Experimental study on the thermal performance of a closed loop pulsating heat pipe with two different inserts

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STUDENT DECLARATION

This is to certify that the thesis entitled, "**Experimental study on the thermal performance of a closed loop pulsating heat pipe with two different inserts**" is an outcome of the investigation carried out by the author under the supervision of **Md. Sojib Kaisar** Assistant Professor, Dept. of Mechanical Engineering, Sonargaon University (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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Dedication

This thesis is dedicated to our Parents.

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Abstract

Thermal control is crucial for managing small electrical and electronic equipment. The most effective method for thermal management is becoming recognized as a closed-loop pulsing heat pipe (CLPHP). This experimental investigation aim is to find a CLPHP to compare the thermal performance of CLPHP with two (copper and aluminum) different wire inserts. This experiment uses ethanol, methanol, distilled water and acetone as working fluids. The impact of employing pure water, methanol, ethanol and acetone as working fluids is investigated in various filling ratios. A copper capillary tube with an inner diameter of 2.75 mm, has been attached. The CLPHP contains six loops, each measuring 50 mm in length for the evaporation, 100 mm adiabatic, and 60 mm condensation sections. They were inserting Copper 0.9 mm wire and Aluminum 0.9 mm wire. The experiment was conducted with Filling Ratio ranging from 40% to 60% and heat input varied between 10 to 60 watts. The findings are compared based on evaporator temperature, condenser temperature, their differences, thermal resistance, heat transfer coefficient, power input, and the impact of filling ratios. The ideal filling ratios for ethanol, Methanol, distilled water and acetone are 60%, 40%, 40% and 40%, respectively, in Copper and Aluminum wire inserts. High boiling fluid, i.e., distilled water and ethanol copper wire insert, works as optimal performance. In comparison, comparatively low boiling points fluid such as methanol and acetone aluminum wire insert deliverers most remarkable performance.

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List of Abbreviations

Words/Signs	Abbreviation
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/C-m^2)
L	Length (mm)
Q	Heat input (W)
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
CLPHP	Closed Loop Pulsating Heat Pipe
OHP	Oscillating Heat Pipe
PHP	Pulsating Heat Pipe
Fig	Figure
ρ	Density of water (kg/m^3)
PLX-DAQ	Parallax Data Acquisition
Cu	Copper
Al	Aluminum

Chapter 1

1 Introduction

1.1 Motivation

One of the most efficient ways to move thermal energy from one place to another is via the use of heat pipes, which are often used for cooling applications that combine conduction and convective heat transfer. The thermal management system is receiving a great lot of attention as a result. One of the most important technologies in the development of electronic products is thermal management, and this trend will continue. The limitations of design are always being pushed, and current trends in thermal management of electronics are quite demanding. Inferred from a market analysis is that the following products are in demand: [1]

A. Thermal resistance of less than 1 KW from the electronic circuit to the heat sink
B. High heat transfer efficiency of up to 250W
C. A heat flow of up to 60 W/cm^2
D. Thermal and mechanical compatibility
E. Durable dependability
F. Miniaturization
G. Low price.

A heat pipe is a tube-shaped container that contains the working fluid. This tube's evaporator part is brought into thermal contact with a hot spot that has to be cooled at one end. A cool point where heat may escape is attached to the opposite end, which is referred to as the condenser portion. The term "adiabatic section" refers to the part of the tube between the evaporator and condenser. The working fluid's pressure and saturation temperature are selected such that they lie between the condenser temperature Tc and the evaporator temperature T_e. Thus, in the evaporator part, the fluid is converted to steam. The produced vapor is moved to the condenser portion, where it condenses. To the evaporator part, the liquid is returned. The latent heat is absorbed in the evaporator and released in the condenser, which are the primary causes of heat transmission. The heat pipes are highly effective since there is a lot of latent heat. They have an evacuation capacity of between 100 and 200 W/cm^2. Heat pipes come in a variety of varieties. They vary in terms of shape and a method for moving fluid within the heat pipe.

Due to ongoing demands for quicker and smaller microelectronic systems, the development of a particular form of passive two-phase thermal control device has increased in the last ten years. A Pulsating Heat Pipe (PHP), also known as an Oscillating Heat Pipe, is one such device that makes use of self-excited thermally generated two phase flow oscillations for improved passive heat transfer.

The heat pipe concept was first put forward by R.S. Gaugler of the General Motors Corporation, Ohio, USA. In a patent application dated 21 December 1942 and published [2] as US Patent No. 2350348 on 6 June 1944, the heat pipe is described as applied to a refrigeration system.

According to Nakayama (1988), Modern electronic cooling systems can be broadly divided into three systems [3]

- First level cooling
- Second level cooling
- Third level cooling

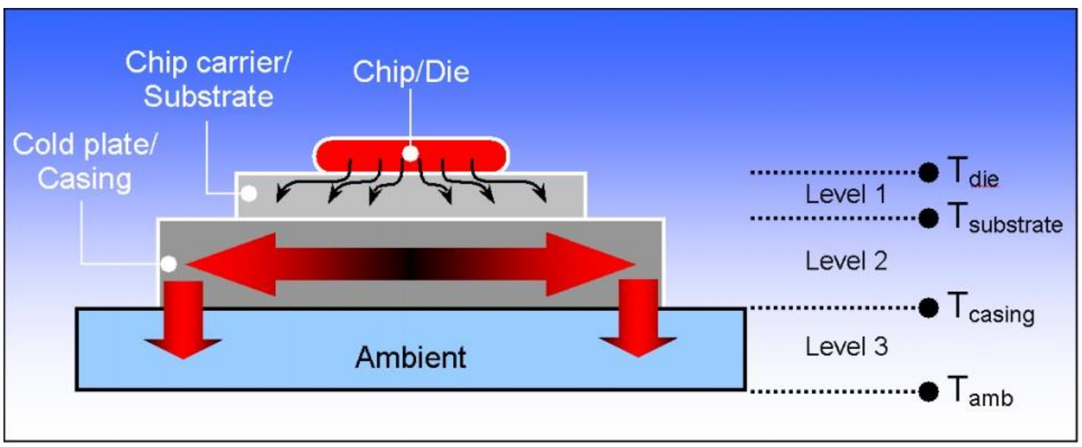

Figure 1-1 Heat transferred mechanism [3]

Phase change methods including pool boiling, jet impingement cooling, and more recently mini/micro channel flow boiling ideas have been developed in recent years while taking tight boundary requirements into account [4]. In parallel, the usage of heat pipes in different forms and designs has shown extensive promise in a variety of applications. The invention of pulsing heat pipes in the early 1990s is consistent with these advances [5] – [7] a highly promising heat transfer technique, ideal for controlling the temperature of electronics.

The primary goal of ‘cooling section’ is to enhance the package or module performance and reliability which are strong function of temperature. The temperature plays a vital role on mentioned three points [8]

- device functionality
- device safety
- device failure

With diverse working fluids and changing filling ratios in accordance with variable power input, inserting copper and aluminum wire, we are attempting to compare the heat transfer properties of a heat pipe in this thesis work. In our experiment, the pressure impact of the internal bubbles and the flow impact on temperature fluctuation are regarded as minimal.

1.2 Heat Pipe

1.2.1 History of heat pipe

A heat pipe is a tool used in the aerospace, power electronics, and micro industries to regulate temperature. The first heat pipes were invented in the 1836s by A. M. and J. Perkins.[5] 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[11] . Then, in 1942, R.S. Gaugler [2] from General Motors has an idea to enhance the heat pipe by circulating the condensation into the vaporization zone utilizing capillarity. However, due to the lack of an obvious necessity at the time due to technology, the gadget was inactive for 20 years. The first heat pipe was then shown by an engineer called George Grover at the Los Alamos National Research Laboratory in 1963. The development of heat pipes was inspired by the straightforward heat-conducting pipes that English bakers employed 100 years ago. Since their invention in 1963, heat pipes have advanced, and today, they are used for a variety of purposes, from tiny heat pipes for cooling laptop computer processors to groups of half-inch-diameter, five-foot-long pipes for NASA spacecraft to pipes with two inches (or larger) in diameter for cooling plastic injection molds.

The pipes' lengths might range from inches to 24 feet or more [11].

Beginning in the 1980s, Sony started using heat pipes in lieu of passive finned heat sinks and forced convection to cool some of its commercial electronic equipment. They were first used in tuners and amplifiers before being quickly adopted in other high heat flux electronics applications.

Heat is dissipated to the surroundings via phase change phenomena and the thermal conductivity of heat pipes. Heat flux density rises in electronics equipment due to their shrinking. The material's excessive temperature rise, which will cause more thermal stresses, is caused by an increase in density. A heat pipe is a device that operates on the working fluid's thermodynamics and hydrodynamics principles. It consists of an evaporator, an adiabatic section, and a condenser section. Heat is transferred from the heat source by the working fluid via evaporation and rejected at the condenser by condensation. The vapor is driven from the evaporator to the condenser by the difference in vapor pressure between the two. Due to the phase change phenomena, latent heat is released at the condenser. The benefit of heat transmission between modest temperature differences over a large distance is provided.

1.2.2 Types of heat pipe

Heat pipes come in a variety of varieties [11]. Here is a list of them:

- Vapor chamber (Flat heat pipe)
- Variable conductance heat pipe (VCHP)
- Pressure controlled heat pipe (PCHP)
- Diode heat pipe
- Thermo-syphon
- Rotating heat pipe

(A) Vapor chamber/flat heat pipe: This kind of heat pipe has a hermetically sealed hollow vessel and a closed loop at either end. This is mostly employed when a relatively small evaporator is subjected to high power and high heat fluxes.

(B) Variable conductance heat pipe: This kind of heat pipe keeps electronics from overheating even when the power and sink conditions are changing over time. In addition to the working fluid, this heat pipe has two extra arrangements above a typical heat pipe: (I) a reservoir, and (ii) non-condensable gases. Argon and helium make up the NCG in a typical VCHP thermosyphon heat pipe.

(C) Pressure Controlled Heat Pipe: PCHP heat pipes can tightly regulate temperature. Here, changing the evaporator temperature will either affect the reservoir volume or the mass of non-condensable gases.

(D) A diode heat pipe has low thermal conductivity in the reverse direction and strong thermal conductivity in the forward direction.

The condenser is situated above the evaporator in the thermo-syphon, which is a gravity-assisted heat pipe. After condensation, liquid flows back to the evaporator by gravity.

(F) Rotating heat pipe: The working fluid is returned to the evaporator using centrifugal force in this form of heat pipe.

1.2.3 Key Components of Heat Pipe

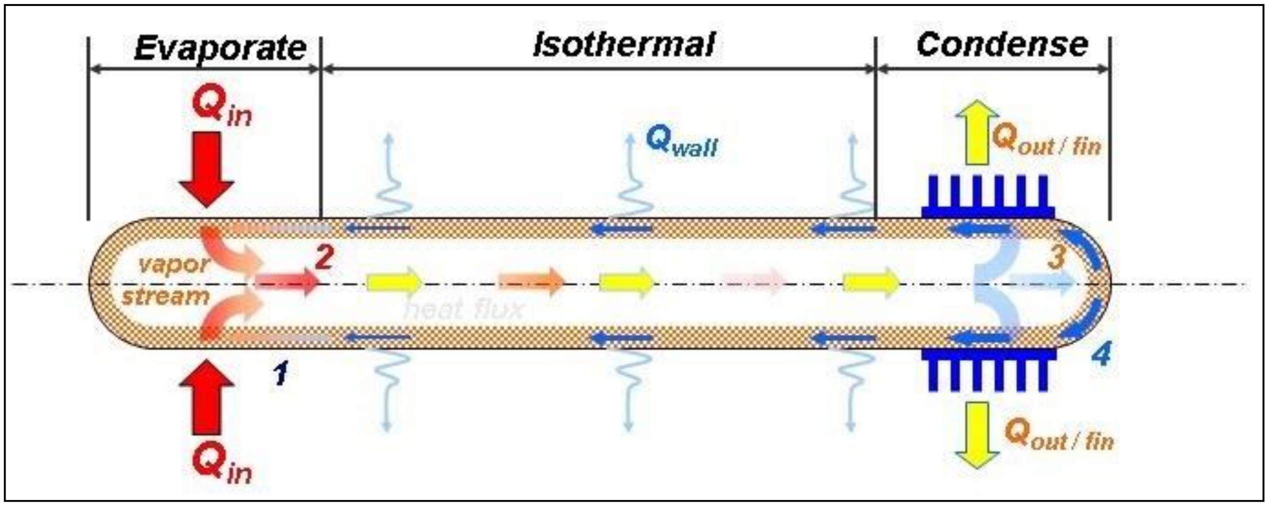

Figure 1-2 Heat pipe mechanism

Two major components of a heat pipe include:

- Container/ shell
- Working fluid

(a) **Containers**: are shells or tubes that hold the working fluid inside of them. It is constructed of a variety of materials, including copper, aluminum, steel, tungsten, and titanium. The container's material has to be more thermally conductive and suitable with the working fluid being employed. In general, copper is utilized because it has a lower cost than other materials and a greater heat conductivity of around 400 w/m° C.

(b) **Working Fluid**: The choice of working fluid for a heat pipe depends on the material being utilized. Water, ammonia, ethanol, methanol, acetone, lithium, sodium, bismuth, nitrogen, and helium are a few examples of different working fluids. Lithium, sodium, and potassium are employed for high temperature applications, whereas nitrogen or helium is used for low temperature applications.

The working fluid vaporizes and transforms into vapor at the evaporator portion, or at the heat source. The latent heat of the fluid is then released to the environment when the vapor passes through a condenser portion (a heat sink) after passing through an adiabatic region, where no heat loss occurs. The working fluid's temperature is always between the triple point and the critical point. Inside the heat pipe, the working fluid constantly stays in a saturated condition.

This pressure difference causes 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. 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. Non-condensing gases, such as those brought on by pollution, obstruct gas flow and decrease the efficiency of the heat pipe, especially at low temperatures and low vapor pressures. The maximum speed at which molecules in a gas might move through the heat pipe is about the speed of sound in the absence of noncondensing gases (i.e., if there is just a gas phase present). In actuality, the rate of condensation at the cold end limits the vapor's speed through the heat pipe, which is far slower than the molecular speed. If the condensing surface is extremely cold, the condensation rate is very close to the sticking coefficient times the molecular speed times the gas density. The evaporation brought on by the surface's limited temperature, nevertheless, substantially balances out this heat flow if the surface is near to the gas's temperature. The evaporation from the surface is often minimal if the temperature difference is more than a few tens of degrees, as can be seen from the vapor pressure curves. It is often exceedingly difficult to sustain such large temperature differences between the gas and the condensing surface due to the gas's very efficient heat transfer. Additionally, these temperature disparities naturally equate to a significant effective thermal resistance on their own. Since the gas densities are larger and the maximal heat fluxes are higher near the heat source, the bottleneck is often less severe there.

1.3 Pulsating heat pipe

Long capillary tubes are bent into several twists to form pulsating heat pipes (PHPs), where the evaporator and condenser portions are placed. There is no wick mechanism to return the condensate to the heating section, which distinguishes PHPs from ordinary heat pipes. As a result, the liquid and vapor do not flow against one another. PHPs may be used to solve a variety

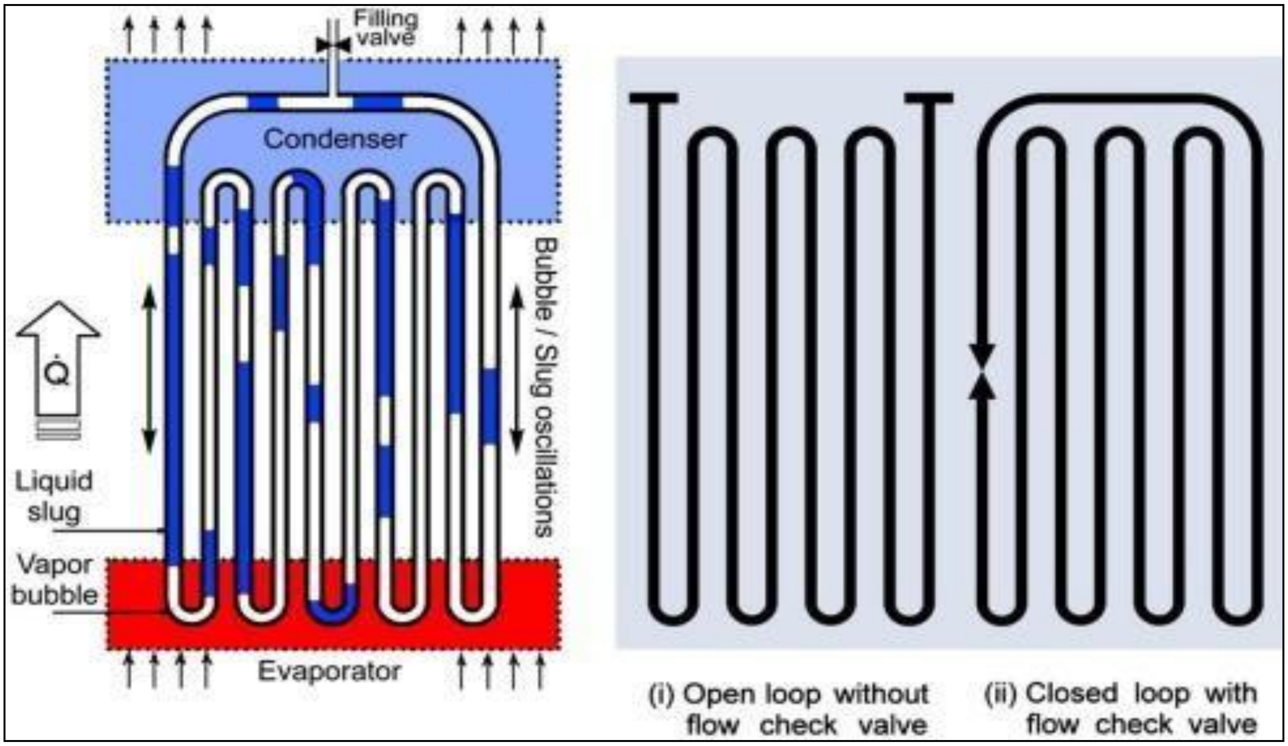

Figure 1-3 Schematic diagram of various PHP

of real-world issues, including electronics cooling. In this area, Gi et al.[12] looked at an O-shaped oscillating heat pipe used to cool a laptop computer's CPU. Because of the PHP structure's simplicity and reduced weight compared to a typical heat pipe, PHPs are excellent choices for space applications. There have been a few experimental and analytical/numerical studies on PHPs since the invention of the PHP in the early 1990s. The investigations largely concentrated on a few early findings for flow pattern visualization and measurements of temperature and effective thermal conductivity.

Like traditional heat pipes, pulsating heat pipes are closed, two-phase systems that may transmit heat without the need for extra power, but they vary significantly from ordinary heat pipes in a number of important respects. Figure 1-3 depicts a typical PHP as a tiny, meandering tube that is only half filled with a working fluid. The ends of the tube may be joined to one another in a closed loop or pinched off and welded shut in an open loop. The tube is twisted back and forth parallel to itself (see Figure 1-3). Researchers concur that the closed loop PHP performs better in terms of heat transmission. Due to this, closed loop PHPs are used for the majority of experimental work. The working fluid may also be circulated in the closed-loop PHP in addition to the oscillatory flow, improving heat transfer. Although the installation of a check valve might enhance the PHPs' ability to transmit heat by forcing the working fluid to flow in a certain direction, installing these valves is challenging and costly. As a result, the PHP structures that are closed-loop and do not have a check valve are the best option.

1.3.1 Parameters affect the performance of PHP

Six significant thermo-mechanical factors have emerged as the key design variables influencing the PHP system dynamics, according to the research that is currently accessible. These consist of:

- Internal PHP tube diameter, input heat flux, working fluid volume to volumetric fill ratio, total number of turns, device orientation with regard to gravity, and
- The thermophysical characteristics of the working fluid.

Use of flow direction control check valves, form of the tube's cross section, combination of the tube material and fluid, rigidity of the tube material, etc.

1.3.2 Design & Geometric Parameters: Diameter & material of tube

The diameter of the heat pipe is important to consider when choosing a heat pipe since it impacts how well it performs when it pulses. The PHP is directly impacted by the interior diameter. Lower wall thermal resistance and increased effective thermal conductivity are the effects of a bigger hydraulic diameter. The inner diameter of the capillary tube must be so tiny that

Dmax= 2[σ/g (liq - vap)] 1/2

Where: Liq = liquid density (Kg/m^3); Vap = vapor density (Kg/m^3); g = gravity acceleration (m/s^2); = working fluid surface tension (N/m);

Surface tension forces take control and stable liquid plugs develop if D Dmax. However, if D > Dmax, the working fluid will stratify by gravity and oscillations will stop6. This is because the surface tension is lowered. Additionally, the choice of tube material is crucial since each kind of material has a unique coefficient of heat transmission.

1.3.3 Number of turns

The more PHP is used, the more adaptable it becomes to operate with any introduction (i.e., at different edge of slant with even). Analysts have shown that if there are fewer spins, the system only operates in the vertical position and not at all in other positions. Additionally, Mamelli [12] found that nine turns Comparing the CLPHP to the one with three turns, there are several benefits: I. It may function in the horizontal heat mode as well.

ii. It has a reduced heat resistance.

iii. In terms of general effectiveness, there are fewer obvious distinctions between other fluids.

