Experimental study on the thermal performance of a closed loop pulsating heat pipe with various angle

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“A Graduation Exercise Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Mechanical Engineering”

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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 various angle”** 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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This is to certify that the investigation conducted by the author under the guidance of **Md. Sojib Kaisar,** Assistant Professor, Dept. of Mechanical Engineering, **Sonargaon University (SU)**, resulted in the thesis, "**Experimental study on the thermal performance of a closed loop pulsating heat pipe with various angles**." This thesis or any portion of it has not been submitted to another institution for the granting of another degree, diploma, or any title or reward that is identical as well.

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May, 2023

Dedication

This research paper is dedicated to my dear father, who has been nicely my supporter until my research was fully finished, and my beloved mother who, for months past, has encouraged me attentively with her fullest and truest attention to accomplish my work with truthful self-confidence.

Abstract

The performance of a closed-loop pulsating heat pipe (CLPHP) was investigated using different parameters such as filling ratio, working fluid, and angle. The results showed higher filling ratios reduced thermal resistance, indicating more efficient heat transfer. Among the studied configurations, the CLPHP filled with ethanol at an 50% ratio and inclined at a 45° angle demonstrated the best performance, with a thermal resistance of 1.38 °C/W. On the other hand, ethanol at a 50% filling ratio and an angle of 180° exhibited the poorest performance, with a thermal resistance of 2.75 °C/W, indicating reduced heat transfer efficiency. The choice of working fluid also played a significant role, with ethanol consistently displaying lower thermal resistances than methanol. The impact of the angle on thermal resistance varied depending on the filling ratio and working fluid. The research findings deviated from the optimal range reported in previous studies, indicating the possibility of dry-out conditions due to fewer turns in the CLPHP and the operation at a 180° angle. This discrepancy could be attributed to the increased liquid phase viscosity, resulting in higher frictional surface shear stress. Additionally, the absence of body force in the horizontal operation mode hindered fluid motion. Overall, the study highlights the importance of considering various parameters in CLPHP design to achieve optimal thermal performance and emphasizes the influence of filling ratio, working fluid, and angle on thermal resistance and heat transfer efficiency.

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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	Heat input (watt)
CLPHP	Closed Loop Pulsating Heat Pipe
OHP	Oscillating Heat Pipe
PHP	Pulsating Heat Pipe
Fig	Figure
P	Density of water (kg/m^3)
CFD	Computational fluid dynamics
FR	Filling Ratio

Chapter 1

1 Introduction

Numerous sectors, from electronics and aerospace to automotive and energy systems, have seen an increase in demand for effective and small cooling solutions in recent years. Traditional cooling techniques like fans and heat sinks are often unable to meet the rising demands for heat dissipation as electronic devices become smaller and more powerful. Due to this, cutting-edge thermal management solutions have emerged, with closed-loop pulsing heat pipes (CLPHPs) receiving a lot of attention and recognition.

In order to effectively and quickly transport heat from a heat source to a heat sink, closed-loop pulsing heat pipes combine the concepts of capillary action, phase change, and two-phase flow. High heat transfer rates, minimal thermal resistance, homogeneous temperature distribution, and the flexibility to work in any direction are just a few benefits they have over traditional cooling techniques.

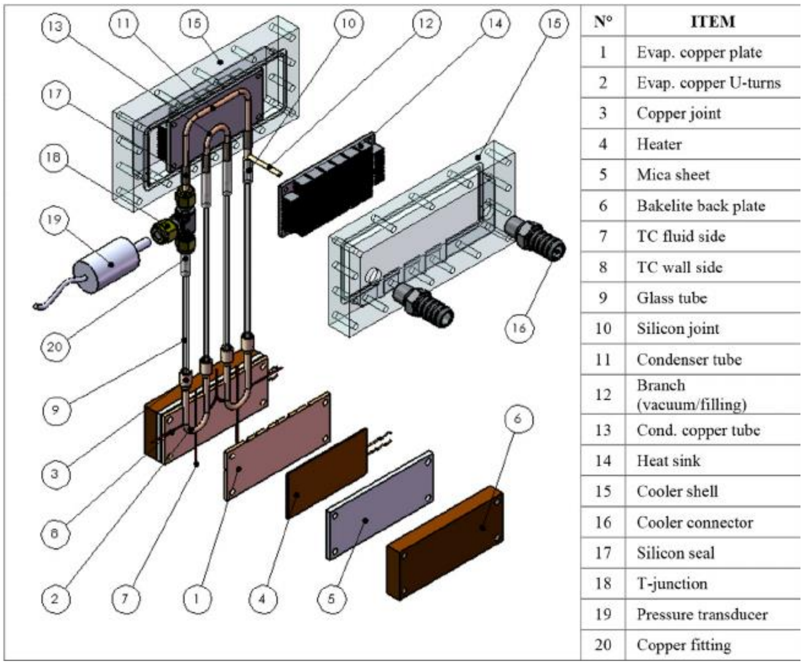
A closed-loop pulsing heat pipe works by circulating a working fluid within a tube with a sealed, looped end. The tube normally comprises several linked parts, including an evaporator section, an adiabatic portion, and a condenser section, and is built of a thermally conductive material like copper or aluminum. These parts are partly filled with the working fluid, which is selected based on its thermophysical characteristics.

