mentionable that though 70%FR shows good performance considering thermal resistance and has a decreasing trend for thermal resistance curve but it is not as the cooling range decreases radically. So 70%FR is not considered very effective.

4.10 Effect of Different Structures

The best outcome is observed at vertical orientation.

Shows performance of the structures at different inclination and filling ratios. The best performances are obtained using normal structure.

The difference is the normal and insert structure is in the heating up of the liquid. The normal structure heats up fast and provides more heat to the liquid resulting in higher temperature due to the inserted wire. This results in a slightly high thermal resistance than insert structures. But normal structures give good start up action. Also, normal structures are best for using at high FR at high heat inputs which gives good result.

4.11 Uncertainty analysis

The performance effectiveness and understanding of the heat transfer characteristics of closed loop pulsating heat pipe is evaluated by measuring wall temperature at different points of the CLPHP. The uncertainties in condenser and evaporator temperature and in thermal resistance are evaluated based on method of Kline and McClintock (1953).

Uncertainty (Thermal Resistance) % = √ (□□1 2 2 + 2 X 100%

+ □□2 □□3 __

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□1 □3

) □

2

Uncertainty (Temperature) % = $\sqrt{\left(\frac{\square\square 1}{\square 1}\right)^2 + \left(\frac{\square\square 2}{\square 2}\right)^2 + \left(\frac{\square\square 3}{\square 3}\right)^2}$ X100%

Parameters (unit)	Maximum uncertainties (%)
Evaporator Temperature (˚C)	3.70
Condenser Temperature (˚C)	3.52
Thermal Resistance (˚C/W)	1.07

4.12 Applications of heat pipe

Since heat pipes have no moving parts, they are extremely reliable. This is the main reason they are used extensively in space applications where maintenance is not available. The main cause of heat pipe failures is gas generation in the heat pipe. This problem is totally eliminated by proper cleaning and assembly procedures. For successful transfer of heat, there is no alternative of a heat pipe. It has popularity for its light weight with high conductance. Heat pipes allow transportation of high fluxes with small temperature difference with no change in operating temperature. It can ensure longer life with a minimum maintenance. Also, they can be built in different geometries and sizes.

Heat pipes are used in-

4.12.1 Production Tools

4.12.2 Medicine and Human Body Temperature Control

4.12.3 Ovens and Furnaces

4.12.4 Transportation Systems and Deicing

4.12.5 Places where low humidity level necessary

4.12.6 Humidity control

4.12.7 Air reheated after cooling in traditional HVAC system

4.12.8 Large quantities of ventilation air need

4.12.9 Electronic component production, assembly and storage

4.12.10 Drugs, chemicals production and storage

4.12.11 Grocery stores

4.12.12 Aerospace and Avionics

4.12.13 Heat Exchangers and Heat Pumps

4.12.14 Gas Turbine Engines and the Automotive Industry

4.13 Limitations of CLPHP:

4.13.1 When heated above a certain temperature, all of the working fluid in the heat pipe will vaporized and the condensation process will cease to occur. This is the dry out condition. In such cases, the heat pipes thermal conductivity is effectively reduced to heat conduction properties of its solid metal casing alone.

4.13.2 If the heat source temperature drops below a certain level, depending on the specific fluid and gas combination in the heat pipe, a complete shut up can occur. So the control feature is particularly useful for last warm up application in addition to its value as a temperature leveler for variable load conditions.

4.13.3 The rate of heat transfer through the heat pipe is solely dependent on the rate of evaporation and condensation. If non-condensable gases are present in the gas mixture, the heat transfer will be affected. To ensure an effective heat transfer, a mechanism has to be established in the heat pipe then.

4.13.4 Most manufacturers do not produce heat pipes smaller than two mm diameter for material limitations. This unavailability is a 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 both are at horizontal position.

CHAPTER - 5
CONCLUTION AND RECOMMENDATION

5.1Conclusion

Closed loop pulsating heat pipes are complex heat transfer systems with strong thermo-hydrodynamic coupling governing the thermal performance. The effect of pressure, bubble formation and phase transfer is very important in design of heat pipes. Different heat input to these devices give rise to different flow patterns inside the tubes. This in turn is responsible for various heat transfer characteristics. The study strongly indicates that design of these devices should aim at thermo- mechanical boundary conditions which resulting convective flow boiling conditions in the evaporator leading to higher local heat transfer coefficient. The inclination angle changes the internal flow patterns thereby resulting in different performance levels.

This experimental investigation shows following outcomes

- ➢ Minimum start-up power for ethanol as working fluid in PHP which is about 15W. ➢The best performance is observed for vertical orientation of the CLPHP ➢The best filling ratio for normal structure is 60% FR.
- ➢ The best performance obtained for normal structures. After normal structures the best performance is obtained by insert structures.
- ➢ Finned structures provide reduced temperature at condenser section but increases thermal resistance.

Now from the above experimental investigation Mixed at 60% FR filling ratio is the best choice. The insert structures can be used for rapid start-up of the CLPHP also these structures can be used at high FR where heat generated is high

5.2Recommendations

5.2.1.1Simulation and flow visualization works can be done on it get a broader idea of the thermal performance.

5.2.1.2 Filling ratios can be varied to other extents to find out different performances.

5.2.1.3 We have taken vertical angles in our experiment. Further experiments might incorporate more angles considered to get more detailed result.

5.2.1.4 CLPHP made of different materials can be used to observe the performance between different materials.

5.2.1.5 Adiabatic section can be improved if possible.

5.2.1.6 Different working fluids can be used to measure the performances of the fluids.

5.2.1.7 More parameters can be applied such surface tension, viscosity changes etc.

5.2.1.8 Nano particles can be mixed with working fluid and can be used to measure performance.

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