1.3.4 Evaporator and condenser section design

Evaporator and condenser design have a significant impact on heat pipe performance. In order to prevent a dry out state, it is a general guideline that the condenser should have a bigger area than the evaporator. The essential heat flux in this range was impacted by the evaporator section lengths. The essential heat transfer flux dropped as the evaporator section lengths became longer. With a heat input of Q1 that is extremely near to the dry out power Qdry-1 corresponding to the operating temperature, it is assumed that the heat pipe is working at an adiabatic temperature of T1. There is a chance of a dry out happening if, under such operating circumstances, the condenser capacity is raised by either reducing the coolant temperature or increasing the coolant mass flow. Due to the working temperature dropping to T2, for which the heat input Q1 is too high, this will occur. Therefore, for traditional heat pipes, increasing the condenser capacity is not always necessary to increase heat transmission. Even while pulsing heat pipes don't have a clearly defined adiabatic working temperature, the influence of condenser capacity may be shown to follow a similar pattern. In addition to changing the working fluid's thermo-physical characteristics, increasing the condenser capacity also changes the slug-annular flow pattern.

transitions, changing the performance as a whole. When practical designing, this element must be taken into consideration.

1.3.5 Bend Effect:

Their U-tern quantities are accessible in PHP geometry. Mamelli [31] explained how twist affects PHP execution. The 180° and 90° twisted weights cause pipe tragedy. Mamelli [23] has also created a numerical model to take the local pressure loss occurring in the PHP into consideration.

1.3.6 Operational Conditions: Ratio of filling:

The volume percentage of the heat pipe that is first filled with liquid is known as the filling ratio. When the maximal heat transfer rate is realized at a certain temperature, the ideal filling ratio is ascertained experimentally.

1.3.7 Temperature of Heat Flux

Although they may be very effective heat spreaders, PHPs are thermally determined non-balance devices, and a temperature difference between the evaporator and condenser is necessary for them to continue operating. Most of the time, it was seen that some basal heat motion or temperature difference was crucial to initiate a flowing stream. The first heat transition varied with each experiment, much as the appropriate charge ratio. As a result, parametric analysis is necessary to fully understand this work. When there aren't many turns, a fundamental heat transition between 5.2 and 6.5 W/cm^2 is anticipated to ignite a smooth movement and reach a satisfying pseudo-unchanging condition

1.3.8 Dry-out conditions

This issue limits how well heat pipes can work. When all of the working liquid has evaporated and the region around the evaporator is completely dry, we may say that a dry out situation has occurred. Low filling percentage results in this situation.

and the pipe receives a lot of heat input. When a dry situation is reached, conduction is the only mechanism through which heat exchange occurs.

1.3.9 Working fluid characteristics

The choice of working fluids is another crucial factor that affects how PHP functions. The qualities of the liquid directly influence the choice of working liquid. Both the ability to exchange heat and the equivalency with the tube material will be influenced by the characteristics. The working fluid should be selected in a way that supports the PHP working temperature run. The following working liquid characteristics should be examined when selecting a working liquid: Similarity to the OHP material(s), heat security, wettability, sensible vapor weight, high inert heat conductivity, low fluid and vapor viscosities, and a satisfactory solidifying point are also factors.

The thermodynamic properties of water make it a good choice for PHP applications for the majority of applications since it has high dormant heat, which distributes more heat with less liquid stream, and high heat conductivity, which restricts data. Water, however, has a high surface pressure and may negatively impact the PHP by adding grating and accelerating the PHP's two-stage stream movements. Given that it has around 33% the surface strains of water, methanol is a good substitute for it, especially in situations where the temperature is below zero

1.3.10 Properties of Working Fluid:

The choice of working fluid is another crucial factor that impacts PHP speed. The choice of working fluid is closely related to the fluid's characteristics. Both the capacity to transport heat and the comparability with the tube material will be impacted by the characteristics. It is important to choose a working fluid that can operate within the PHP operating temperature range. Table 1 displays the range of temperatures for several fluids.

The following working fluid qualities should be looked at when choosing a working fluid:

The material's compatibility with OHP (s),

Thermal stability is another.

Acceptable freezing point

Fourth, a manageable vapor pressure, High thermal conductivity and latent heat,

Low viscosities of liquid and vapor,

Water's high latent heat, which distributes heat more evenly with less fluid movement, and high thermal conductivity, which reduces d_T, making it a suitable option for PHP applications in the majority of cases. Water does, however, have a high surface tension, which might be detrimental to the PHP as it could increase friction and restrict the PHP's two-phase flow oscillations. Due to its lower surface tension than water, methanol makes a viable replacement, particularly in sub-zero situations.

Table 1 Temperature Range of Working Fluid

Working Fluid	Melting Point (°C)	Boiling Point (°C)	Useful Range (°C)
Methanol	-98	64	10 to 130
Ethanol	-112	78	0 to 130
Water	0	100	30 to 200
Acetone	-94.7	56	25 to 55

1.3.11 CLPHP Limitations

The rate of condensation and evaporation is the only factor affecting how quickly heat is transferred through the heat pipe.

• **Capillary Limit**: This condition arises when the capillary pressure is insufficient to transfer enough liquid from the condenser to the evaporator. leads in the evaporator to dry out. Dry out makes it impossible for the thermodynamic cycle to continue, and the heat pipe stops working correctly.

• **Boiling Limit**: this condition develops when the liquid in the wick boils and evaporates, leading to dry out. It is brought on by radial heat flux into the heat pipe.

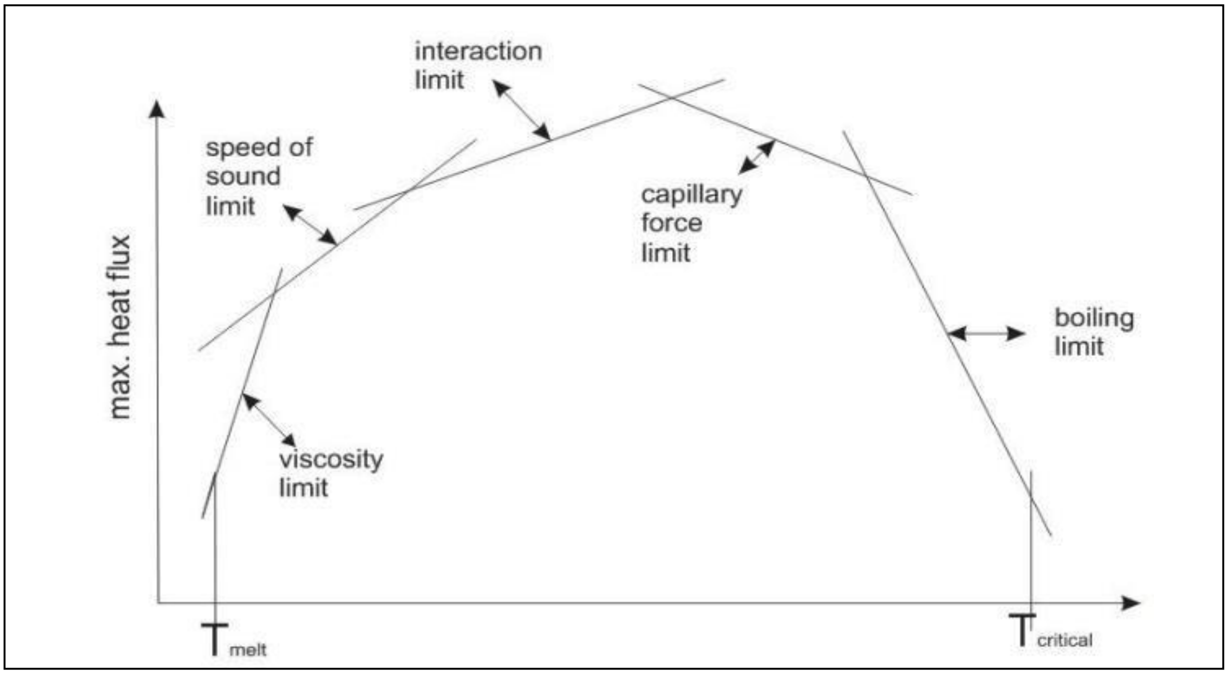

Figure 1-5 Limitation of PHP

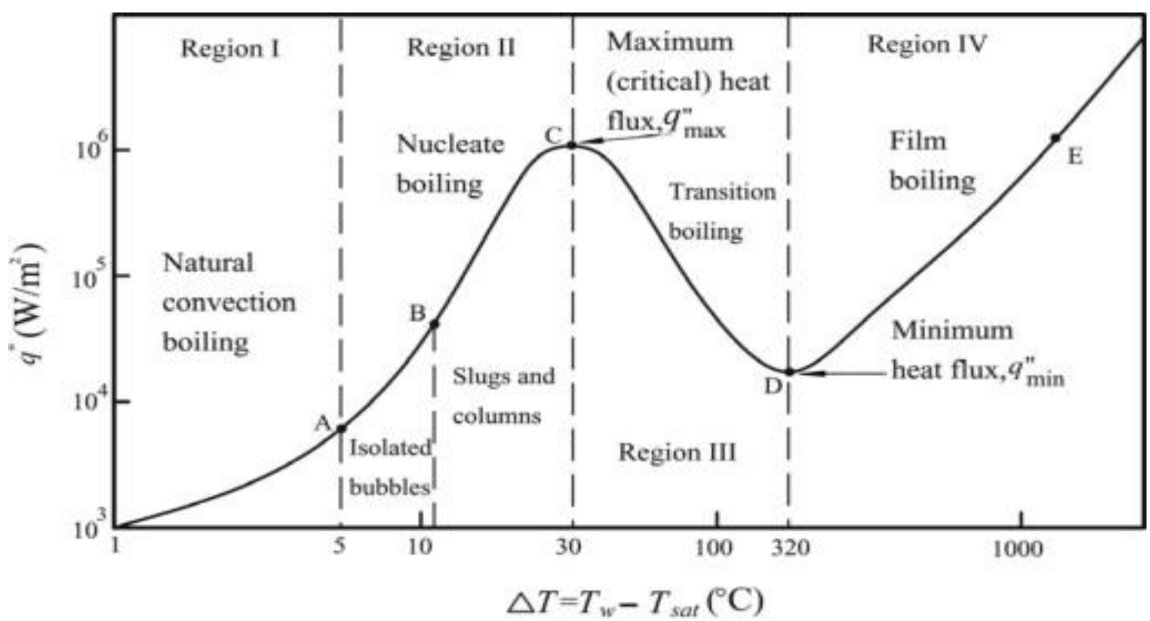

Figure 1-4 Boiling Curve [32]

1.3.12 Convectional Heat Transfer

Convection is a significant way of mass transport in fluids and one of the main kinds of convective heat transfer. Both advections, in which matter or heat is transferred by the larger-scale motion of currents in the fluid, and diffusion, the random Brownian motion of individual particles in the fluid, are mechanisms for convective heat and mass transmission. Convection is the word used to describe the combination of advective and diffusive transfer in the context of heat and mass transport. The word "convection" is often used to refer broadly to the convection process, heat transmission by convection as opposed to mass transfer by convection. As contrast to "forced heat convection," which occurs when forces other than buoyancy (such as a pump or fan) move the fluid, "free heat convection" (natural heat convection) is caused by temperature-induced changes in buoyancy. The term "convection" should only be used in its broadest meaning in mechanics, and for the sake of clarity, distinct forms of convection should be distinguished. Based on driving power, convection may be divided into two categories:

• **Natural/free/Passive convection**: This phenomenon is brought on by temperature variations that alter the density and therefore the relative buoyancy of the fluid. Bulk fluid flow results from the movement of heavier, denser components falling and lighter, less dense ones rising. Therefore, natural convection can only happen in a gravitational field. The Rayleigh number may be used to identify when natural convection begins (Re).

• **Forced/Active convection**: Also known as heat advection, this kind of convection occurs when external surface forces, like a fan or pump, are applied. Usually, forced convection is utilized to speed up heat transfer. The Nusselt Number may be used to calculate the ratio of convective to conductive heat transfer across the boundary (Nu).

Were,

Nu =

$Convective\ Heat\ Transfer$

$Conductive\ Heat\ Transfer$

= $h.\ e$ / sk

Likewise, Nu = f (Re)

Reynold's Number is used here.

Numerous empirical formulae are related to this since the function depends on several factors.

1.4 Hypothesis

We know copper has higher thermal conductivity, and aluminum's thermal conductivity is comparatively low [9].

Aluminum can never perform better at heat transmission than copper does. Because it is less expensive, lighter, and more corrosion-resistant than steel, aluminum is often a preferable option for heat sinks. Therefore, it's feasible that over time, aluminum heat sinks might outperform a corroded, dirty copper heat sink.

And we know in CLPHP with copper wire insert Thermal resistance will low rather than with-out insert [10]

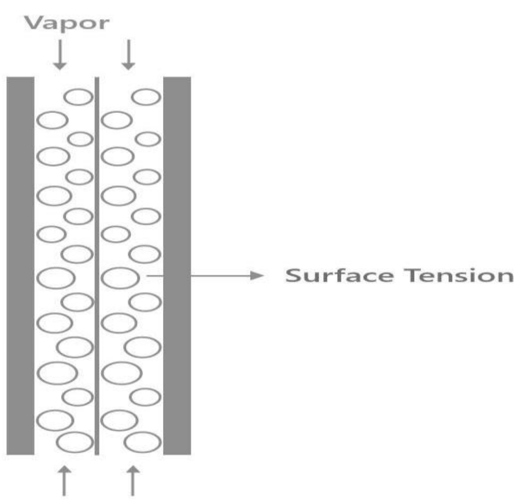

Figure 1-6 CLPHP with wire insert

1.5 Objectives

The aims of this thesis are:

1. To investigate the performance of CLPHP with copper wire insert with various working fluids
2. To examine the performance of CLPHP with aluminum wire insert with same working fluids used for copper wire insert
3. To compare the thermal performance of CLPHP with two (copper and aluminum) different wire inserts.

Chapter 2

2 Literature Review

2.1 Close Loop Pulsating Heat Pipe

Like traditional heat pipes, pulsating heat pipes are closed, two-phase systems that may transmit heat without the need for extra power, but they vary significantly from ordinary heat pipes in a number of important respects. A typical PHP as a tiny, meandering tube that is only half filled with a working fluid. The ends of the tube may be joined to one another in a closed loop or pinched off and welded shut in an open loop. The tube is twisted back and forth parallel to itself. Researchers concur that the closed loop PHP performs better in terms of heat transmission. Due to this, closed loop PHPs are used for the majority of experimental work. The working fluid may also be circulated in the closed-loop PHP in addition to the oscillatory flow, improving heat transfer. Although the installation of a check valve might enhance the PHPs' ability to transmit heat by forcing the working fluid to flow in a certain direction, installing these valves is challenging and costly. As a result, the PHP structures that are closed-loop and do not have a check valve are the best option.

Recently, Holley and Faghri [13] and Zuo et al. [14] [15] prototyped and studied PHPs using a sintered metal wick. Both heat transmission and liquid dispersion should be aided by the wick. A PHP must have at least one area that is heated and another that is cooled. The capillary tube's bends are often where the evaporators and condensers are situated. A working fluid is first partly injected into the tube after it has been emptied. As liquid slugs and vapor bubbles, the liquid and its vapor will be dispersed throughout the pipe. The bubbles in the PHP's evaporator portion will see a rise in vapor pressure as it warms up. This pushes the liquid slug towards the direction of the heat pipe's condenser portion. The vapor bubbles will start to condense as they get to the condenser. Vapor pressure falls when the vapor transitions phases, causing the liquid to return to the condenser end. In this manner, the PHP is configured to have a constant oscillating flow. New vapor bubbles will also arise as a result of boiling the working fluid. There are two types of research on PHPs: experimental and theoretical. While experimental research has concentrated on either defining the heat transfer or visualizing the flow pattern in PHPs.

Theoretical studies try to numerically and analytically simulate the heat transfer and/or fluid dynamics related to oscillating two-phase flow. A PHP is a sophisticated heat transfer device whose performance is strongly governed by a thermo-hydraulic coupling. It functions fundamentally as a heat transfer non-equilibrium device. The ongoing upkeep or sustenance of these non-equilibrium situations inside the system is crucial to the device's performance success. The pressure pulsations that are created in the system lead to the transfer of liquid and vapor slugs. Due to the device's intrinsic design, these pressure pulsations are entirely thermally powered, therefore no additional mechanical power source is needed for the fluid transfer.

2.1.1 Evolutions of PHP

In the 1960s, conventional heat pipes (CHP) really started to take off; since then, a number of other geometries, working fluids, and wick structures have been suggested [14]. New heat pipe forms, such capillary pumped loops and loop heat pipes, have been developed during the last 20 years in an effort to solve some of the drawbacks of traditional heat pipes by separating the liquid and vapor fluxes.

The pulsing or oscillating heat pipe is a novel form of heat pipe that was created in the 1990s by Akachi et al (PHP or OHP) [16] . Because it could be able to dissipate the large heat fluxes needed by next-generation electronics, PHP is most often used in electronics cooling. Other suggested uses for PHPs include pumping water or preheating air. This review article will explain how pulsing heat pipes work, provide an overview of the research and development over the last ten years, and go through any unresolved problems.

Based on self-excited oscillation and assuming reciprocal excitation between pressure oscillation and void fraction, Miyazaki and Akachi [16] developed the wave equation of pressure oscillation in a PHP. By resolving the wave equation, they also derived a closed-form solution for the wave propagation velocity.

In their experimental study on the oscillatory flow in the PHP, Miyazaki and Arikawa[17] determined the wave velocity, which was in reasonable agreement with Akachi et al. [16]'s prediction.

According to Lee et al [18], nucleate boiling and vapor oscillation create bubble oscillations, and the departure of tiny bubbles is regarded as the typical flow pattern at the evaporator and adiabatic section, respectively.

Numerous experiments were performed by Khandekar [8] for different PHP settings. He investigated of how various criteria affected their behavior (filling ratio, heat input, number of turns, orientation). He increased his knowledge of the heat and fluid flow mechanics of PHPs as a result of his experiments. He spoke on the need of choosing a tube diameter that would allow for flow oscillations.

Additionally, Khandekar et [19] carried out some flow visualizations when a PHP was in use. They identified four operating regimes that are comparable to the PHP operating curve (the heat pipe's total thermal resistance as a function of input power). At low heat input, the oscillations' amplitude is constrained, and as heat input increases, the thermal resistance marginally lowers. A slug flow pattern results from a more pronounced drop in thermal resistance with increased heat input. However, when the heat input is increased, a preferred flow direction gradually emerges. When the flow pattern is circular rather than slug-like and the preferred flow direction is clearly identified, the thermal

There is little resistance and a plateau. Finally, the evaporator dries out when there is a significant heat flux because the thermal resistance sharply rises as the heat input rises.

In their studies with three different fluids, Khandekar et al. [19] gave further information (ethanol, water, R-123). In contrast to the latter, where the critical diameter was on par with (or even slightly below) the tube diameter, the critical diameter for ethanol and water was much greater than the tube diameter. Their research indicates that the filling ratio and orientation of the PHPs have an impact on the influence of bubbles on the two-phase oscillating flow that emerges from the extreme operational limits of PHPs (i.e., PHP entirely empty or fully loaded with liquid). The bubbles tend to restrict the mobility of the two-phase fluid at high filling ratios (like 95% of liquid) and advantageous orientations (like evaporator at the bottom, condenser at the top). Gravity was shown to be a factor even for water at moderate filling ratios (roughly 20% to 70%, which actually results in oscillations), i.e., even for a critical diameter noticeably larger than the tube diameter (highly confined situation). However, with R-123, the PHP was found to function despite a critical diameter slightly lower than the tube diameter. All of these findings were explained by taking into account how bubbles affected the two-phase flow as well.

P. Charoensawan et al [20]. have a piece on how CLP affects them.

HP's thermal performance is affected by a variety of factors, including the device's inclination angle, working fluid, number of turns, and internal tube diameter. The results of this experiment showed that buoyancy forces have an impact on bubble shape, internal diameter must be specified with a critical Bond number within the limit, and performance can be increased by increasing the ID and/or number of meandering turns. Gravity has a significant impact on CLPHP performance. Depending on the operating circumstances, relative amounts of latent and sensible heat, and flow characteristics, various fluids are advantageous.

In a meandering closed loop heat transfer system, Hosoda et al. [21] looked at the propagation of vapor plugs. They noticed that at large liquid volume fractions, a straightforward flow pattern appeared. Under these circumstances, only two vapor plugs may be found separately in adjacent rounds, and one of them begins to contract as the other begins to expand. Additionally, a streamlined numerical solution was carried out under a number of significant presumptions, excluding any potential liquid coating between the tube wall and the vapor stopper.

Riehl [22] tested an open loop PHP in various orientations using a variety of working fluids. Using water, ethanol, propanol, methanol, and acetone as working fluids, he compared the thermal performance of a PHP. Methanol and acetone produced the best thermal performance under his test circumstances, while water produced the poorest. Additionally, he noticed that when using methanol rather of water, the oscillations in the PHP are more significant and frequent. This was explained by the methanol's low latent heat, which encourages boiling and nucleation and, as a result, fluid flow instability. Finally, he discovered that horizontal orientation performed thermally better than vertical orientation. But the significance

With ethanol and methanol, the ratio of thermal resistances in horizontal and vertical orientation is more than two, but with water, thermal performance is virtually completely independent of orientation.

With the use of a high-speed video, Xu et al. [23] were able to see the oscillatory flow in a closed loop PHP. Different oscillation modes for methanol and water were found. Water was used as the working fluid, and this emphasized the coalescence and vapor plug break-up processes, especially at the tube U-bends. Based on an analytical model, they concluded that the capillary pressure is not constant in the bends, causing a localized buildup of liquid. Additionally, they claimed that the low surface tension of the working fluid, methanol, limits the coalescence or break-up. The liquid plugs are then longer than they are with water.