Due to its low boiling point, the working fluid vaporizes when heat is applied to the evaporator portion. The pressure differential created inside the system propels the resultant vapor phase in the direction of the condenser portion. The vapor emits heat to the atmosphere as it passes through the condenser and condenses back into a liquid phase. The closed-loop cycle is subsequently completed by the condensed liquid returning through capillary action to the evaporator part.

The existence of oscillatory motion within the working fluid is the distinguishing characteristic of closed-loop pulsating heat pipes. The capillary forces and the vapor-liquid interface combine to provide self-sustaining, high-frequency oscillations of the liquid plugs or slugs within the tube, which causes the pulsing motion. This pulsing flow encourages improved heat transfer properties because it prevents the creation of a stagnant thermal boundary layer and continuously refreshes the liquid-vapor surfaces.

The geometry of the pipe, the characteristics of the working fluid, the filling ratio, and the heat load provided are some of the variables that affect the thermal performance of closed-loop pulsing heat pipes. To improve the design and operation of CLPHPs for various applications, researchers have thoroughly explored these parameters. Additionally, improvements in manufacturing methods have aided in the creation of flexible and tiny CLPHPs, allowing their incorporation into intricate systems with limited space.

There are several industries in which closed-loop pulsing heat pipes might be used. They may be used in applications requiring precise temperature control and significant heat dissipation, such as cooling of high-power electronic components, circuit boards, and LEDs. CLPHPs have also shown potential in the thermal control of sophisticated materials processing and aerospace systems, as well as in the cooling of energy conversion technologies like fuel cells and solar cells.



N°	ITEM
1	Evap. copper plate
2	Evap. copper U-turns
3	Copper joint
4	Heater
5	Mica sheet
6	Bakelite back plate
7	TC fluid side
8	TC wall side
9	Glass tube
10	Silicon joint
11	Condenser tube
12	Branch (vacuum/filling)
13	Cond. copper tube
14	Heat sink
15	Cooler shell
16	Cooler connector
17	Silicon seal
18	T-junction
19	Pressure transducer
20	Copper fitting

Figure 1-1 Electronics cooling using CLPHP [1]

Finally, closed-loop pulsing heat pipes are a state-of-the-art thermal management technology that provides effective and space-saving cooling solutions for a variety of sectors. CLPHPs have the potential to revolutionize heat transfer and enhance the performance and dependability of several applications because of their distinct operating principles and benefits. The design and execution of closed-loop pulsing heat pipes are still being investigated and improved as part of ongoing research and development, assuring their widespread acceptance and future developments in the area of thermal management.

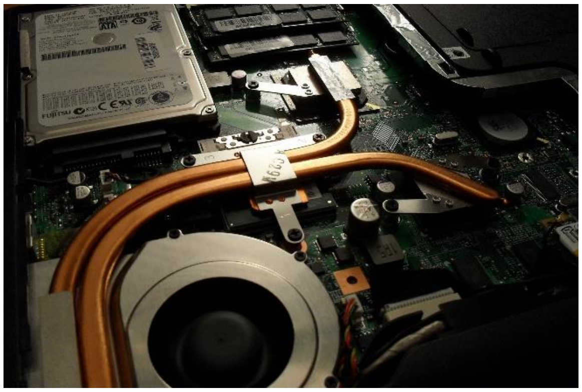


Figure 1-2 Heat pipe in real life electronics use (https://en.wikipedia.org/wiki/Heat_pipe)

Additionally, there have been a number of developments made as a result of research and development into closed-loop pulsing heat pipes that are intended to enhance their functionality. The optimization of the geometric arrangement of CLPHPs is one area of emphasis. To improve heat transmission and overall system efficiency, researchers have experimented with various tube sizes, lengths, and forms. In order to improve fluid mixing and heat transmission within the pipes, different internal features, such as grooves or fins, have also been researched.