Experimental research on the operating limitations of closed loop pulsating heat pipes is presented by Honghai Yang et al. in their publication at [24]. (CLPHPs). Vertical bottom heated, horizontal heated, and vertical top heated orientations were the three operating orientations examined. On thermal performance and performance limitation, the impacts of inner diameter, operating orientation, filling ratio, and heat input flux were examined. The CLPHPs were run until they reached a performance threshold marked by severe evaporator overheating (dry-out). It is possible to handle heat loads that are rather high. The effects of inner diameter, filling ratio, operational orientation, and heat load on thermal performance and the occurrence of performance restriction in the form of evaporator dry-out were examined in an experimental investigation on two closed loop pulsing heat pipes (CLPHPs). In general, the vertical bottom heat mode with a 50% filling ratio gives CLPHPs their greatest thermal performance and highest performance cap. Performance variations brought on by various heat modes (i.e., the gravity effect) become very minor or even inconsequential as the inner diameter shrinks.

In this study, we investigated the influence of inner diameter and inclination angles on the operating limit of closed loop oscillating heat pipes with check valves (CLOHP/CV). R123 was utilized as the working fluid in copper tubes with an ID of 1.77 and 2.03 mm and 10 turns. The evaporator, adiabatic, and condenser sections had five equal lengths with inclination angles of 0, 20, 40, 60, 80, and 90°. According to P. Meena et al. [25], the critical temperature rose when the inner diameter changed from 1.77 to 2.03 mm. The critical temperature rose as the inclination angles grew from 0 to 90 degrees.

In a tiny U-shaped channel, oscillatory flow and heat transport were quantitatively examined by Zhang and Faghri [26]. The heating portions were the two sealed ends of the U-shaped tube. In the center of the U-shaped channel was the condenser portion. With two sealed ends (heating portions) at the top, the U-shaped channel was positioned vertically. Investigations were also conducted on how different non-dimensional characteristics affected PHP performance. The amplitude and circular frequency of the oscillation were empirically correlated.

Given that sensible heat accounts for over 90% of the heat transfer from the evaporator to the condenser, Shaffi et al. [27] and Zhang and Faghri [28] both discovered that heat transmission in a PHP is mostly caused by the exchange of heat. The major impact of evaporation and condensation on the functioning of PHPs was the oscillation of liquid slugs, and latent heat had less of an impact on the total amount of heat transmission.

By conducting an experiment, Kang et al. [29] showed that the temperature difference between silver Nano-fluids and DI-water dropped by 0.56-0.65°C at an input power of 30–50W at the same charge volume.

A scientific experiment was carried out by Qu et al. [30] using base water and 56 nm-diameter spherical Al_2O_3 particles. When the power input was 58.8W at 70% filling ratio and 0.9% mass fraction, the maximum thermal resistance was lowered by 0.14 °C/W (or 32.5%) in comparison to pure water.

The downsizing of heat pipes led to a significant advancement in the present use of heat pipe technology. The American and Japanese heat pipe businesses have lately been actively conducting studies on the use of heat pipes even with a diameter of 2 mm for cooling of the laptop PC and CPU.

The tiny heat pipe has shown to have a surprising impact in recent years when used to dissipate heat and maintain a constant temperature for computers and other electrical devices. Therefore, a comprehensive analysis of the small heat pipe is essential for its ongoing development and performance enhancement.

This post will first evaluate some experimental findings that were made using a full-sized PHP. We shall pay special attention to the effects of fluid and tube diameters, as well as orientation. The findings of an experimental examination of the oscillating flow in a single tube of a single liquid plug under adiabatic circumstances (purely hydrodynamic aspect) and under non-adiabatic conditions will next be discussed to aid in our analysis of the results obtained at the system scale (thermal effects due to heating of the test-section).

Chapter 3

3 Experimental Setup

As mentioned in the preceding chapter, the general knowledge of the CLPHP function was still in the growing phases at the initiation of the current study endeavor.

3.1 Common peripheral devices

- Pulsating heat pipe
- Working fluid
    - Methanol
    - Ethanol
    - Distilled Water
    - Acetone
- Test stand
- Heating apparatus
    - Variac
    - Power Supply Unit
    - Nichrome Thermal Wire
    - EPE Insulation foam
- Insulating apparatus
    - Mica tape
    - Glass wool
    - Foam tape
    - Asbestos tape
- Measuring apparatus
    - Temperature Sensor (DS18B20)
    - Multimeter

- Other Equipment
    - AC fan
    - Adapter circuit
    - Arduino Mega
    - Arduino 1.5.2 Compiler
    - Glue Gun
    - Super Glue
    - Electric Wire
    - Copper Wire 0.9mm (Insert)
    - Aluminum Wire 0.9mm (Insert)
    - Digital Vernier Caliper.
- Data Acquisition System (DAQ)
    - PLX-DAQ

3.2 Description of Different types of Apparatus

3.3 Working Fluid:

3.3.1 Methanol:

Methanol is a substance with the chemical formula CH_3OH, also known as methyl alcohol, wood alcohol, wood naphtha, or wood spirits (often abbreviated MeOH). Because it was previously produced primarily as a byproduct of the destructive distillation, methanol was given the name "wood alcohol."

from wood. Modern methanol is made in an industrial catalytic process directly from hydrogen, carbon dioxide, and monoxide.

The most basic alcohol, methanol is a light, volatile, colorless liquid that is flammable and has a distinct odor that is very similar to that of ethanol (drinking alcohol). Methanol, in contrast to ethanol, is extremely toxic and not suitable for human consumption. It serves as a denaturant for ethanol and is used as an antifreeze, solvent, fuel, and polar liquid at room temperature. Additionally, it is employed in the transesterification reaction used to make biodiesel.

Methanol is frequently found in trace amounts in the environment and is naturally produced in the anaerobic metabolism of numerous bacterial species. As a result, a negligible amount of methanol vapor is present in the atmosphere. Methanol in the atmosphere is oxidized by sunlight over the course of several days to carbon dioxide and water.

In the presence of oxygen, including in the open air, methanol burns to produce carbon dioxide and water:

$2\ CH_3OH + 3\ O_2 \rightarrow 2\ CO_2 + 4H_2O$

Methanol properties:

Table 2 Methanol properties

SL. No.	Parameters	Symbol	Quantity	Unit
1.	Freezing temperature	T_{freeze}	-97.6	°C
2.	Boiling temperature	T_{boil}	64.7	°C
3.	Density	P	792	kg/m³
4.	Specific heat (at 20°C)	C_p	2.5	Kj/kg-k
5.	Vapor pressure	Pv	13.02	kPa
6.	Molar mass	Ms	32.04	g/mol

3.3.2 Ethanol

Ethanol is also known as ethyl alcohol and drinking alcohol, but is most frequently just referred to as alcohol or spirits. It is the main type of alcohol present in alcoholic drinks made by yeasts fermenting sugars. It is one of the earliest neurotoxic psychoactive drugs.

human recreational drug use. When consumed in large enough quantities, it can lead to alcohol intoxication. In contemporary (post-mercury) thermometers, ethanol serves as the active fluid, an antiseptic, a fuel, and a solvent. It is a flammable, colorless liquid that is volatile and has a potent chemical odor.

Its chemical name, CH_3CH_2OH, is frequently shortened to C_2H_5OH or C_2H_6O.

Ethanol properties:

Table 3 Ethanol properties

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 25°C)	C_p	2.57	Kj/kg-k
5.	Vapor pressure	Pv	5.95	kPa
6.	Molar mass	Ms	46.07	g/mol

3.3.3 Acetone

Acetone is a flammable, highly volatile substance. It quickly permeates the body through cutaneous absorption, ingestion, and inhalation. Acetone is metabolized after it has been absorbed, although the choice of metabolic pathway and the pharmacokinetics appear to be dose-dependent. Acetone excretion can be seen in the breath and urine. Acetone inhaled is narcotic and has short-term effects on the central nervous system, although it is not neurotoxic. Employees exposed to acetone for weeks do not display persistent concerns in work conditions. Acetone is not mutagenic or genotoxic. As it stands, acetone is dangerous because it increases the toxicity of methylglyoxal and other volatile organic solvents.

Acetone properties:

Table 4 Acetone properties

SL. No.	Parameters	Symbol	Quantity	Unit
1.	Freezing temperature	T_{freeze}	-95	°C
2.	Boiling temperature	T_{boil}	56	°C
3.	Density	P	784	kg/m³
4.	Specific heat (at 25°C)	C_p	4.184	Kj/kg-k
5.	Vapor pressure	Pv	1	kPa
6.	Molar mass	Ms	58.08	g/mol

3.3.4 Distilled Water

Water that has been heated into vapor and then condensed back into liquid in a different container is known as distilled water. The original container still contains any impurities in the original water that do not boil at or below the boiling point of water. So, one kind of cleansed water is distilled water.

Distilled Water properties:

Table 5 Distilled Water properties

SL. No.	Parameters	Symbol	Quantity	Unit
1.	Freezing temperature	T_{freeze}	0	°C
2.	Boiling temperature	T_{boil}	100	°C
3.	Density	P	997	kg/m³
4.	Specific heat (at 25°C)	C_p	4.187	Kj/kg-k
5.	Vapor pressure	Pv	3.157/25 °C	kPa
6.	Molar mass	Ms	18.01528	g/mol

3.4 Test Stand

All additional equipment is put onto a wooden frame that serves as the basic framework. The kerosene wood frame can support any weight with the necessary stability. The test stand, which is made of wood, is where the heat pipe is kept. There is a base on which a box has been placed. It houses the heat pipe's evaporator portion. Ni-C thermal wire (also known as Nichrome Wire), which is attached to the variac, is used to connect the evaporator section. Two columns that are set within a sizable wooden foundation serve as the structure's main structural supports. It includes a base that tilts rearward to accommodate an AC fan for forced convection.

3.5 Heating Apparatus

3.5.1 Nichrome Wire

The average composition of nichrome wire is 80% nickel and 20% chromium. Nichrome wire has a high internal resistance, which causes it to heat up quickly when electricity is applied and cool down quickly when the heat source is turned off or removed. It has a greater melting point than other wire and maintains its strength as the temperature increases. It is non-magnetic, has a high degree of flexibility, and neither oxidizes nor corrodes. In our experiment, we heated up the test part using Nichrome wire, and the internal resistance was around 18 m. Its specific heat is 450 JKg-1K-1 and its resistivity ranges from 1.0 x 10-6 to 1.5 x 10-6 m.

3.5.2 VARIAC

A variac offers variable voltage to execute various processes or those that sometimes call for a different voltage. With this power supply, we were able to employ voltages between 20 and 80 volts.

It is coupled with the power source to provide variable power (heat input) via changing voltage output.

Table 6 Variac Specification

Phase	3ϕ
Rated capacity	300 volts
Rated frequency	60 Hz

3.6 Insulating Apparatus

3.6.1 Mica Tape (Electric Insulation)

As nichrome wire was wound all around the evaporator, this was utilized as electrical insulation. The name "mica" refers to a class of minerals with flawless cleavage. They are really silicate sheets. Given the material's sparkling look, the term "micare" is a translation of the Latin word "micare," which means to shine. Mining for mica is the first step in Von Roll's dedication to the material, which continues with the creation of specialty mica tapes and mica auxiliary components. Next comes the highly specialized sector of making paper from mineral.

Phlogopite and muscovite are the two varieties of mica that Von Roll utilizes in a wide range of applications, depending on the required electrical characteristic, particularly in:

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

3.6.2 Glass Wool (thermal Insulation)

Glass fibers are organized with the aid of a binder to create glass wool, an insulating material with a texture like that of wool. To keep the heat contained in the desired area, this was employed around the adiabatic portion. The procedure creates many tiny air gaps between the glass, and these air pockets provide excellent thermal insulation capabilities. Glass wool is made as slabs or rolls, with various mechanical and thermal characteristics. On the surface to be insulated, it may alternatively be created as a substance that may be sprayed on or applied directly. Games Slayter, a worker at the Owens-Illinois Glass Co., created the contemporary process for making glass wool (Toledo, Ohio). In 1933, he filed his first patent application for a novel method of producing glass wool.

3.6.3 Foam tape

EPE Insulation from heat and noise is provided by foam tape. A few wraps of foam tape may provide both space and adhesion between several wires in wiring and cabling systems. It is helpful in robot drive trains and other activities, and it performs a range of significant roles in the development of robots. Foam tape is produced in a variety of forms, including rolls.
Additionally, other adhesives, such as rubber and acrylic adhesives, are utilized on the tape itself, each of which has its own benefits and cons. This was utilized in the adiabatic portion to surround glass wool.

3.6.4 Asbestos tape

Typically, it is used for thermal insulation. Duct tape was designed to be used for taping different types of ducts, notably those used for heating. Its name, which everyone has grown to know and love, derives from this highly useful purpose. The tape prevents heat from escaping, making it a practical and cost-effective device. Duct tape has evolved into a popular household item with many applications. It is available in a wide range of hues, sizes, and degrees of quality. We utilized 2" wide by.25" thick asbestos tape for our experiment.

3.6.5 Silicon Tube

The extremely durable elastomer known as silicone tubing has exceptional levels of strength, flexibility, and resistance. Silicone tubing is extremely adaptable and can be stretched without ripping. Its considerable flexibility prevents steel from being weakened by frequent bending and twisting. Since silicone tubing can be made as a medical-grade material and is both exceedingly sanitary and non-toxic, it is a preferred option for usage in healthcare and medical applications.

3.7 Cooling Apparatus

3.7.1 Fan

We utilized an axial AC fan to cool the system. The most often used and most economical kind of cooling fan is an axial fan, whether they are AC axial fans or another type. They circulate air through the fan on a straight axis and are sometimes referred to as "box fans." Low system impedance or low-pressure environments are ideal for this kind of fan's performance. An axial fan's noise output may be minimized by reducing fan speed. owing to their low degree of audible noise and affordable price range.

3.8 Measuring Apparatus

3.8.1 Temperature Sensor (DS18B20)

The DS18B20 is an integrated circuit sensor having a temperature-dependent electrical output that may be used to monitor temperature (in 150^{o}C). Six sensors in all are attached to the pulsing heat pipe's wall: three for the evaporator part and the remaining three for the condenser section. To measure temperature, they are calibrated and attached to various heat pipe segments. It is inexpensive and, as a result of its popularity, is offered in a variety of probes.

The best advantage of employing the sensors is obtained by integrating them with the Arduino microcontroller to get precise data and readings using programming language.

The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an
alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18B20
communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. It has an operating temperature range of -55°C to +125°C
and is accurate to ±0.5°Cover the range of -10°C to +85°C. In addition, the DS18B20 can derive power
directly from the data line ("parasite power"), eliminating the need for an external power supply. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same
1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a
large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment, or machinery, and process monitoring and
control systems.[33]

3.8.2 Multimeter

A VOM (volt-ohm-milli-ammeter), commonly referred to as a multimeter or multimeter, is an electronic measuring device that integrates many measurement capabilities into a single unit. Voltage, current, and resistance may all be measured using a conventional multimeter. Readings are shown on an analog multimeter's microammeter, which has a moving pointer.

3.8.3 Watt Meter

A lot of electricity can harm the wattmeter, which is a highly delicate device. All wattmeters are designed to handle a safe maximum current. The maximum permitted current in many devices is restricted to 16 A. It denotes a power output of 3,680 W at 230 V AC mains voltage. It is important to keep this current and power amount in mind to avoid harming the wattmeter. Overload protection is also included in certain gadgets.

3.8.4 Arduino Mega 2560 micro-controller

ADC: 10 bits

Analogue reference: 2.56 volt

Sensor range: 0 ^{o}C-110^{o}C (working)

Smallest measured temp: 0.11^{o}C

A microcontroller board called the Arduino Mega is based on the ATmega2560 (datasheet).

It contains 16 analog inputs, 4 hardware serial ports, a 16 MHz crystal oscillator, 54 digital input/output pins, 15 of which may be utilized as PWM outputs, a USB port, a power connector, and an analog input.

A reset button and an ICSP header. It comes with everything required to support the microcontroller; to get started, just plug in a USB cable, an AC-to-DC converter, or a battery. The majority of shields made for the Arduino Duemilanove or Diecimila are compatible with the Mega.

3.8.5 Arduino Compiler

The software is executed on the Arduino mega using the Arduino 1.5.2 compiler. In addition, a customized piece of software was created to get exact temperature input.

3.9 Other Equipment

3.9.1 Electric Wire

Electric wire with a tiny diameter was used to conduct the flow of electricity. Heat sensor component that combines the DS18B20 electrical wire needed to give and receive data.

3.9.2 Syringe 10ml

Pascal developed the hydraulic press and the syringe while experimenting. These devices are based on the idea known as Pascal's principle, which states that pressure applied to a confined liquid will travel undiminished through the liquid in all directions regardless of the area to which the pressure is applied.

3.9.3 Aluminum foil tape

Foil tapes have a specifically designed metal-foil backing that helps explain its flexible, conductive, and robust properties.

It is use to glue between Sensor and CLPHP

3.9.4 Digital Vernier Caliper

- Metric or imperial dual reading
- Extra-large display screen
- Hardened stainless steel
- Four measurement functions
- Fine adjustment roller
- Complete with storage case and battery
- Material: stainless steel
- Range: 0-150mm/ 6 inches
- Measuring range mm.: 0-150mm
- Good quality product

3.10 Data acquisitions system (DAQ)

PLX-DAQ

PLX-DAQ is a Parallax microcontroller data acquisition add-on tool for Microsoft Excel. Any of our microcontrollers connected to any sensor and the serial port of a PC can now send data directly into Excel. PLX-DAQ has the following features:

- Plot or graph data as it arrives in real-time using Microsoft Excel
- Record up to 26 columns of data
- Mark data with real-time (hh:mm:ss) or seconds since reset
- Read/Write any cell on a worksheet
- Read/Set any of 4 checkboxes on control the interface
- Example code for the BS2, SX (SX/B) and Propeller available
- Baud rates up to 128K
- Supports Com1-15

System Requirements

- Microsoft Windows 98
- Microsoft Office/Excel 2000 to 2003
- May not work with newer software; no longer supported.

3.11 Experiment visualization set-up

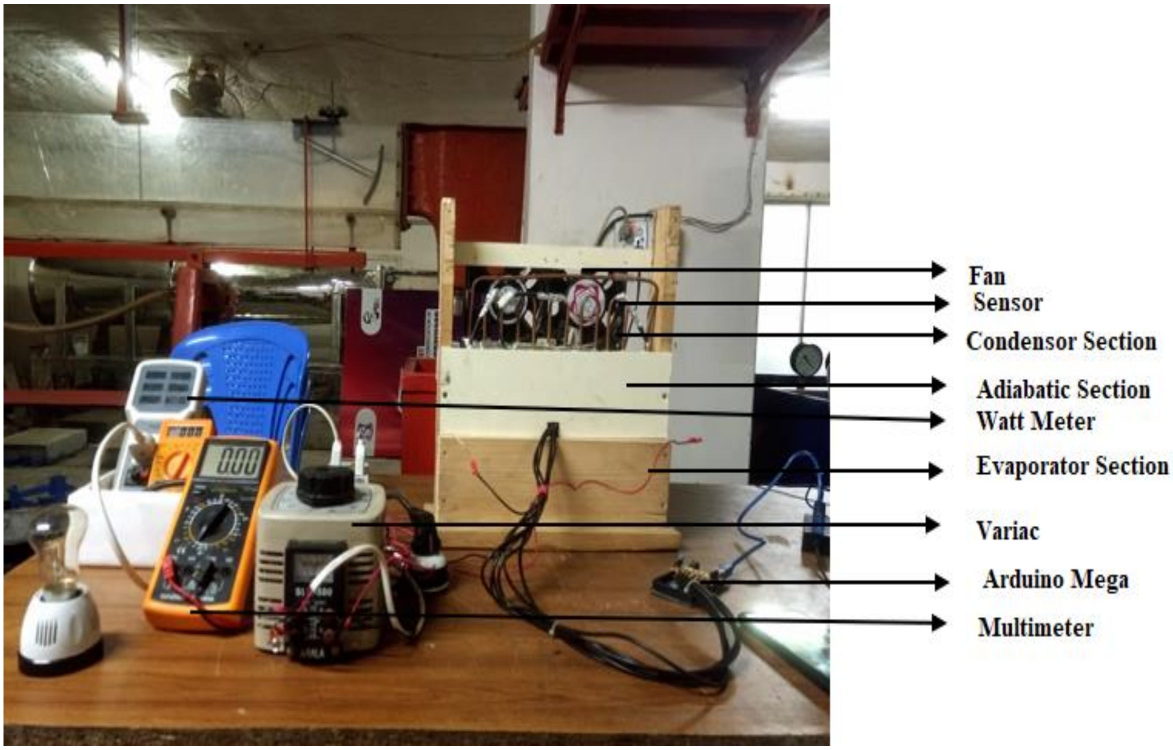

Figure 3-1 Experimental setup

3.11.1 Pulsating heat pipe

A metallic tube with capillary dimensions that has been wound in a serpentine pattern and connected end to end makes up a closed loop pulsating heat pipe or oscillating heat pipe. There are three sections in it:

3.11.2 Evaporator Section

The area of the heat pipe where the working fluid absorbs heat and evaporates is known as this section. It is situated on the heat pipe's lower section. Nichrome wire that is connected to the variac provides heat to the heat pipe. Since the copper tube is a good conductor of electricity, Nichrome wire should not be connected to it directly as this could result in a short circuit. Therefore, a mica sheet surrounds the Nichrome wire and is kept apart from a copper tube. As a result, the mica tape serves as a heat conduit for the copper tube. To ensure better heat sealing in our experiment, the evaporative side was also thermally insulated with asbestos tape. The heat loss was decreased in this manner.

Condenser Section:

It's the part of the heat pipe where heat from the working fluid is rejected. The working fluid condenses and rejects a small amount of heat that was absorbed from the evaporator section in this section. This portion of the experiment is on the upper section of the heat pipe.

Adiabatic Section:

It is situated between the condenser and evaporator sections. Here, the fluid's liquid and vapor phases flow in the opposite directions, and there is little heat transfer between the fluid and the surroundings. The section that is insulated is covered with glass wool and foam tape.

Table 7 Pipe Parameters

Parameters	**Condition**
Inner diameter	2.75 mm
Outer diameter	2.0 mm
Total length	295.0 mm
Length of evaporator section	50mm
Length of adiabatic section	100 mm
Length of condenser section	60 mm
Material	copper

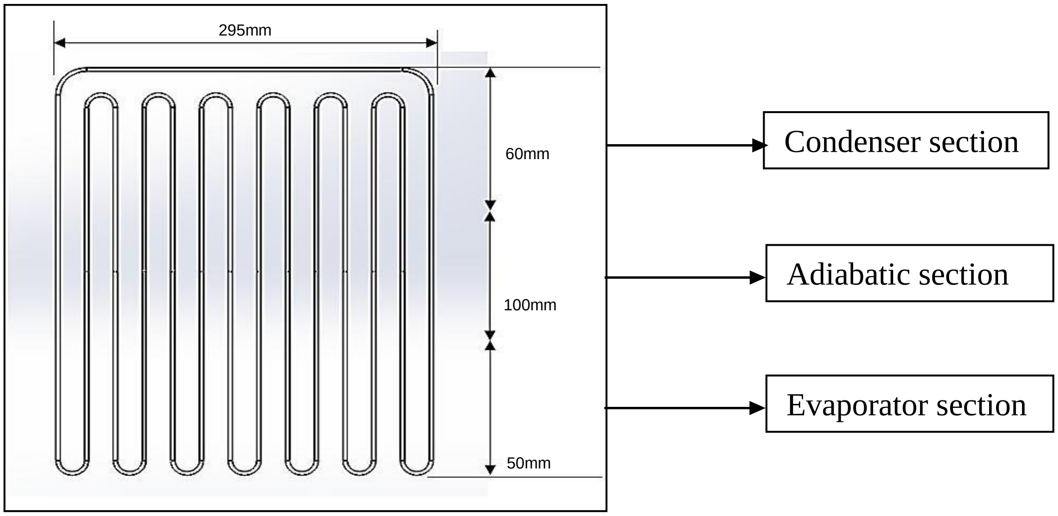

Figure 3-2 Schematic of experimental CLPHP

3.12 Experimental procedure

The following method has been chosen all through the and followed precisely during the a whole:

a) Before filling the working fluid, dry air is blasted inside of heat pipe to check that there is no other fluid present inside the pipe.

b) CLPHP is filled with working fluid using a syringe again for quantity of filling ratios ranging from 40% to 60% in stages of 10%.

c) The needed wattage is adjusted by leveraging the power unit and the heat load is changed from 10 W to 60 W in increments of 10W.

d) A digital thermometer and six K-type (DS18b) thermocouples are utilized for measuring temperature. Three thermocouples are attached in the evaporator portion and three thermocouples in the condenser section which are covered by aluminum foil for accurate temperature detection. The thermocouples are calibrated using saturated steam and ice bath and validated using the standard calibration curve.

e) A data accusation system coupled with a computer is employed for automated data collecting. The accuracy level of MS 6514 digital thermometer and. All measurement uncertainties provided for a 95% confidence interval; uncertainty analysis was carried out based just on of ANSI/ASME standard [20]. The maximum uncertainty in the experimental data was determined to be ± 2.26%.

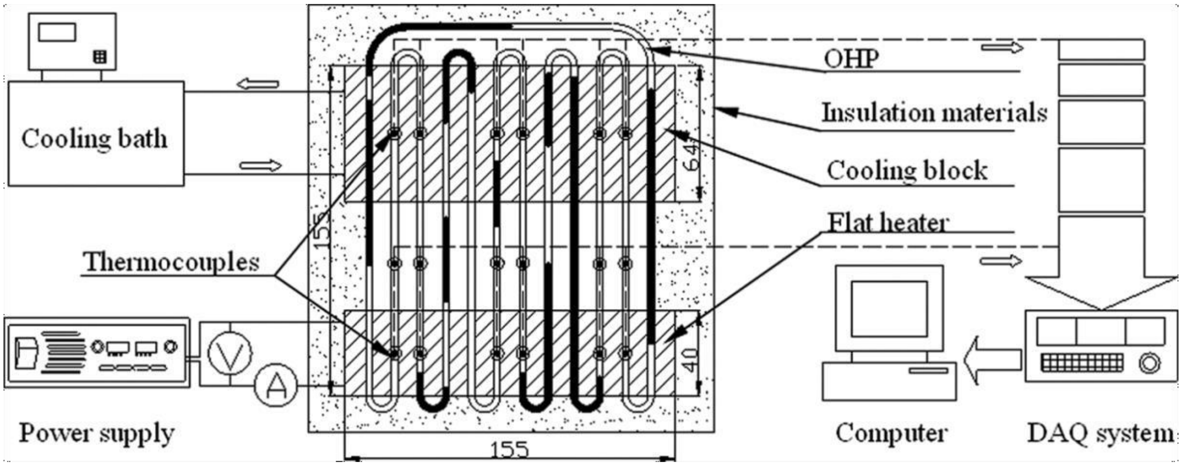

Figure 3-4 Schematic diagram of experimental setup

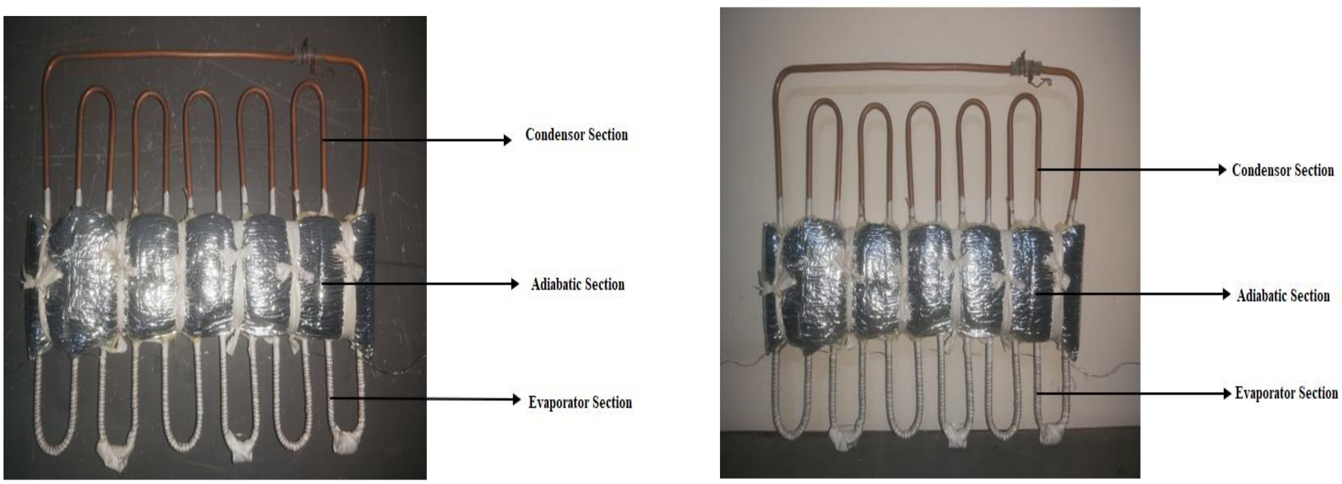

Figure 3-3 Copper and Aluminum CLPHP setup

The trials were conducted after the completion of the whole setup. The building included:

Base and frame made of wood

A wooden platform to put up the whole apparatus on.

Nichrome wire wound in the evaporator, adiabatic, and condensation sections

Heat pipe installation Placing thermocouple connections on the heat pipe at the proper places

An electrical connection between the cooling fan, the heating coil, and the Arduino Mega so that the program may run and the appropriate data readings can be taken.

Three different heat pipe filling ratios and four different working fluids were used in the experiment.

The heat pipes were first held vertical while being injected with distilled water at a rate of 40% to fill the heat pipe.

The system received various heat inputs, and temperature readings of the system's various components were determined using a computer software and an Arduino.

The technique described above was continued, with the filling ratio subsequently altered while using the same fluid.

For the working fluids ethanol and methanol, respectively, the aforementioned three procedures were followed methodically.

In the chapter on graphical analysis, many compared graphs were drawn for each of the experimental data sets.

3.12.1 Experimental procedure of copper wire inserts

Figure 3-5 Copper wire insert CLPHP

Dry air is blown within the heat pipe to ensure there is no other fluid inside the pipe before adding the working fluid. Using a syringe once again, working fluid is injected into CLPHP at quantity filling ratios ranging from 40% to 60% in increments of 10%. The power unit is used to vary the required wattage, and increments of 10W are used to change the heat load from 10 W to 60 W. First ethanol then methanol then distilled water then acetone use to measure the thermal resistance and thermal co-efficient.

3.12.2 Experimental procedure of aluminum wire inserts

Figure 3-6 Aluminum wire insert CLPHP

Before introducing the working fluid, dry air is blasted within the heat pipe to make sure there isn't any other fluid present. Working fluid is once again injected into CLPHP using a syringe at quantity filling ratios ranging from 40% to 60% in increments of 10%. The needed wattage may be changed using the power unit, and the heat load can be changed from 10 W to 60 W using increments of 10 W. To evaluate the thermal resistance and thermal co-efficient, ethanol, methanol, distilled water, and acetone were first used.

3.12.3 Data collection (DAQ)

After running the experiment, Arduino mega synergy with PLX DAQ instantly sends data to excel and graph, and data logging is done using this system. For that, no human error while taking data can be prevented.

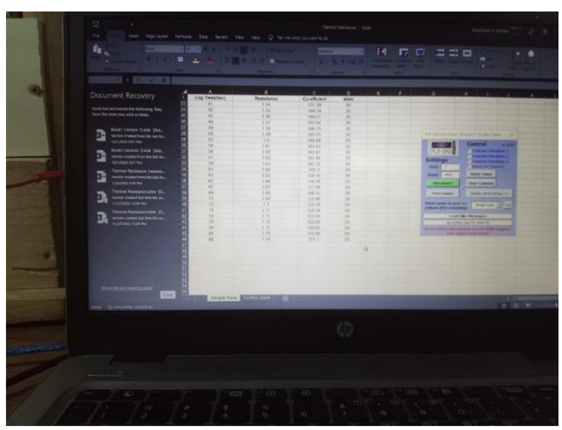

Figure 3-7 PLX DAQ

3.13 Precautions

The following factors were considered while conducting the experiment:

All other sources that may have an impact on the process of heat transfer were turned off throughout.

Before measuring the temperature, the sensor (DS18B20 sensors) utilized in the experiment has to be carefully examined.

The injection of fluid must be exact since the fill ratio affects the operation of the heat pipe.

Temperature measurements must be collected only when that specific temperature reaches steady state or a constant value & always tightly seal the silicon tube cause many times condenser condense maybe leak form CLPHP

Never try to blow out the fluid from the mouth. If you do, you will notice blisters in lips.

3.14 Before purchasing and bending CLPHP

Always try to buy Mueller Because it is flexible to bend any desired shape.

If the bender and Angle can’t be found, try to find a refrigerator repair shop. They will help to bend the pipe.

If your U bend is a 20mm gap between two heat pipes, always try to bend 22mm or 23mm (U bend) Cause after the insulation gap between the two pipes shrinks.

Chapter 4

4 Result and Discussion

In this chapter, we will discuss our results graphically and try to explain the impact briefly. Our interesting statistical graphical graph was created using Origin Pro.

4.1 Ethanol

4.1.1 Ethanol 40% Filling Ratio Copper Wire insert:

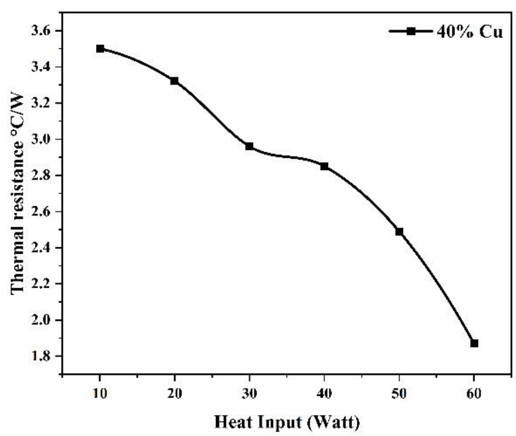

Figure 4-1 Thermal Resistance Vs heat input

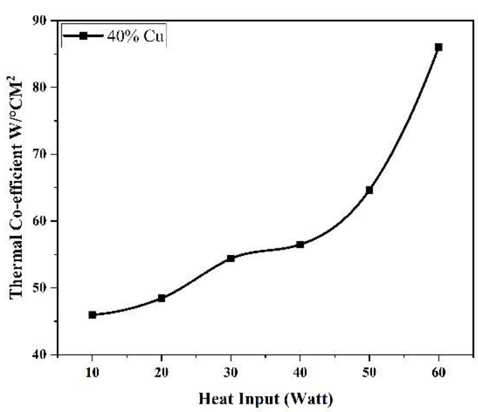

Figure 4-2 Thermal Co-efficient Vs heat input

In Figure 4-1 we see Thermal resistance is in 10 watt 3.5 and further increasing the heat input it's almost steady but in 30 watts in changes big in magnitude for thermal resistance after that 40 watt it's almost steady and further increasing the heat input it linearly decreasing thermal resistance.

In this 4-2 figure the changes of thermal coefficient as same as thermal thermal resistance 10 to 40 watt thermal co-efficient is almost steady but after 50 watt it change and rising thermal co-efficient massively.

4.1.2 Ethanol 40% Filling Ratio Aluminum Wire insert

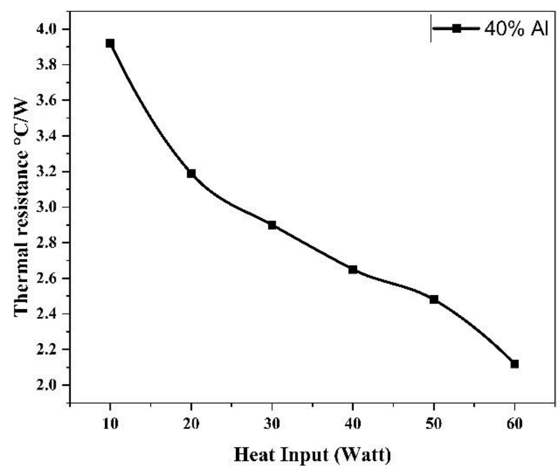

Figure 4-3 40% Thermal Resistance Vs heat input

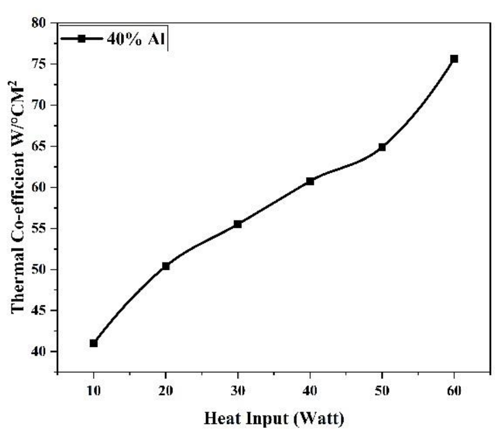

Figure 4-4 40% Thermal Co-efficient Vs heat input

In 4-3 figure the thermal resistance is higher than copper insert. But in beginning the change is thermal resistance is high 10 to 20 watt but after that it goes linearly 60.

In this figure 4-4 we see the changes of thermal co-efficient is higher in 10 to 20 watts but after that 20 to 60 watt the thermal co-efficient is linearly rising.

4.1.3 Ethanol 50% Filling Ratio Copper Wire insert

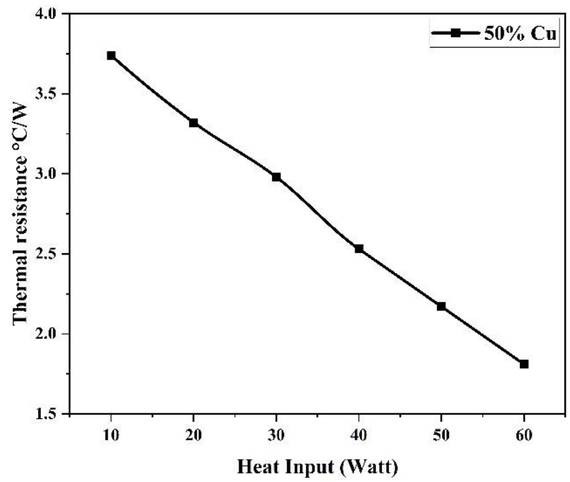

Figure 4-5 Thermal Resistance Vs heat input

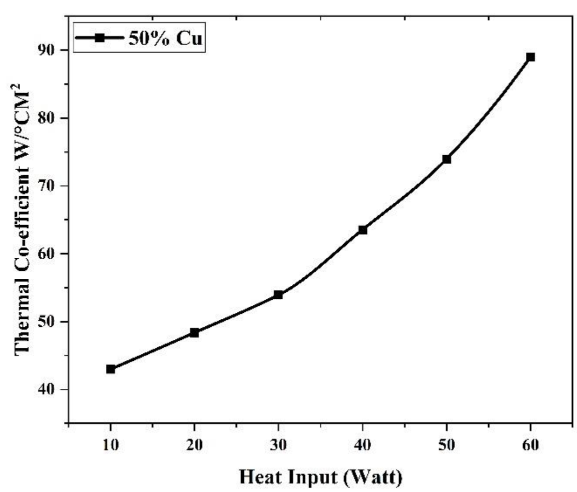

Figure 4-6 Thermal Co-efficient Vs heat input

In figure 4-5 the thermal resistance is 10-to-20-watt changes slightly after 20 watts to 60 watt it almost steady and linearly decreasing the thermal resistance.

In this figure 4-6 we see after 10 watt the thermal co-efficient is rising almost steady and 50 watt after significate change in notice.

As we saw in thermal resistance this thing also repeats in here.

4.1.4Ethanol 50% Filling Ratio Aluminum Wire insert

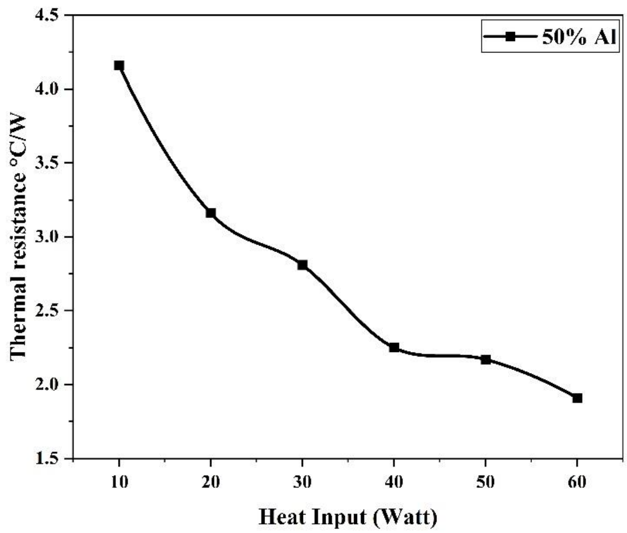

Figure 4-7 Thermal Resistance Vs heat input

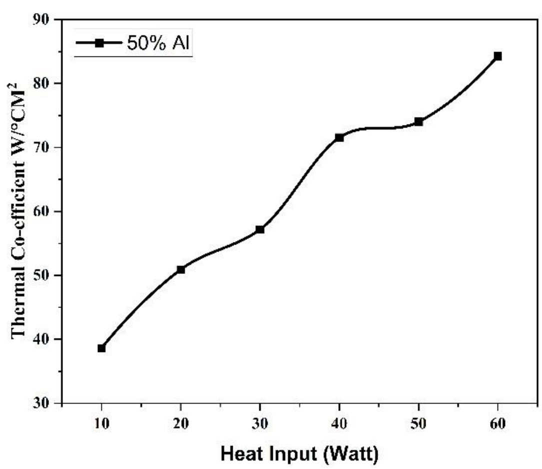

Figure 4-8 Thermal Co-efficient Vs heat input

In this figure 4-7 the thermal resistance is higher than the copper insert. And the massive change the thermal resistance in 10 to 20 watts but after than it's become steady and 50 watts after it may dry up and all the bubble plug condense after resulting 60 watts again rising thermal resistance rather than failing

In this Figure 4-8 we saw similar rising what we see in thermal resistance in 40 watt it may form bubble in CLPHP and transfer heat massively to the condenser resulting rising thermal co-efficient. But after 50 watt it become steady.

4.1.5 Ethanol 60% Filling Ratio Copper Wire insert

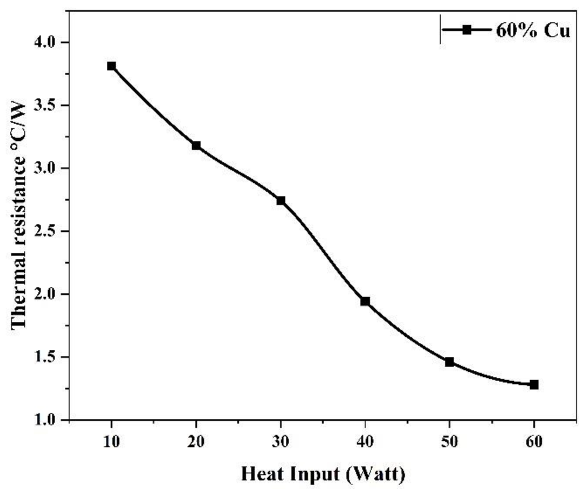

Figure 4-9 Thermal Resistance Vs heat input

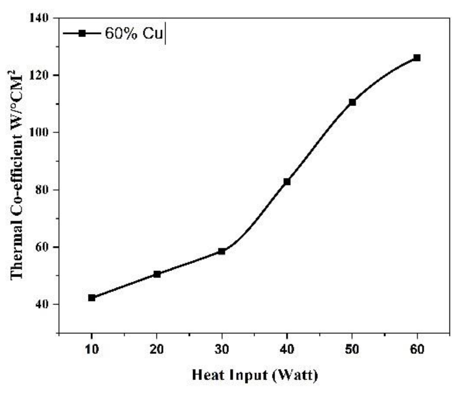

Figure 4-10 Thermal Co-efficient Vs heat input

In this figure 4-9 we see the thermal resistance linearly falling and after 50 watt it become steady almost.