The choice of appropriate working fluids for closed-loop pulsating heat pipes is another critical consideration. Boiling point, heat capacity, and viscosity are a few thermophysical qualities that differ amongst fluids and have an effect on heat transport. To determine the best options for certain applications, researchers have examined a wide variety of working fluids, including pure liquids and binary mixes. Research on nanofluids, which are suspensions of nanoparticles in conventional working fluids, has also shown promise in improving the efficiency of heat transmission in CLPHPs.

Closed-loop pulsating heat pipes' capacity for heat transmission is significantly influenced by the filling ratio, which describes the volume per cent of the working fluid within the pipe. By maximizing the filling ratio, one may prevent excessive pressure drop and fluid stagnation while yet ensuring that there is enough working fluid to enable effective heat transmission. To determine the ideal filling ratio for various operating situations and geometrical configurations, researchers have carried out experimental and numerical analyses.

Additionally, a crucial factor that influences the performance of closed-loop pulsing heat pipes is the heat load delivered to them. Higher heat loads often lead to faster heat transfer rates and more violent oscillatory action. However, the amount of heat that CLPHPs can efficiently manage has a limit over which the system may become unstable or perform worse. Therefore, for the effective use of closed-loop pulsating heat pipes, it is crucial to comprehend the heat transmission limitations and create control systems to regulate the heat load.

Closed-loop pulsing heat pipes must be carefully integrated into a variety of systems, which requires careful consideration of elements such as system orientation, physical limitations, and interface design. Because they may function in any direction, CLPHPs have the benefit of being appropriate for both horizontal and vertical applications. Due to their adaptability, they may be used in a variety of industries, including renewable energy systems, automobile cooling, and space exploration.

Closed-loop pulsing heat pipes have gotten a lot of interest lately for their flexibility and compactness. Microsystems and small-scale electronic equipment may now be cooled using miniature CLPHPs. These small-footprint heat pipes are perfect for situations where space is at a premium since they have a high capacity for heat transmission. Contrarily, flexible CLPHPs provide effective thermal management in complicated systems by permitting conformal cooling of unevenly shaped components.

Despite the many benefits and developments, there are still certain obstacles to the widespread use of closed-loop pulsing heat pipes. These difficulties include the need for a deeper comprehension of intricate two-phase flow phenomena, the creation of precise modelling and simulation tools, and the affordability of production processes. These problems are still being researched, and efforts are being made to advance closed-loop pulsing heat pipe technology.

1.1 Type of heat pipe & revolution of heat pipe

The amazing heat transfer technology known as heat pipes has changed thermal management in various sectors. Since their creation, several varieties of heat pipes have been created, each with special benefits and characteristics. Let us examine the many heat pipe varieties and their historical contributions.

The most popular and commonly used heat pipe form is a capillary heat pipe. They are made from an evacuated, sealed tube filled with a working fluid, usually a liquid-vapor mixture. The pipe's inner wall has a wick structure that encourages capillary action, which drives the heat transfer process and helps the fluid circulate. Aerospace systems, energy conversion devices, and electronics cooling all use capillary heat pipes.

1.2 Types of Heat Pipe

1. **Vapor Chamber Heat Pipes**: The vapor chamber heat pipe is an upgraded kind of heat pipe with improved heat-spreading characteristics. They use a construction that is flat and plate-like and has a sealed chamber that is filled with a working fluid. High-power electronic parts, CPUs, and LED lighting systems may be efficiently cooled by the vapor chamber's excellent heat dispersion over its surface.

2. **Loop Heat Pipes**: An evaporator, a condenser, and a connecting loop comprise the closed-loop heat pipe (LHP). They use a closed-loop working fluid circulated by the difference in vapor pressure between the evaporator and the condenser. Because of their well-known capacity to transmit heavy heat loads over long distances, LHPs are well-suited for space applications, including cooling satellites and spacecraft.

3. **Pulsating Heat Pipes**: Self-excited oscillatory flow is the basis for how pulsating heat pipes (PHPs) work. They consist of a sealed tube divided into an adiabatic area, a condenser, and an evaporator. Heat transmission is facilitated by the working fluid oscillating as liquid plugs or slugs. PHPs are small and adaptable and used in renewable energy systems, innovative material thermal management, and electronics cooling.