In this figure 4-10 the thermal co-efficient changing happening almost the same the thermal resistance.

10 to 30 watts it almost steady but after 40 watts it change massively and rising goes on.

4.1.6 Ethanol 60% Filling Ratio Aluminum Wire insert

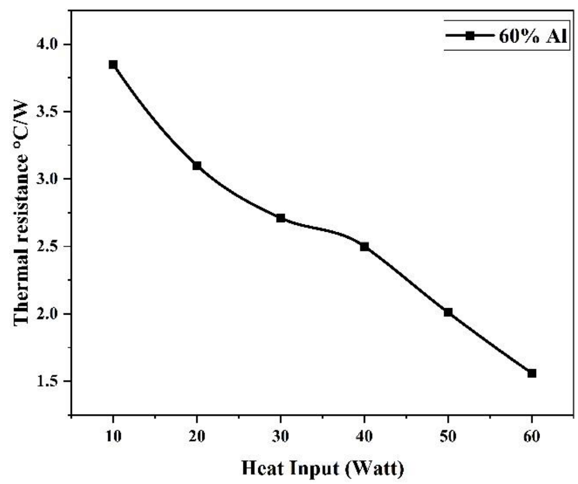

Figure 4-11 Thermal Resistance Vs heat input

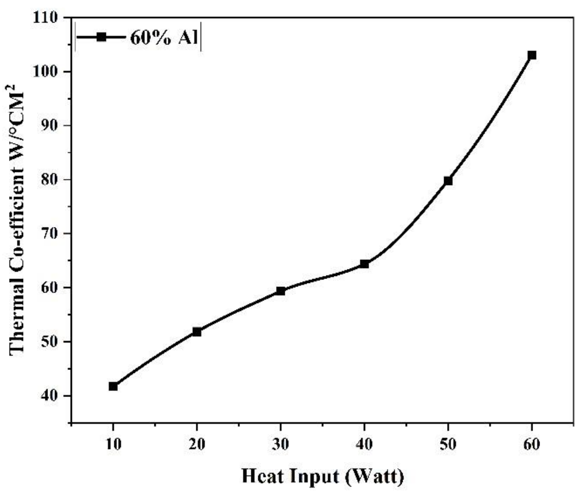

Figure 4-12 Thermal Co-efficient Vs heat input

In this figure 4-11 we see the 10-to-30-watt thermal resistance is almost steady but after 40 watts the changes are linearly happing.

In this figure we see 10 to 30 watt the changes is almost steady but after the 40 watt the change is happing and rising thermal co-efficient.

4.1.7 Ethanol Copper and Aluminum wire insert comparison

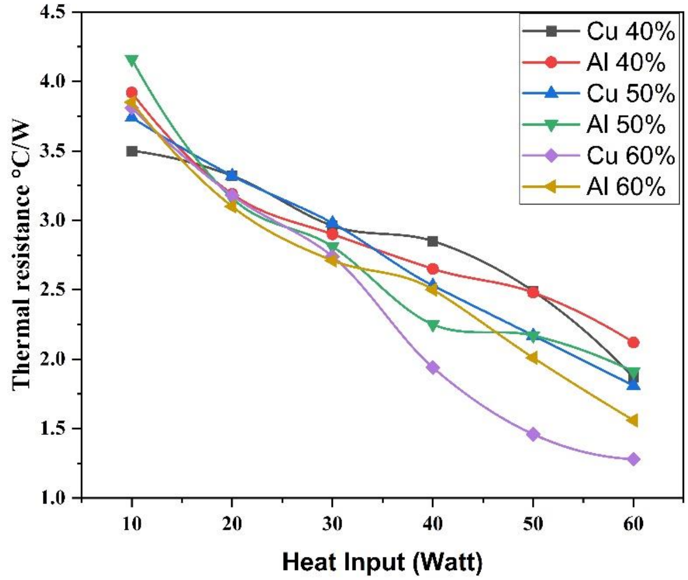

Figure 4-13 Thermal Resistance Vs heat input

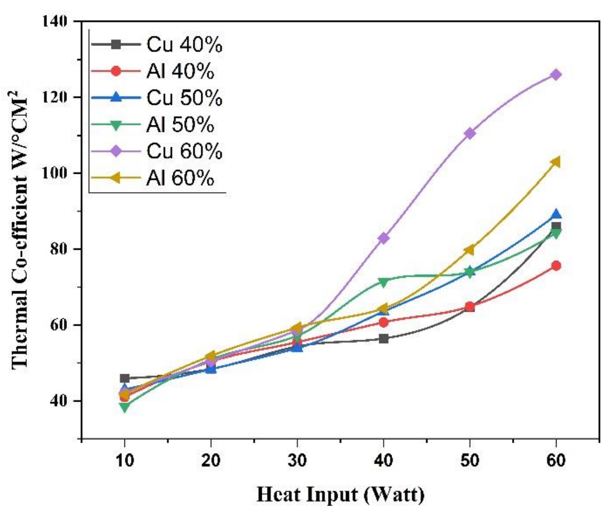

Figure 4-14 Thermal Co-efficient Vs heat input

In this graph, we see copper outperformed aluminum. And the best optimal filling ratio is copper insert 60% for the ethanol.

We see the aluminum wire insert, the very poor, outperformed the copper insert.

Same we see in the figure 4-12 copper insert wire worked best reaching higher thermal co-efficient.

4.2 Methanol

4.2.1 Methanol 40% Filling Ratio Copper Wire insert

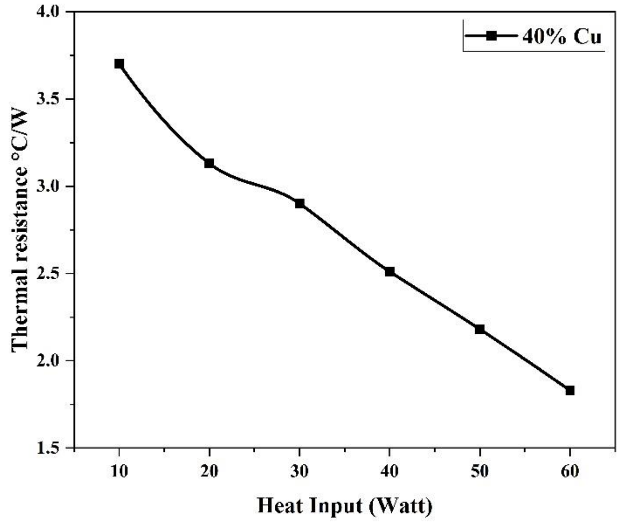

Figure 4-15 Thermal Resistance Vs heat input

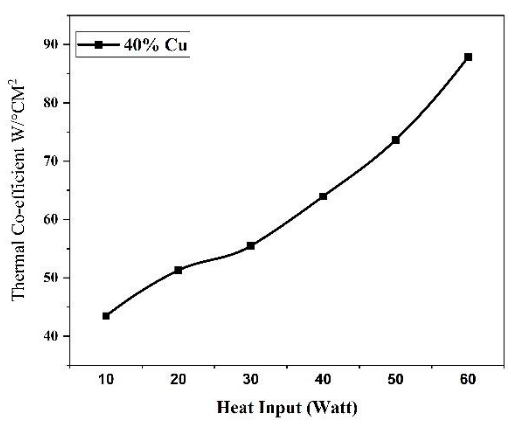

Figure 4-16 Thermal Co-efficient Vs heat input

In this figure 4-15 thermal resistance 10 to 20 watts fall rapidly than 20 to 30 watts steady and 40 to 60 watts the thermal resistance linearly falling.

In this figure 4-16 show thermal co-efficient 10 to 20 watt rising then 20 to 30 watt steady the thermal co-efficient then rising the thermal co-efficient then reach 90.

4.2.2 Methanol 40% Filling Ratio Aluminum Wire insert

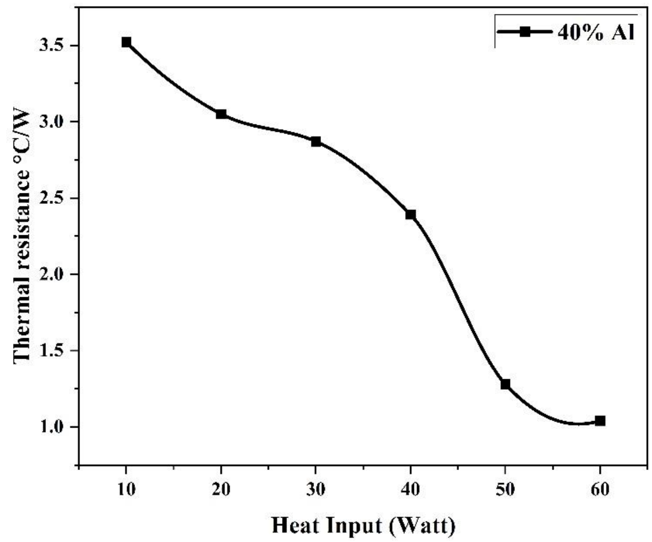

Figure 4-17 Thermal Resistance Vs heat input

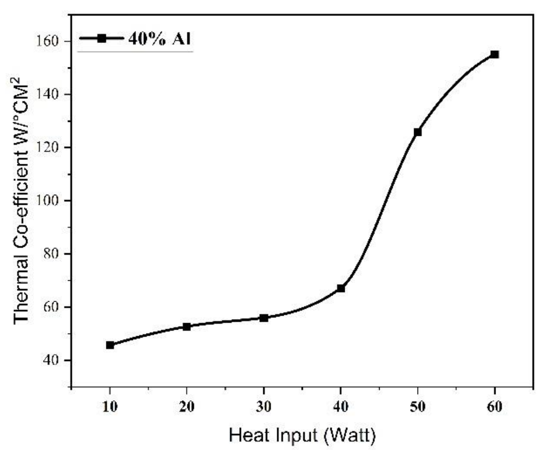

Figure 4-18 Thermal Co-efficient Vs heat input

In this figure 4-17 we see the thermal resistance is higher than the copper insert CLPHP. And 10-to-20-watt changes slightly but in 30 to 60 massive decreasing happing.

The figure 4-18 shows the 10 to 40 watt thermal co-efficient is almost steady but after the 40 watts to 60 the massive thermal co-efficient is rising.

4.2.3 Methanol 50% Filling Ratio Copper Wire insert

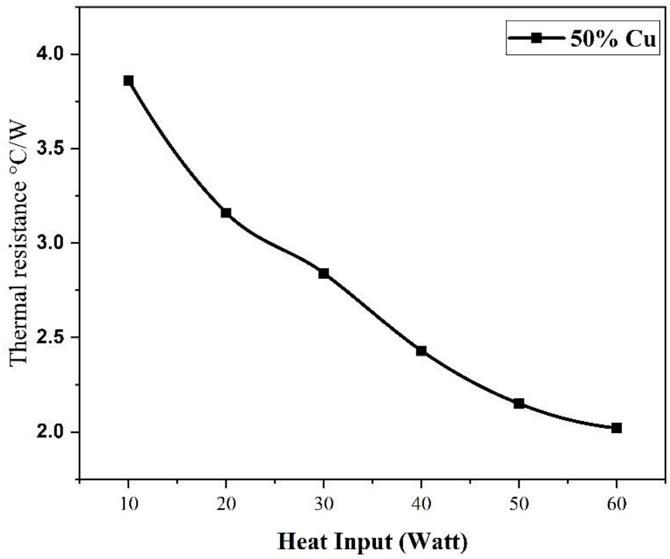

Figure 4-19 Thermal Resistance Vs heat input

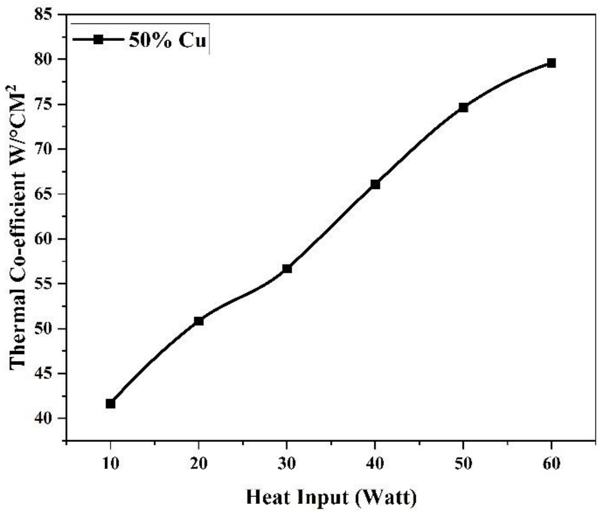

Figure 4-20 Thermal Co-efficient Vs heat input

In this figure 4-19 shows 10-20 watts thermal resistance fall rapidly then 20-30 watts is almost steady and after that 40-60 watts linearly decreasing thermal resistance.

In this figure 4-20 thermal co-efficient 10-20 rising rapidly after that 20-30 progress of thermal co-efficient is slow then 30-60 watts thermal co-efficient rising linearly.

4.2.4 Methanol 50% Filling Ratio Aluminum Wire insert

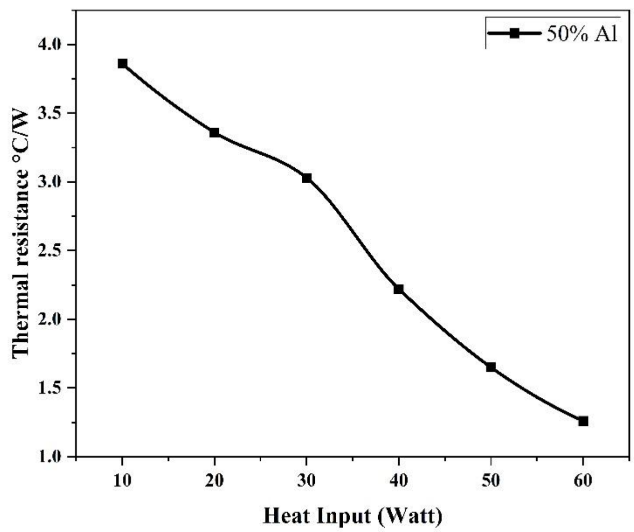

Figure 4-21 Thermal Resistance Vs heat input

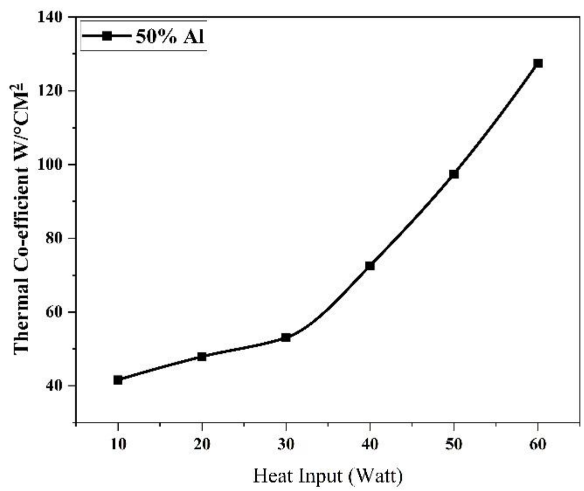

Figure 4-22 Thermal Co-efficient Vs heat input

In this figure 4-21 we show thermal resistance 10-20 watt falling rapidly then 20-30 watts almost steady thermal resistance then 30-60 watts decreasing linearly.

In this figure 4-22 we show thermal co-efficient 10-30 watts rising almost steady then 30-60 watts rising linearly.

4.2.5 Methanol 60% Filling Ratio Copper Wire insert

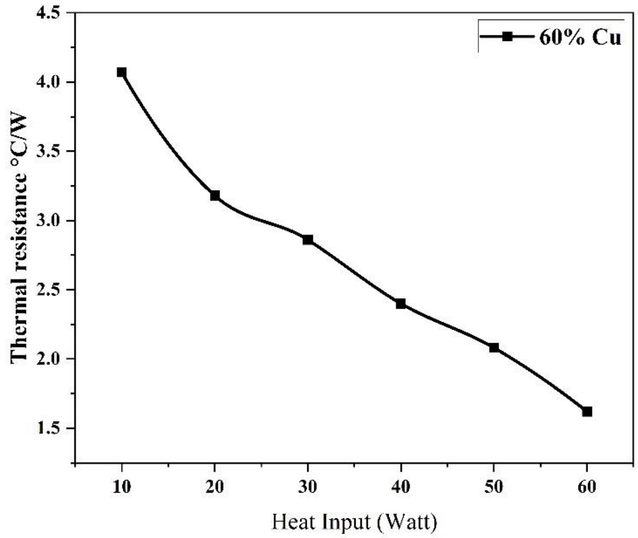

Figure 4-23 Thermal Resistance Vs heat input

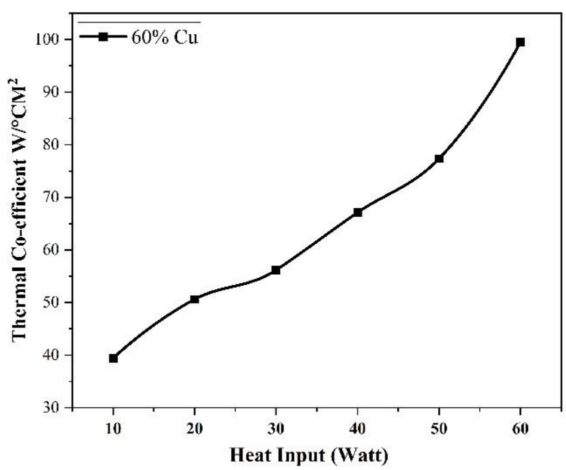

Figure 4-24 Thermal Co-efficient Vs heat input

In this figure 4-23 we show thermal resistance 10-20 watts falling rapidly then 20-30 watts thermal resistance rising due to bobble formation and again 30-60 watts thermal resistance falling linearly. In this figure 4-24 shows the thermal co-efficient rising 10 to 20 watt rising rapidly than 30 to 60 watts linearly rising the thermal co-efficient.

4.2.6 Methanol 60% Filling Ratio Aluminum Wire insert

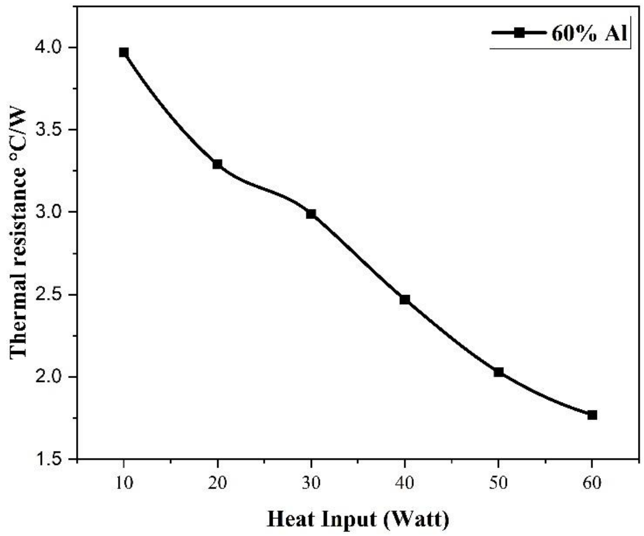

Figure 4-25 Thermal Resistance Vs heat input

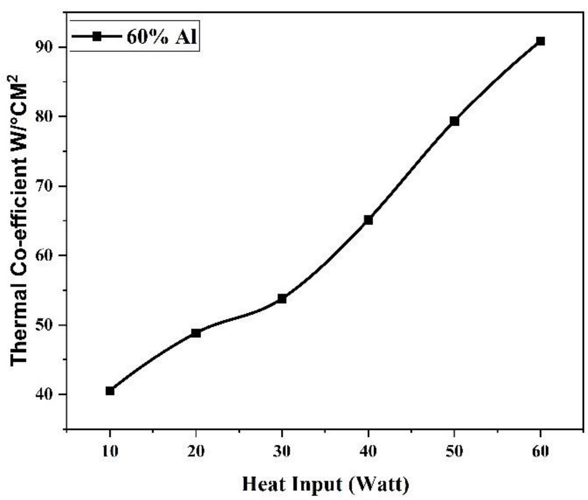

Figure 4-26 Thermal Co-efficient Vs heat input

In this figure 4-25 show that 10-to-20-watt thermal resistance falling rapidly then 20 to 30 watt the thermal resistance almost steady and then falling linearly to 60 watts.

In this figure 4-26 thermal co-efficient 10 to 20 watt rising rapidly then 20 to 30 steady and 30 to 30 watt the thermal co-efficient rising linearly.

4.2.7 Methanol Copper and Aluminum wire insert comparison

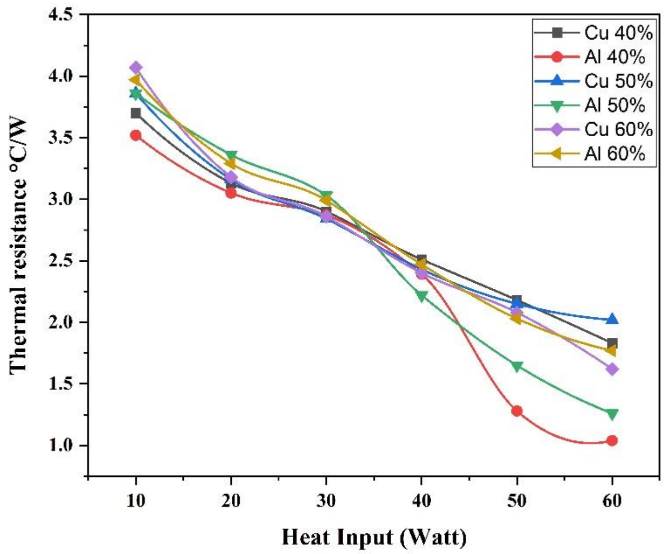

Figure 4-27 Thermal Resistance Vs heat input

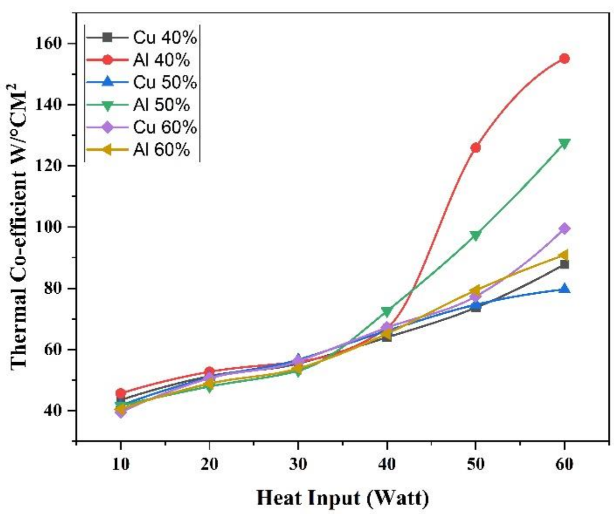

Figure 4-28 Thermal Co-efficient Vs heat input

In this figure 4-27 shows the aluminum wire insert 40% shows best performance. Then 50% al wire inserts.

in methanol aluminum show best performance than copper wire insert.

In this 4-28 figure the Methanol dominate the thermal co-efficient and show 40% filling ratio best thermal co-efficient.

4.3 Distilled water

4.3.1 Distilled water 40% Filling Ratio Copper Wire insert:

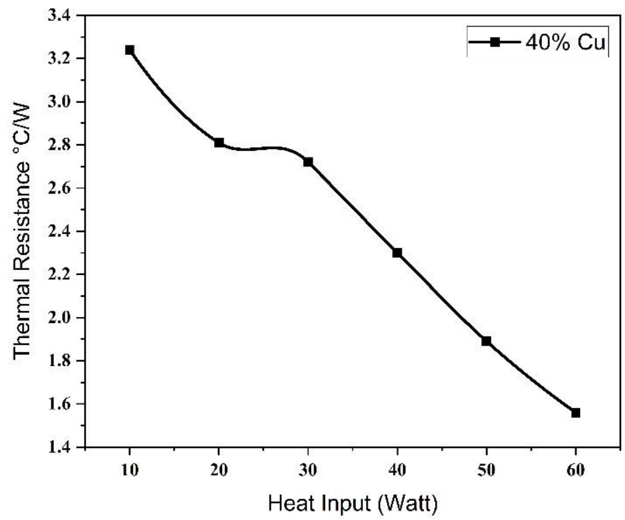

Figure 4-29 Thermal Resistance Vs heat input

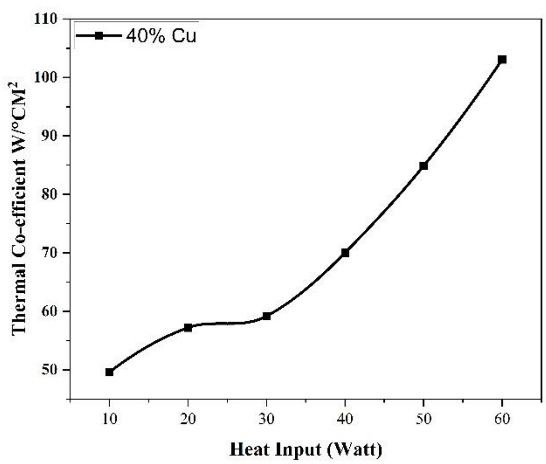

Figure 4-30 Thermal Co-efficient Vs heat input

In this graph 10 to 20 watt the thermal resistance falls then 20 to 30 thermal resistances almost steady then 30 to 60 watt the thermal resistance falls linearly.

In this 4-30 graph shows the thermal resistance 10 to 20 watt rising rapidly and 20 to 30 it's stayed the steady then 30 to 60 watt the thermal co-efficient rising linearly.

4.3.2 Distilled water 40% Filling Ratio Aluminum Wire insert

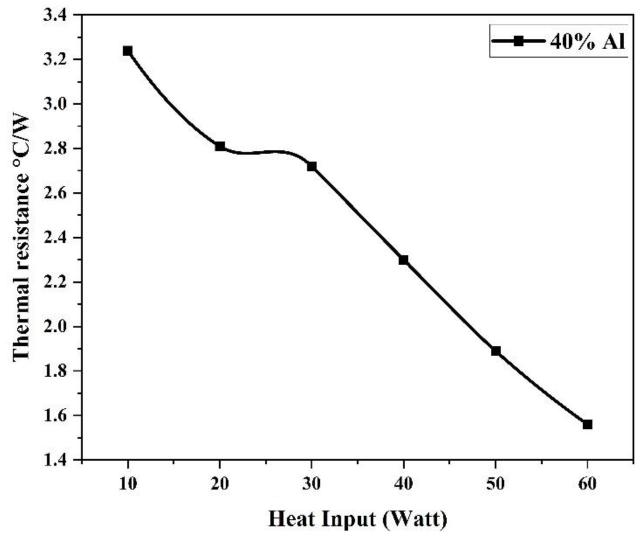

Figure 4-31 Thermal Resistance Vs heat input

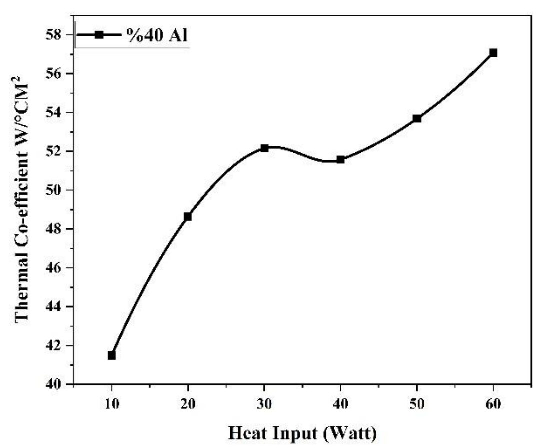

Figure 4-32 Thermal Co-efficient Vs heat input

In this figure the thermal resistance falling rapidly 10 to 30 watts then it became steady and almost stayed in steady in 60 watts.

In this figure 4-32 shows thermal co-efficient rising 10 to 30 watt rising rapidly then 30 to 40 steadies then linearly rising.

4.3.3 Distilled water 50% Filling Ratio Copper Wire insert

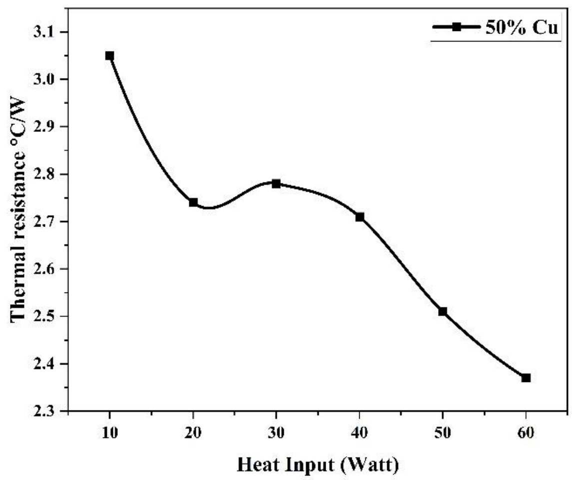

Figure 4-33 Thermal Resistance Vs heat input

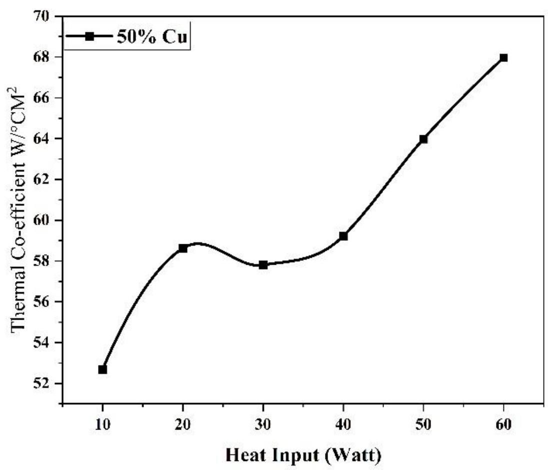

Figure 4-34 Thermal Co-efficient Vs heat input

In this figure 4-33 shows the thermal resistance fall rapidly 10 to 20 watts then stayed steady and falling gradually.

In this figure 4-34 show that 10 to 20 watt thermal co-efficient rising rapidly than 20 to 40 watt it become steady and then rising linearly.

4.3.4 Distilled water 50% Filling Ratio Aluminum Wire insert

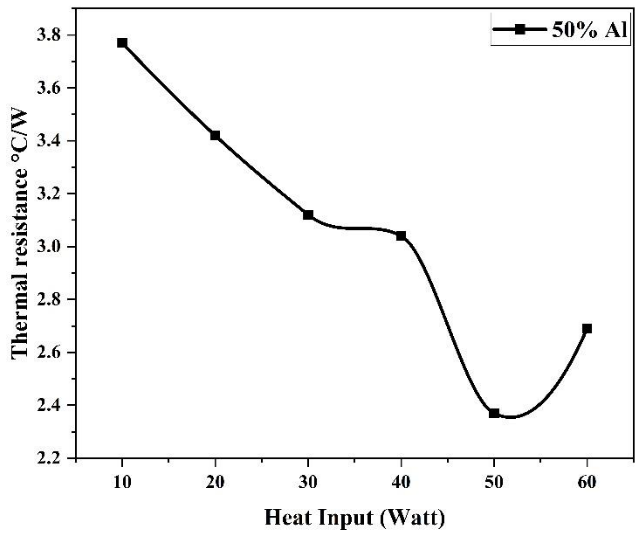

Figure 4-35 Thermal Resistance Vs heat input

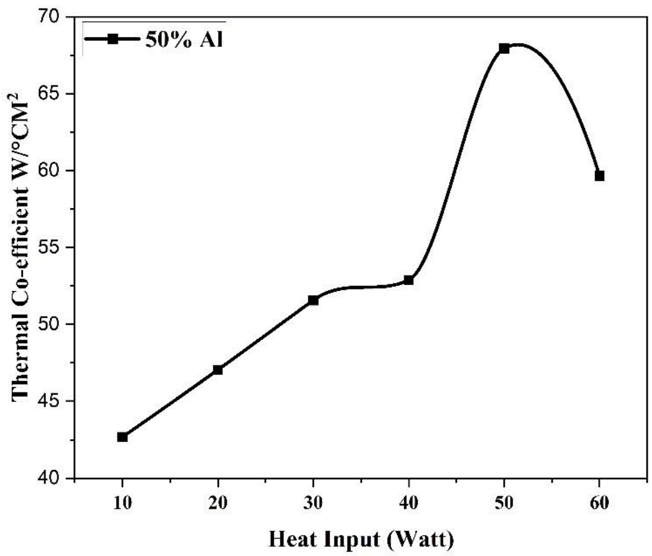

Figure 4-36 Thermal Co-efficient Vs heat input

In this 4-35 figure shows that thermal resistance falling linearly then become steady then fall rapidly 40 to 50 water due to bubble and plug formation but in 60 watt it loses heat to travel up the condenser so for that rater falling it up again.

This figure 4-36 show that similar outcome what we see in thermal resistance.

4.3.5 Distilled water 60% Filling Ratio Copper Wire insert

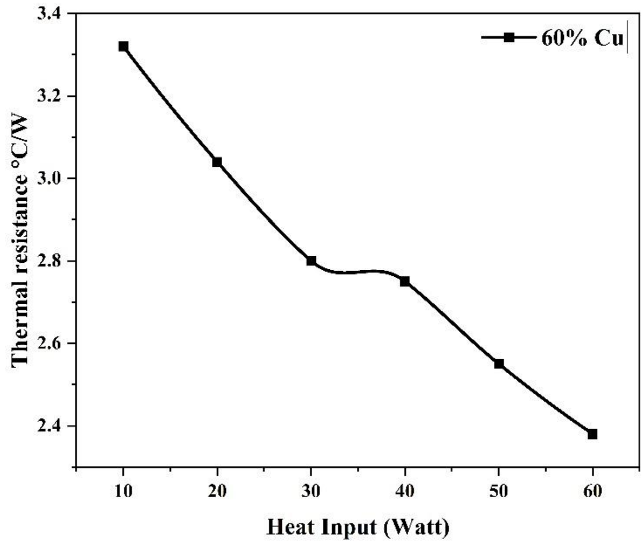

Figure 4-37 Thermal Resistance Vs heat input

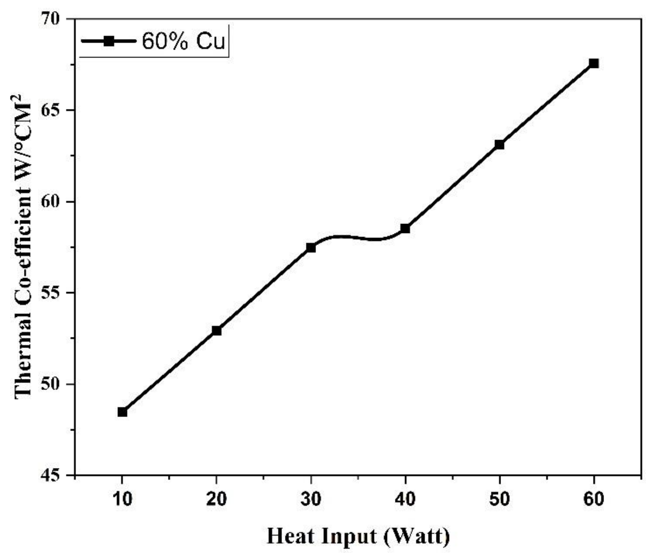

Figure 4-38 Thermal Co-efficient Vs heat input

In this figure 10-to-30-watt thermal resistance fall rapidly then steady and 40 to 60 watts linearly falling.

In this figure 10-to-30-watt thermal resistance rising than steady then 40 to 60 watts linearly rising.

4.3.6 Distilled water 60% Filling Ratio Aluminum Wire insert

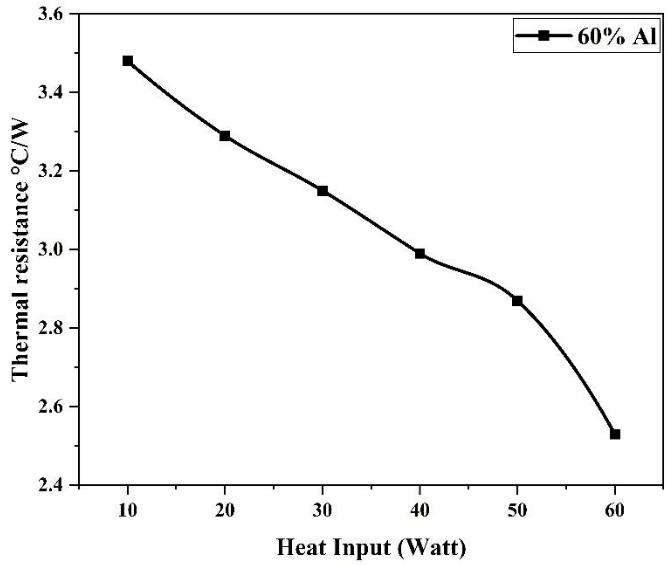

Figure 4-39 Thermal Resistance Vs heat input

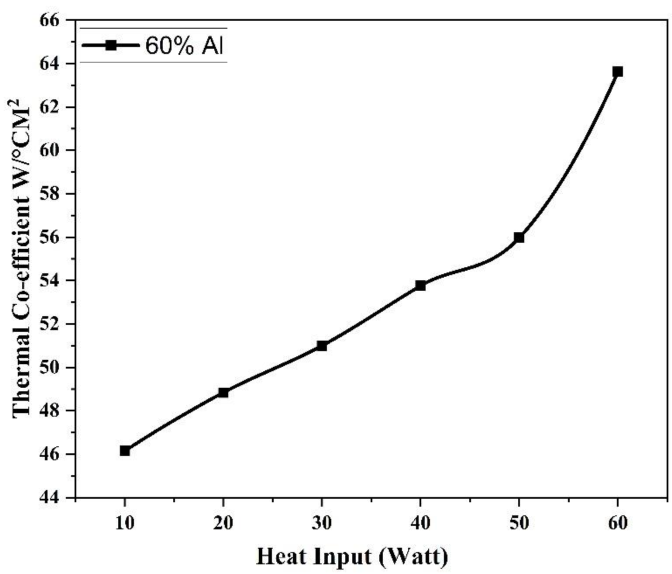

Figure 4-40 Thermal Co-efficient Vs heat input

In this graph 4-39 linearly falling then steady 40 to 50 watt and rapid falling in 60 watts.

In this 4-40 thermal co-efficient rising and steady and rising again.

4.3.7 Distilled Water Copper and Aluminum wire insert comparison

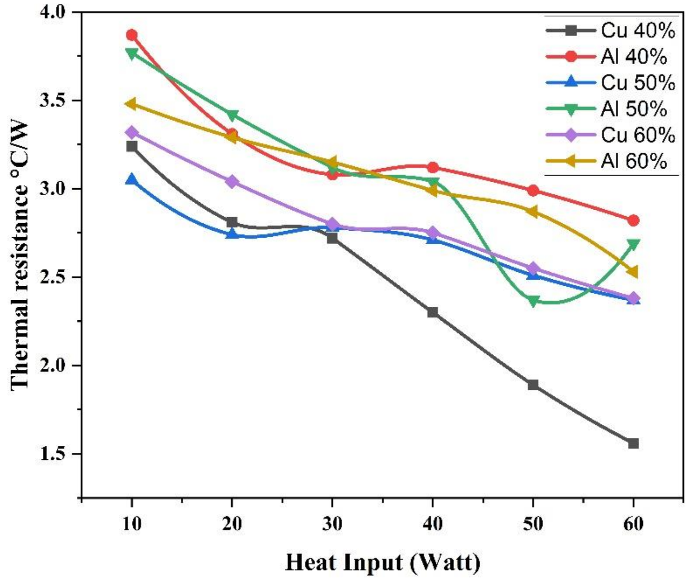

Figure 4-41 Thermal Resistance Vs heat input

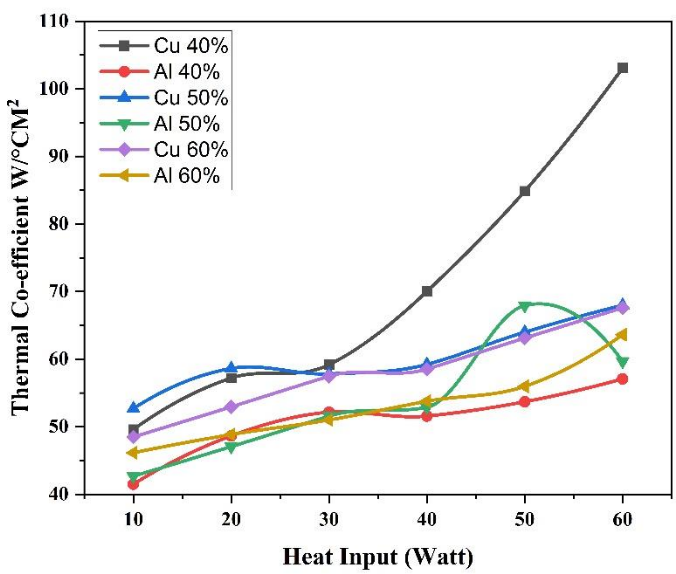

Figure 4-42 Thermal Co-efficient Vs heat input

In this 4-41 copper 40% filling ratio gives optimal performance.

In this 4-42 thermal co-efficient graph shows that copper 40% filling ratio give best thermal co-efficient.

4.4 Acetone

4.4.1 Acetone 40% Filling Ratio Copper Wire insert:

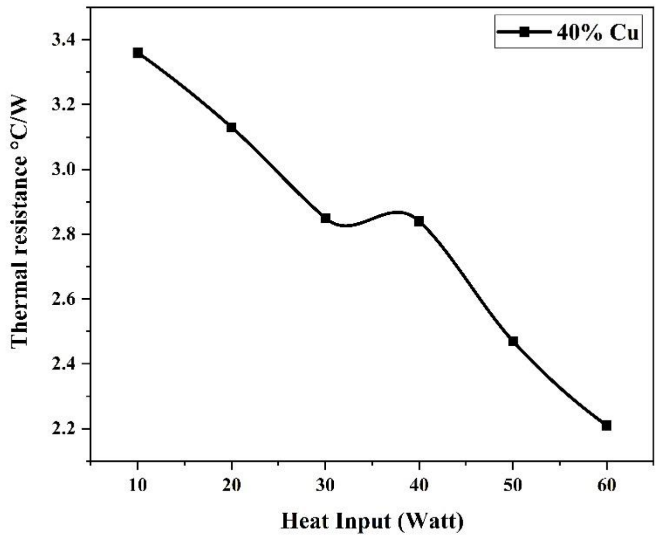

Figure 4-43 Thermal Resistance Vs heat input

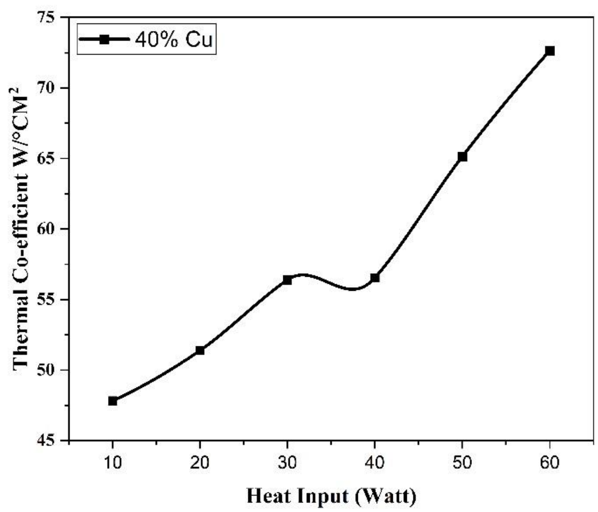

Figure 4-44 Thermal Co-efficient Vs heat input

In this 4-43 graph acetone falling rapidly than almost steady in 30 to 60 watts.