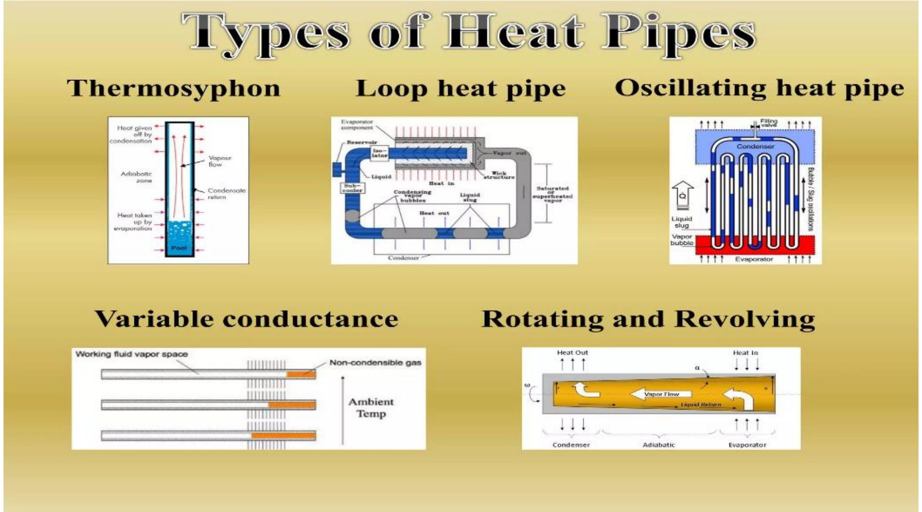


Figure 1-3 Types of heat pipe (Fundamentals of Heat Pipes with Applications and Types, 2018.)

Heat pipes have made important contributions to thermal control throughout history:

1. **Early Development**: George Grover undertook ground-breaking research on heat transmission devices in the early 1940s when the idea of heat pipes first emerged (GEORGE GROVER, 81, INVENTED HEAT TRANSFER DEVICE – Sun Sentinel, 2018.). Grover's study provided the conceptual framework for comprehending heat pipes' fundamentals and future uses.
2. **Applications in Space**: Heat pipes were popular throughout the Space Age. NASA used heat pipes in the 1960s to control the temperatures of various spacecraft parts, including the astronauts' suits, fuel tanks, and electrical systems. In order to maintain dependable functioning in the harsh conditions of space, heat pipes were essential.
3. **Electronics Cooling**: As electronic technology advanced quickly, the need for effective cooling solutions increased significantly. In the late 1970s and early 1980s, heat pipes started to gain popularity as an alternative method for cooling devices. They allowed for the downsizing and increased dependability of electronic equipment by providing higher heat transfer capability, compactness, and the capacity to tolerate high heat fluxes.
4. **Materials and manufacturing advancements**: Over time, improvements in materials and manufacturing methods have improved heat pipe technology even further. The

performance of heat pipes was enhanced by creating innovative wick architectures like sintered copper and micro-grooved surfaces. Additionally, improvements in manufacturing techniques made it possible to produce heat pipes with intricate shapes, facilitating their integration into diverse systems.

Heat pipes have expanded into various industries, including the automobile, aerospace, energy, and telecommunications. Power electronics, LED lights, heat exchangers, heat recovery systems, nuclear reactors, and other items are all cooled using them. Heat pipes' adaptability and effectiveness continue to spur innovation in these sectors.

1.3 Selection Closed loop pulsating heat pipe

Improved Heat Transmission Performance: Compared to conventional heat pipes, CLPHPs have better heat transmission properties. The working fluid's pulsing motion encourages effective heat transmission by often renewing the liquid-vapor interfaces and preventing the development of thermal boundary layers that are not moving. There are now opportunities to raise the overall effectiveness of thermal management systems because of this improved heat transfer performance.

Self-Sustained Oscillatory Flow: A remarkable occurrence in CLPHPs that enables the system to self-regulate is the self-excited oscillatory flow. Improved heat distribution and fewer temperature gradients occur from the working fluid's effective mixing, made possible by the oscillatory motion. Advanced thermal management solutions may be created by investigating the underlying causes and improving the oscillatory behaviors of CLPHPs.