In this 4-44 graph shows same linearly rising and steady in 30 to 40 watts then rising again,

4.4.2 Acetone 40% Filling Ratio Aluminum Wire insert

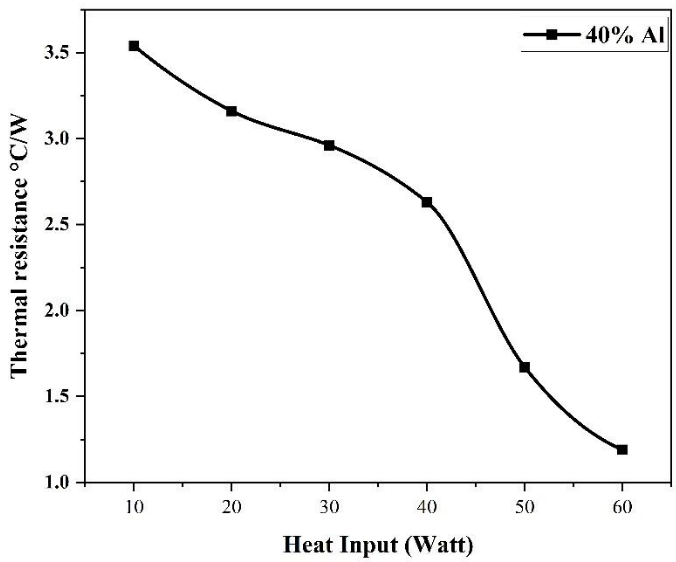

Figure 4-45 Thermal Resistance Vs heat input

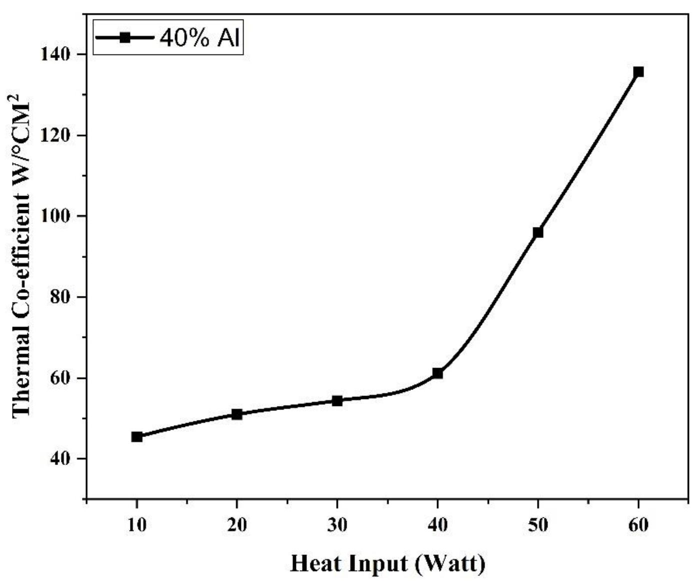

Figure 4-46 Thermal Co-efficient Vs heat input

In this 4-45 graph shows the thermal resistance falling and 20 to 50 almost steady but in 60 it goes rapid falling.

In this 4-46 figure shows 10 to 40 almost steady rising the thermal co-efficient than 40 to 60 watt gives linearly rising.

4.4.3 Acetone 50% Filling Ratio Copper Wire insert

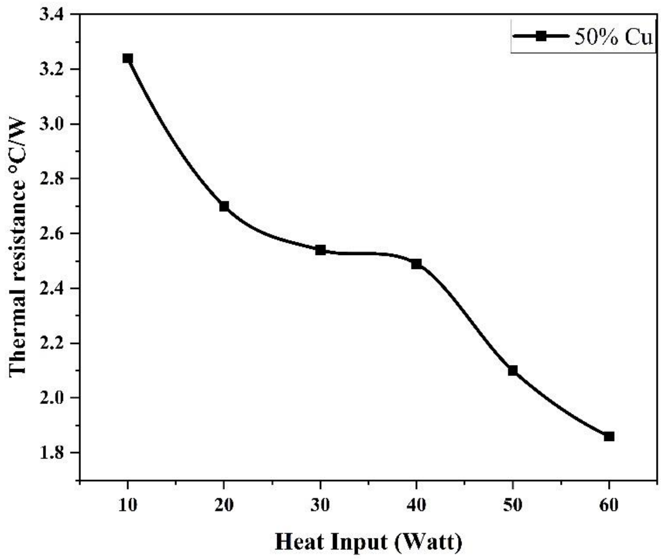

Figure 4-47 Thermal Resistance Vs heat input

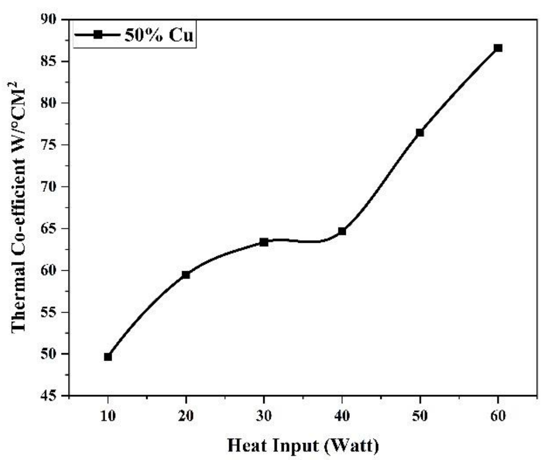

Figure 4-48 Thermal Co-efficient Vs heat input

In this figure 4-47 shows 10 to 20 rapid thermal resistance falling then almost steady.

In this figure 4-48 shows linearly rising and steady in 30 to 40 watt and rising again.

4.4.4 Acetone 50% Filling Ratio Aluminum Wire insert

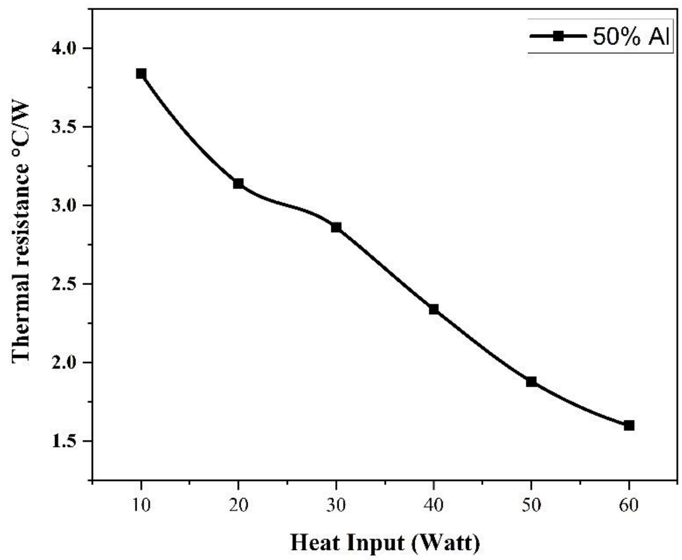

Figure 4-49 Thermal Resistance Vs heat input

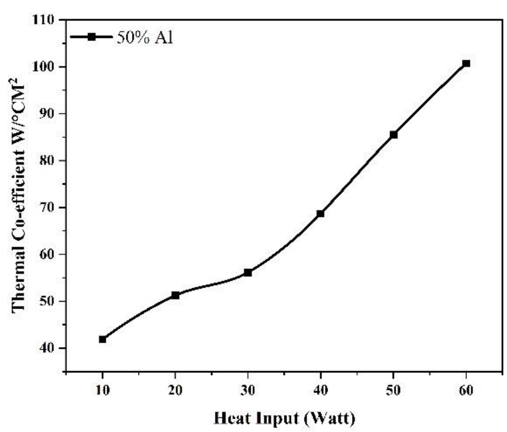

Figure 4-50 Thermal Co-efficient Vs heat input

In this 4-49 shows that 10 to 20 watts then steady to 30 to 40 then decrease linearly.

In this 4-50 figure shows that 10 to 30 then linearly rising.

4.4.5 Acetone 60% Filling Ratio Copper Wire insert

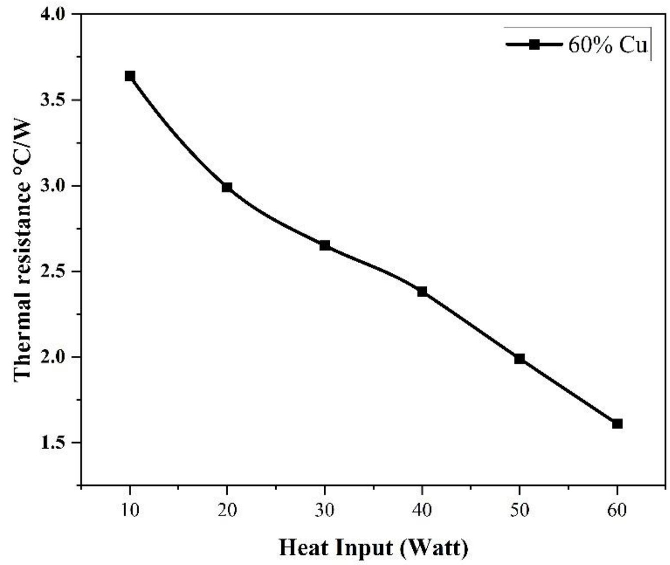

Figure 4-51 Thermal Resistance Vs heat input

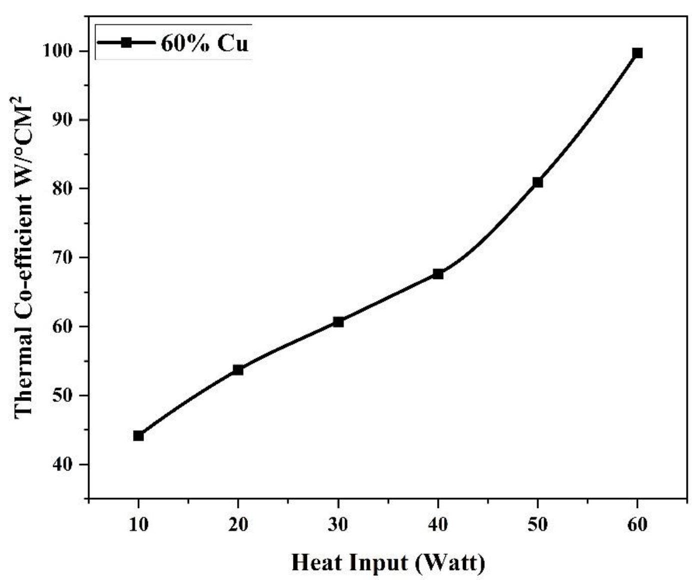

Figure 4-52 Thermal Co-efficient Vs heat input

In this figure 4-51 show that 10 to 30 watt steady then thermal resistance decrease show that slowly.

In this 4-52 shows that 10 to 40 steady rising then 40 to 60 watts.

4.4.6 Acetone 60% Filling Ratio Aluminum Wire insert

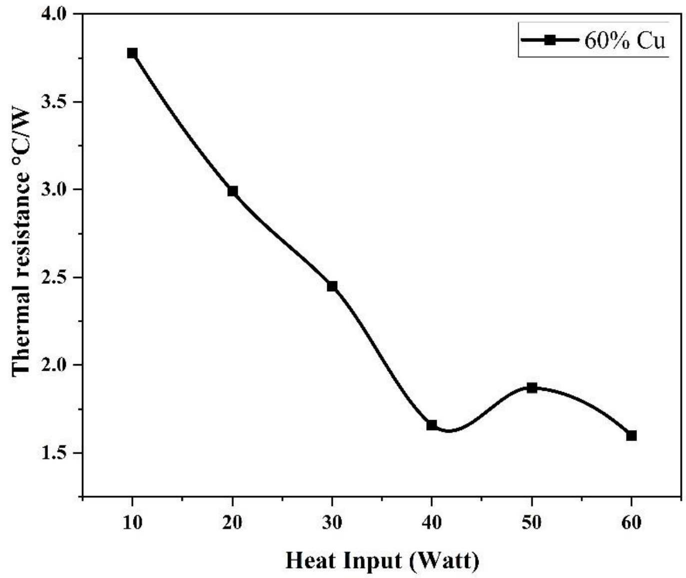

Figure 4-53 Thermal Resistance Vs heat input

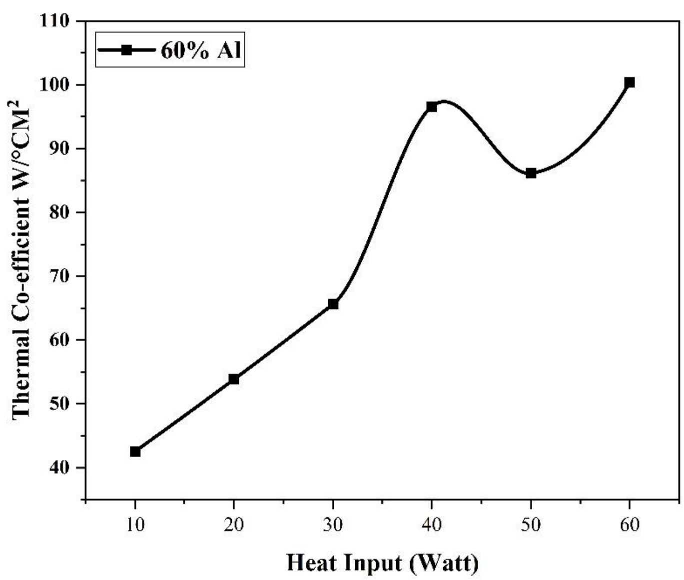

Figure 4-54 Thermal Co-efficient Vs heat input

In this figure 4-53 gradually falling 10 to 40 watts then it rising 40 to watt then falling again.

In this 4-54 shows that 10 to 30 linearly rising then falling then rising again.

4.4.7 Acetone Copper and Aluminum wire insert comparison

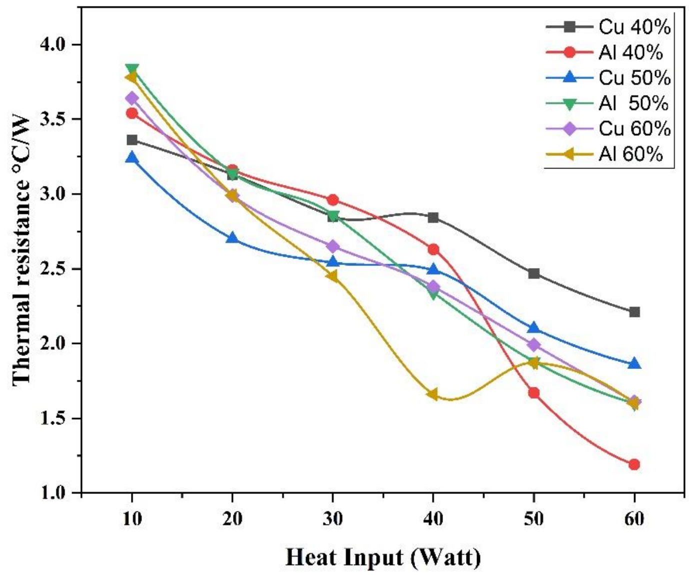

Figure 4-55 Thermal Resistance Vs heat input

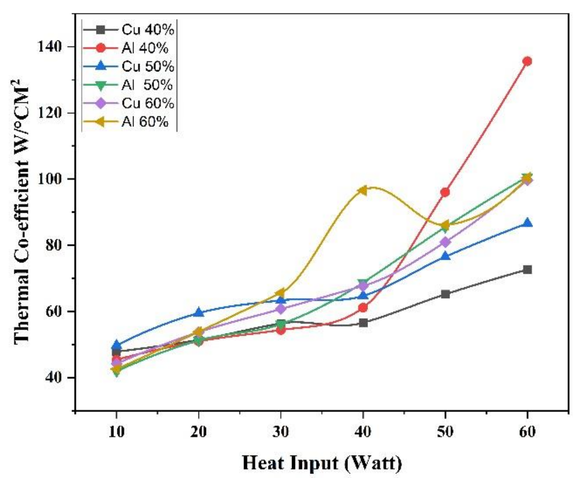

Figure 4-56 Thermal Co-efficient Vs heat input

This figure 4-54 (Acetone of 40% FR) shows that, Aluminum wire insert has the better outcome for thermal resistance. However, 60% FR, shows better thermal performance in between 30-40 W. In this 4-56 shows the acetone thermal co-efficient rising 40% Aluminum wire insert best outcome.

4.5 General Study

• Four different working fluids were used to study the heat transfer properties of the CLPHP: acetone, ethanol, and methanol.

• Factors including pressure, buoyancy, and bubble movement may affect how a heat pipe operates. For the evaporator and condenser sections, the temperature distribution throughout the heat pipes may be characterized as following an almost exponential pattern.

However, when heat is added, the temperature in the condenser part does not rise as quickly as it does in the evaporator area. Between the evaporator and the condenser, it was assumed that an adiabatic region existed, where the temperature was anticipated to remain constant. However, the temperature did not stay constant in the region that was thought to be adiabatic; rather, it climbed slightly as the heat input increased. This may be explained by the fact that design and construction cannot be completed without minor flaws.

• Determining the efficiency and comprehending the CLPHP's heat transfer characteristics are necessary for assessing the heat pipe's performance. Therefore, experimental data were recorded, examined, and compared in order to find the ideal range for heat pipe design and construction. Steady state analysis was used to guide the experiment.

4.6 Copper and Aluminum wire insert Thermal Curve Characteristic

Copper and Aluminum wire inserts. High boiling fluid, i.e., Distilled water and Ethanol Copper wire insert, functions as best performance. In contrast, comparably low boiling points fluid such as Methanol and Acetone Aluminum wire insert deliverers most astonishing performance.

4.7 Effect of Working fluid

The ideal filling ratios for ethanol, methanol, distilled water and acetone are 60%, 40%, 40% and 40%, respectively, in Copper and Aluminum wire inserts

4.8 Hypothesis and Experimental Result Analysis

We have already studied that inserting the copper wire in CLPHP showed more significant result than without insert [9]. So, as we also know, Copper's thermal conductivity is higher than Aluminum's. So, when we hypothesized experimenting with 0.9 mm copper and aluminum wire, we hoped Copper would find the best optimum way. Still, it shows copper wire inserts give only in high boiling fluid, and aluminum wire inserts work best in low boiling fluid.

As we know, we can't see visually in CLPHP while running the experiment, but after the result, we can say the wicked heat play much vital role.

Chapter 5

5 Conclusion

In this paper, " Experimental study on the thermal performance of a closed loop pulsating heat pipe with two different inserts" fresh experimental data on heat transmission are presented. The idea of heat enhancement is used in these works to create a design technique. The technique is implemented simply, quickly, and easily when the approach is used. It was encouraging and helpful to comprehend the ins and outs of the CLPHP's operating principle that the investigation on three working fluids at a variety of filling ratios was conducted. The location of the heat pipe and the working fluid, which control the characteristics of heat transfer, are important factors that this approach helped us understand, but further study is still required to determine how the system behaves in response to the efficacy of the method.

The findings of our experiment support the following assertions:

The key to determining a working fluid's efficacy is its thermal resistance. With increasing heat input, thermal resistance diminishes. The decrement rate is larger at lower heat inputs and lower at higher heat inputs. The ideal filling ratios for ethanol, methanol, distilled water and acetone are 60%, 40%, 40% and 40% respectively.

The heat input rises linearly with the heat transfer coefficient. Different working fluids have a significant impact on heat transfer coefficient, which also rises as heat input rises. The ideal filling ratio and heat resistance are same. More bubbles are developing, which causes more heat flow, as the rate of heat transfer increases.

In High Boling point fluid like Distilled Water (i.e., Boiling temperature 100 °C), Ethanol (i.e., Boiling temperature 78.37 °C) Here Copper Wire insert works best and optimal way While the comparatively low boiling point than Distilled water and Ethanol, Methanol (i.e., Boiling temperature 64.7 °C) & Acetone (i.e., Boiling temperature 56 °C) Works Aluminum works optimal way.

In our experiment, we sought to collect comparison data to identify better operating conditions to boost the heat transfer rate. The ideal filling ratios for ethanol, methanol, distilled water and acetone are 60%, 40%, 40% and 40%, respectively, in Copper and Aluminum wire inserts. High boiling fluid, i.e., Distilled water and Ethanol Copper wire insert, works as optimal performance. In comparison, comparatively low boiling points fluid such as Methanol and Acetone Aluminum wire insert deliverers most remarkable performance.

5.1 Recommendation

It is anticipated that many useful and complex mathematical models of PHPs will be put up for theoretical assessments, particularly of the nonlinear behavior analytical technique. Due to the limits of two-phase flow theories, it is necessary to further develop the concept of pulsing or oscillating flow characteristics and heat transmission processes. Moreover, given the rapid advancement of supercomputers, numerical simulations will undoubtedly get wide interest. Following our trial, the following suggestions are made for CLPHP's future development:

• For more effective and diverse outcomes, this research may combine various working fluids, binary fluids, and Nano fluids. That will guarantee the ideal discovery of a selection of fluids.

• Copper heat pipes were used. Other materials, such as stainless steel for more flexibility, may be used to provide a more thorough concept for the heat pipe. Additionally, a variety of alloys may be employed, and the Biot number may be considered for a more precise result.

• Testing at multiple angular orientations is necessary to get data in various orientations.

• The whole year was spent doing our experiment. As a result, the climate changed with the seasons. For a normal reading, the room temperature should be kept under control and the atmospheric characteristics should be consistent.

• To examine the causes of variations in thermal resistance and to make additional advancements, computational fluid dynamics (CFD) analysis may be performed.

• To prevent excessive heat loss, the working environment should be made more adiabatically.

• The vast range of the dry out mechanism is yet unknown, which is necessary for future adoption of this technology to be more securely established.

• No research has been done on the lifespan of a CLPHP. Therefore, years of ongoing research should be conducted to fully comprehend the functioning and life cycle of a CLPHP.

• To prevent excessive heat loss, the working environment should be made more adiabatically.

CHAPTER 6

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7 APPENDIX

7.1 Mathematical Equations and Calculations

7.1.1 Calculation of filling Ratio

Let, V = Internal volume of the heat pipe

= 100% Fill Ratio

Now, V = $\frac{\pi \times D_i^2 \times L}{4} mm^2$

= $\frac{3.1416 \times 2.75_i^2 \times \{(295 \times (2 \times 240) + (10 \times 210\}}{4}$ mm^2

=17076.27 mm^2

≈17.107 ml

= 17 ml

The complete internal volume of the pipe is taken into consideration to be the system's maximum capacity as there isn't a separate container for working fluid in the test configuration. For instance, 6.8 ml, 8.5 ml, and 10.2 ml of working fluids were employed to evaluate the properties of heat transfer, yielding respective ratios of 40%, 50%, and 60%.

7.1.2 Calculation of Heat Input

Let, Q = Power Input (Heat Input)

= V.I. Cos θ

In our experiment 20W~70W power was used for the reading at the interval of 10W. The power was achieved through the voltage variation mentioned in following table:

Table 8 Heat input Calculation

V	**I**	**Cos θ**	**Q**
27.13	0.388	1	10
37.83	0.542	1	20
46.03	0.66	1	30
53.23	0.761	1	40
59.32	0.852	1	50
64.71	0.852	1	60

7.1.3 Calculation of Thermal Resistance

Let, R_{th} = Thermal Resistance

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

$= \frac{T_e - T_C}{Q}$ C°/W

7.1.4 Calculation of Heat transfer Co-efficient

Let, h = Heat transfers co-efficient

$= \frac{Q}{A_e(\Delta T)}$ W/ C°/-m^2

$= \frac{Q}{A_e(T_{e-T_c})}$ W/ C°-m^2

Now $A_e = \pi \times 2.75 \times (12\times50)$ {6 turns mean 12 CLPHP 50mm Eva} mm^2

7.2 Micro-controller Code

```
#include <OneWire.h>
#include <DallasTemperature.h>

#define WATT 10.0

#define ONE_WIRE_BUS 10
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

float temp[6];
long recordTime;
```

```
void setup() {
  Serial.begin(9600);
  sensors.begin();

  // set excel top row label
  Serial.println("CLEARSHEET");
  Serial.println("LABEL,Log Time(Sec),Resistance,Co-efficient,Watt");
  delay(500);
}

void loop() {
  sensors.requestTemperatures();
  for (byte i = 0; i < 6; i++) {
    float tempC = sensors.getTempCByIndex(i);
    if (tempC != DEVICE_DISCONNECTED_C) temp[i] = tempC;
Serial.print((String)temp[i] + ",");
  }
Serial.println();

  recordTime = millis() / 1000;
  float eva = temp[0] + temp[1] + temp[2] / 3.0;
  float con = temp[3] + temp[4] + temp[5] / 3.0;
  float resist = (eva - con) / WATT;
  float coeffi = WATT / (0.0062203 * (eva - con));

  Serial.println((String)"DATA," + recordTime + "," + resist + "," + coeffi + "," + WATT);
  delay(1000);
}
```

7.3 Circuit Diagram

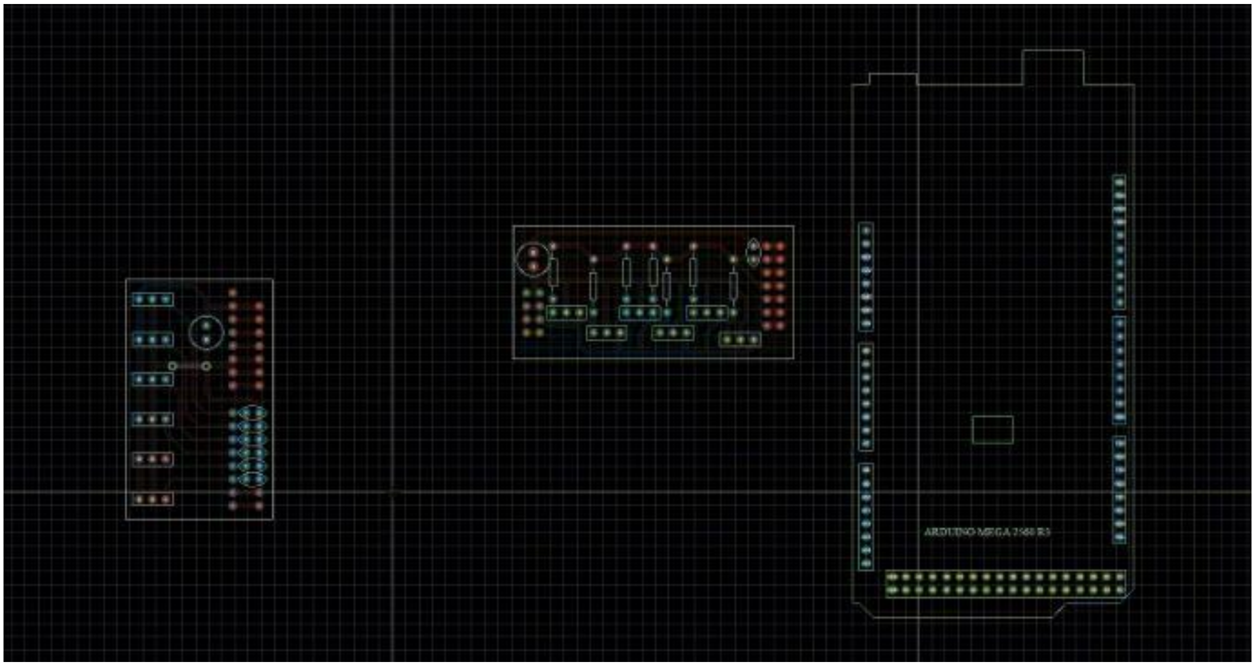

Figure 7.1 Circuit Diagram

7.4 Data Collection

7.4.1 40% Ethanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.5	45.96	10
601	3.32	48.44	20
600	2.96	54.36	30
601	2.85	56.47	40
600	2.49	64.63	50
601	1.87	86.04	60

7.4.2 50% Ethanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.74	42.97	10
600	3.32	48.37	20
601	2.98	53.91	30
600	2.53	63.54	40
600	2.17	73.97	50
601	1.81	89.02	60

7.4.3 60% Ethanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.81	42.24	10
600	3.18	50.5	20
600	2.74	58.61	30
601	1.94	82.93	40
600	1.46	110.49	50
600	1.28	126.02	60

7.4.4 40% Ethanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.92	41	10
600	3.19	50.39	20
600	2.9	55.5	30
600	2.65	60.73	40
601	2.48	64.88	50
600	2.12	75.65	60

7.4.5 50% Ethanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	4.16	38.6	10
600	3.16	50.9	20
600	2.81	57.16	30
600	2.25	71.53	40
602	2.17	74.01	50
600	1.91	84.28	50

7.4.6 60% Ethanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.85	41.71	10
600	3.1	51.86	20
600	2.71	59.33	30
600	2.5	64.36	40
600	2.01	79.83	50
600	1.56	103.03	60

7.4.7 40% Methanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.7	43.45	10
600	3.13	51.29	20
600	2.9	55.45	30
601	2.51	63.97	40
600	2.18	73.65	50
601	1.83	87.82	60

7.4.8 50% Methanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.86	41.67	10
600	3.16	50.85	20
600	2.84	56.68	30
601	2.43	66.08	40
600	2.15	74.64	50
601	2.02	79.58	60

7.4.9 60% Methanol Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	4.07	39.45	10
601	3.18	50.6	20
600	2.86	56.16	30
601	2.4	67.12	40
600	2.08	77.34	50
601	1.62	99.51	60

7.4.10 40% Methanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.52	45.66	10
600	3.05	52.71	20
600	2.87	55.97	30
600	2.39	67.13	40
600	1.28	125.92	50
600	1.04	155.06	60

7.4.11 50% Methanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.86	41.62	10
600	3.36	47.89	20
600	3.03	53.06	30
600	2.22	72.56	40
600	1.65	97.48	50
600	1.26	127.55	60

7.4.12 60% Methanol Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.97	40.51	10
600	3.29	48.84	20
600	2.99	53.8	30
600	2.47	65.12	40
600	2.03	79.34	50
600	1.77	90.86	60

7.4.13 40% Distilled Water Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.24	49.59	10
600	2.81	57.2	20
600	2.72	59.18	30
600	2.3	70.01	40
600	1.89	84.85	50
601	1.56	103.07	60

7.4.14 50% Distilled Water Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.05	52.67	10
600	2.74	58.62	20
600	2.78	57.8	30
600	2.71	59.22	40
600	2.51	63.98	50
601	2.37	67.96	60

7.4.15 60% Distilled Water Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.32	48.47	10
600	3.04	52.93	20
600	2.8	57.47	30
600	2.75	58.52	40
601	2.55	63.11	50
600	2.38	67.57	60

7.4.16 40% Distilled Water Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.87	41.49	10
600	3.31	48.64	20
600	3.08	52.15	30
600	3.12	51.57	40
600	2.99	53.68	50
600	2.82	57.08	60

7.4.17 50% Distilled Water Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.77	42.68	10
600	3.42	47.05	20
600	3.12	51.56	30
600	3.04	52.88	40
600	2.37	67.93	50
601	2.69	59.66	60

7.4.18 60% Distilled Water Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.48	46.15	10
600	3.29	48.84	20
600	3.15	51	30
600	2.99	53.76	40
600	2.87	55.97	50
600	2.53	63.62	60

7.4.19 40% Acetone Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.36	47.81	10
600	3.13	51.38	20
600	2.85	56.39	30
600	2.84	56.54	40
601	2.47	65.14	50
600	2.21	72.64	60

7.4.20 50% Acetone Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.24	49.69	10
600	2.7	59.47	20
600	2.54	63.36	30
600	2.49	64.66	40
600	2.1	76.48	50
601	1.86	86.59	60

7.4.21 60% Acetone Copper insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.64	44.2	10
600	2.99	53.74	20
600	2.65	60.71	30
600	2.38	67.68	40
600	1.99	80.97	50
601	1.61	99.76	60

7.4.22 40% Acetone Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.54	45.39	10
600	3.16	50.95	20
600	2.96	54.38	30
600	2.63	61.09	40
600	1.67	96.03	50
600	1.19	135.62	60

7.4.23 50% Acetone Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.84	41.87	10
600	3.14	51.21	20
600	2.86	56.16	30
600	2.34	68.68	40
600	1.88	85.46	50
600	1.6	100.7	60

7.4.24 60% Acetone Aluminum insert

Log Time(Sec)	Resistance	Co-efficient	Watt
600	3.78	42.56	10
600	2.99	53.85	20
600	2.45	65.6	30
600	1.66	96.58	40
600	1.87	86.14	50
600	1.6	100.41	60

7.4.25 Sample data collection from PLX-DAQ

Log Time (Sec)	Resistance	Co-efficient	Watt
1	0.83	194.37	10
3	0.89	181.14	10
5	0.95	168.49	10
7	1.01	158.45	10
9	1.07	150.42	10
10	1.11	145.05	10
12	1.16	138.04	10
14	1.21	133.05	10
16	1.25	128.4	10
18	1.3	124.06	10
20	1.34	120.01	10
22	1.38	116.39	10
24	1.41	113.82	10
25	1.45	110.55	10
27	1.5	106.88	10
29	1.53	105.13	10
31	1.56	102.89	10

Log Time (Sec)	Resistance	Co-efficient	Watt
33	1.6	100.48	10
35	1.64	98.3	10
37	1.67	95.98	10
38	1.71	94.11	10
40	1.74	92.3	10
42	1.76	91.54	10
44	1.8	89.42	10
46	1.81	88.7	10
48	1.84	87.19	10
50	1.88	85.36	10
52	1.91	84.06	10
53	1.93	83.15	10
55	1.96	82.18	10
57	1.99	80.72	10
59	2.03	79.39	10
61	2.04	78.98	10
63	2.07	77.71	10
65	2.1	76.63	10
67	2.11	76.33	10
68	2.13	75.36	10
70	2.16	74.56	10
72	2.18	73.7	10
74	2.2	72.94	10
76	2.23	72.25	10
78	2.25	71.38	10
80	2.26	70.99	10
81	2.29	70.09	10
83	2.3	69.83	10
85	2.33	69.02	10
87	2.35	68.41	10
89	2.37	67.75	10
91	2.39	67.34	10
93	2.41	66.81	10
95	2.43	66.18	10
96	2.45	65.56	10
98	2.46	65.28	10
100	2.49	64.68	10
102	2.51	64.15	10
104	2.52	63.77	10
106	2.53	63.46	10
108	2.55	62.94	10

Log Time (Sec)	Resistance	Co-efficient	Watt
110	2.58	62.38	10
111	2.6	61.88	10
113	2.6	61.73	10
115	2.61	61.59	10
117	2.65	60.76	10
119	2.66	60.43	10
121	2.67	60.29	10
123	2.69	59.82	10
125	2.69	59.68	10
126	2.71	59.36	10
128	2.74	58.77	10
130	2.75	58.37	10
132	2.76	58.33	10
134	2.76	58.33	10
136	2.79	57.59	10
138	2.81	57.25	10
139	2.82	57.08	10
141	2.83	56.74	10
143	2.83	56.91	10
145	2.85	56.37	10
147	2.87	55.96	10
149	2.89	55.72	10
151	2.9	55.44	10
153	2.91	55.28	10
154	2.92	55.04	10
156	2.94	54.77	10
158	2.94	54.61	10
160	2.97	54.15	10
162	2.97	54.15	10
164	2.98	54	10
166	2.99	53.85	10
168	3.01	53.4	10
169	3.02	53.26	10
171	3.03	53.15	10
173	3.03	53.04	10
175	3.04	52.89	10
177	3.05	52.67	10
179	3.07	52.32	10
181	3.08	52.28	10
182	3.09	52.1	10
184	3.09	51.96	10

Log Time (Sec)	Resistance	Co-efficient	Watt
186	3.1	51.82	10
188	3.11	51.72	10
190	3.11	51.62	10
192	3.13	51.38	10
194	3.15	51.07	10
196	3.15	51.07	10
197	3.16	50.94	10
199	3.16	50.83	10
201	3.17	50.63	10
203	3.19	50.4	10
205	3.2	50.27	10
207	3.2	50.17	10
209	3.21	50.14	10
211	3.22	49.98	10
212	3.22	49.85	10
214	3.24	49.62	10
216	3.25	49.43	10
218	3.27	49.21	10
220	3.26	49.24	10
222	3.27	49.21	10
224	3.29	48.9	10
226	3.3	48.72	10
227	3.3	48.72	10
229	3.31	48.59	10
231	3.31	48.5	10
233	3.32	48.38	10
235	3.33	48.32	10
237	3.33	48.35	10
239	3.34	48.11	10
240	3.35	48.02	10
242	3.35	47.99	10
244	3.35	47.99	10
246	3.36	47.81	10
248	3.37	47.69	10
250	3.38	47.55	10
252	3.38	47.63	10
254	3.38	47.52	10
255	3.39	47.43	10
257	3.4	47.28	10
259	3.39	47.37	10
261	3.41	47.11	10

Log Time (Sec)	Resistance	Co-efficient	Watt
263	3.41	47.17	10
265	3.41	47.08	10
267	3.41	47.14	10
269	3.42	46.97	10
270	3.44	46.71	10
272	3.45	46.6	10
274	3.46	46.51	10
276	3.46	46.4	10
278	3.46	46.51	10
280	3.46	46.49	10
282	3.48	46.24	10
283	3.47	46.29	10
285	3.49	46.12	10
287	3.49	46.1	10
289	3.49	46.01	10
291	3.49	46.01	10
293	3.51	45.77	10
295	3.52	45.69	10
297	3.52	45.69	10
298	3.52	45.66	10
300	3.53	45.55	10
302	3.53	45.55	10
304	3.53	45.58	10
306	3.54	45.47	10
308	3.55	45.29	10
310	3.55	45.31	10
312	3.56	45.15	10
313	3.55	45.29	10
315	3.56	45.13	10
317	3.57	45.05	10
319	3.57	45.05	10
321	3.57	44.97	10
323	3.58	44.89	10
325	3.58	44.86	10
326	3.59	44.79	10
328	3.6	44.71	10
330	3.6	44.71	10
332	3.6	44.63	10
334	3.61	44.53	10
336	3.6	44.63	10
338	3.61	44.55	10

Log Time (Sec)	Resistance	Co-efficient	Watt
340	3.61	44.48	10
341	3.62	44.35	10
343	3.63	44.3	10
345	3.63	44.32	10
347	3.62	44.37	10
349	3.65	44.1	10
351	3.64	44.2	10
353	3.64	44.12	10
355	3.65	44.07	10
356	3.65	43.99	10
358	3.66	43.97	10
360	3.65	43.99	10
362	3.66	43.92	10
364	3.67	43.75	10
366	3.67	43.82	10
368	3.67	43.77	10
370	3.67	43.77	10
371	3.68	43.67	10
373	3.69	43.62	10
375	3.69	43.57	10
377	3.69	43.57	10
379	3.69	43.6	10
381	3.69	43.57	10
383	3.7	43.5	10
384	3.71	43.35	10
386	3.72	43.21	10
388	3.71	43.28	10
390	3.7	43.45	10
392	3.7	43.45	10
394	3.72	43.21	10
396	3.71	43.28	10
398	3.73	43.06	10
399	3.73	43.13	10
401	3.73	43.13	10
403	3.73	43.06	10
405	3.73	43.06	10
407	3.74	42.99	10
409	3.74	43.04	10
411	3.75	42.92	10
413	3.74	43.04	10
414	3.75	42.89	10

Log Time (Sec)	Resistance	Co-efficient	Watt
416	3.75	42.85	10
418	3.76	42.75	10
420	3.76	42.73	10
422	3.76	42.75	10
424	3.75	42.82	10
426	3.77	42.66	10
427	3.77	42.59	10
429	3.77	42.61	10
431	3.78	42.59	10
433	3.77	42.66	10
435	3.77	42.61	10
437	3.78	42.54	10
439	3.77	42.59	10
441	3.79	42.45	10
442	3.8	42.35	10
444	3.79	42.38	10
446	3.8	42.35	10
448	3.8	42.35	10
450	3.8	42.28	10
452	3.8	42.31	10
454	3.8	42.28	10
456	3.81	42.17	10
457	3.81	42.17	10
459	3.8	42.28	10
461	3.81	42.21	10
463	3.81	42.14	10
465	3.81	42.21	10
467	3.8	42.28	10
469	3.81	42.21	10
471	3.81	42.21	10
472	3.81	42.21	10
474	3.81	42.14	10
476	3.83	42.01	10
478	3.83	41.98	10
480	3.83	41.98	10
482	3.83	41.98	10
484	3.84	41.89	10
485	3.82	42.05	10
487	3.83	41.96	10
489	3.84	41.92	10
491	3.83	41.98	10

Log Time (Sec)	Resistance	Co-efficient	Watt
493	3.84	41.82	10
495	3.84	41.87	10
497	3.84	41.82	10
499	3.85	41.78	10
500	3.85	41.73	10
502	3.85	41.78	10
504	3.85	41.71	10
506	3.85	41.71	10
508	3.86	41.67	10
510	3.86	41.67	10
512	3.85	41.71	10
514	3.86	41.67	10
515	3.86	41.6	10
517	3.87	41.58	10
519	3.87	41.51	10
521	3.86	41.64	10
523	3.86	41.64	10
525	3.87	41.53	10
527	3.88	41.47	10
528	3.87	41.51	10
530	3.88	41.47	10
532	3.86	41.6	10
534	3.87	41.51	10
536	3.87	41.51	10
538	3.88	41.47	10
540	3.87	41.49	10
542	3.88	41.44	10
543	3.88	41.47	10
545	3.89	41.38	10
547	3.87	41.53	10
549	3.88	41.44	10
551	3.89	41.31	10
553	3.89	41.29	10
555	3.9	41.24	10
557	3.89	41.31	10
558	3.9	41.24	10
560	3.9	41.24	10
562	3.89	41.31	10
564	3.89	41.31	10
566	3.9	41.24	10
568	3.91	41.16	10

Log Time (Sec)	Resistance	Co-efficient	Watt
570	3.9	41.22	10
572	3.91	41.16	10
573	3.92	41	10
575	3.91	41.16	10
577	3.9	41.2	10
579	3.91	41.07	10
581	3.92	41.05	10
583	3.92	41.02	10
585	3.92	41.05	10
586	3.92	40.98	10
588	3.92	40.98	10
590	3.93	40.94	10
592	3.92	40.98	10
594	3.92	40.98	10
596	3.91	41.07	10
598	3.93	40.92	10
600	3.92	41	10
601	3.93	40.94	10
603	3.93	40.94	10