Compact and Versatile Design: CLPHPs provide design options that are both compact and versatile, making them appropriate for a variety of applications. They are very adaptive to areas with limited space, such as electronic equipment, where effective heat dissipation is essential because of their compact footprint and flexibility to work in any direction. Researching CLPHPs' design features may result in the creation of flexible and miniature heat pipe systems.

Diverse Application Areas: CLPHPs have potential in several sectors, including advanced materials processing, energy conversion systems, electronics cooling, and aerospace. You can investigate several application areas and help enhance thermal management in many domains by selecting CLPHPs for investigation.

Research Potential: Although CLPHPs have received much attention, there is still much to learn and explore. Numerous research topics may be investigated, including geometric design optimization, the effects of various working fluids, innovative manufacturing processes, the development of cutting-edge control schemes, and performance analysis under various operating situations. By choosing CLPHPs, you may actively participate in advancing knowledge of and opportunities for using this revolutionary heat transfer technology.

There are various convincing reasons to use closed-loop pulsing heat pipes (CLPHPs) for research. They are a great option for developing the field of thermal management due to their improved heat transfer performance, self-sustained oscillatory flow, compact design, variety of application areas, and research potential. You can help build effective and cutting-edge heat transfer solutions for various industries by learning about the complexities of CLPHPs.

1.4 Factors influencing how well CLPHPs perform

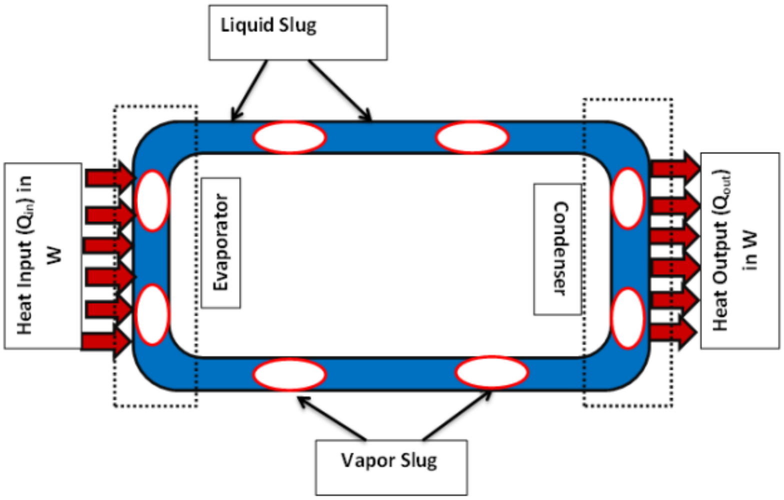


Figure 1-4 Working Schematic CLPHP[4]

Six significant thermo-mechanical characteristics have emerged as the main design parameters influencing the PHP system dynamics, according to the literature that is currently accessible. The internal diameter of the PHP tube, the input heat flux, the volumetric filling ratio of the working fluid, the total number of turns, the device's orientation concerning gravity, and the thermophysical characteristics of the working fluid are among them.

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

1.5 Design and geometrical parameters: Dimensions and tube material

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 internal diameter has a direct impact on PHP. A bigger hydraulic diameter affects lower wall thermal resistance and higher effective thermal conductivity. The inner diameter of the capillary tube must be so tiny that Dmax= 2[/g (liq - vap)]1/2

Where: Liq = liquid density (Kg/m3); Vap = vapor density (Kg/m3); g = gravity acceleration (m/s2); = 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.

1.6 Count of turns

The more PHP is used, the more adaptable it becomes to function in any situation (i.e., at any edge of slant with even). Analysts have shown that if there are fewer spins, the system only operates in the vertical position rather than in other positions.

Additionally, (MEPC.1-Circ.896, 2021.) 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 reduced heat resistance.

iii. Regarding general effectiveness, there are fewer obvious distinctions between other fluids.

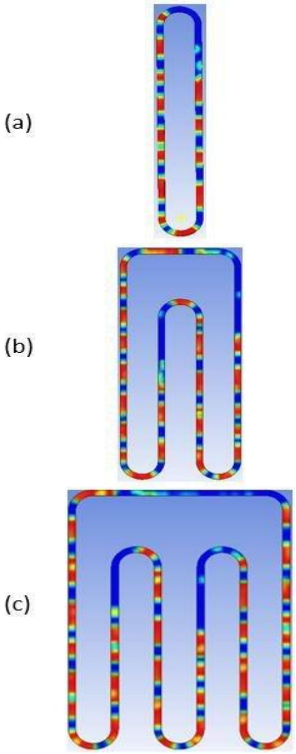


Figure 1-5 Number of turn effect CLPHP in CFD [6]

1.7 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 evaporator section lengths impacted the essential heat flux in this range. 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 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 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, increasing the condenser capacity is only sometimes necessary for traditional heat pipes to increase heat transmission. Although there is no precise adiabatic working temperature for pulsing heat pipes, the influence of condenser capacity tends to follow a similar path. In addition to changing the working fluid's thermo-physical characteristics, expanding the condenser's capacity also varies the slug-annular flow pattern transition, which ultimately changes the performance. The practical designing process must consider this.

1.8 Bend Effect

Their U-tern quantities are accessible in PHP geometry.[7] explained how twist affects PHP execution. The 180° and 90° twisted weights cause pipe tragedy.[8] has also created a numerical model to consider the local pressure loss occurring in the PHP.

1.9 Operational Conditions: Ratio of filling:

The volume percentage of the heat pipe 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.

1.10 The 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 understand this work fully. When there are few turns, a fundamental heat transition between 5.2 and 6.5 W/cm2 is anticipated to ignite a smooth movement and reach a satisfying pseudo-unchanging condition.

1.11 A dry environment

This issue limits how well heat pipes can work. A dry-out situation occurs when all the working liquid has evaporated, and the region around the evaporator is completely dry. This situation develops when the pipe receives a strong heat input and a low filling proportion. When a dry situation is reached, conduction is the only mechanism through which heat exchange occurs.

1.12 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. The characteristics will influence both the ability to exchange heat and the equivalency with the tube material. The working fluid should be selected to support the PHP working temperature run. The following working liquid characteristics should be examined when selecting a working liquid: Similarity to the OHP materials, 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 most applications since it has high dormant heat, which distributes more heat with a 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% of the surface strains of water, methanol is a good substitute for it, especially in situations where the temperature is below zero.

1.13 Research Gap

This [9]work outlines the need for more tests to corroborate various theoretical models and to achieve consistent findings for the thermal performance of a horizontal closed-loop oscillating heat pipe (HCLOHP). According to the research, the findings for horizontal orientation are less substantial than those for bottom heat mode, and the effects of the filling ratio and operating temperature should have been noted. In order to fill this research gap, the authors advise more experimental studies on an HCLOHP's thermal performance under typical working settings.

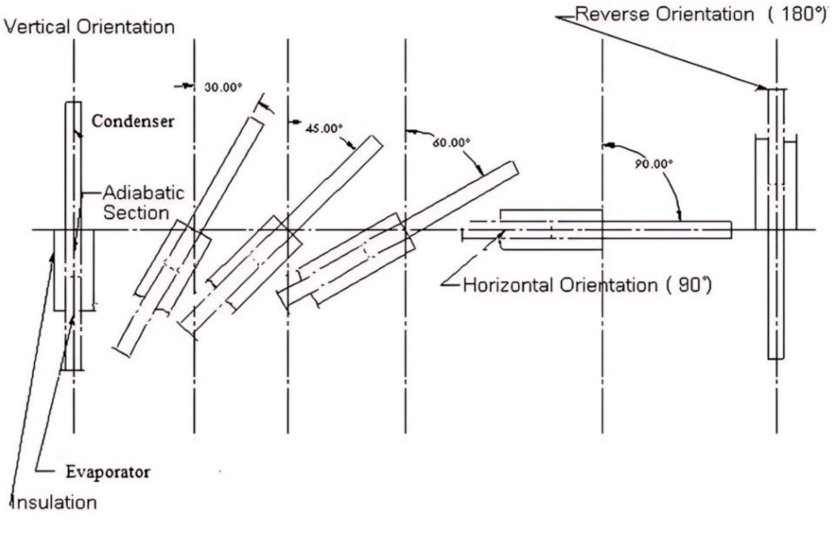


Figure 1-6 Wooden movable holder and changing of orientation angle

1.14 Objectives

The study indicates that the results for horizontal orientation are less significant than those for bottom heat mode, and it should have considered the impacts of filling ratio and operating temperature. To close this knowledge gap, the authors suggest more experimental investigations on an HCLOHP's thermal performance under normal operating conditions [9].

The aims of this thesis are:

1. To investigate the performance of CLPHP with 45° and 180° also filling ration 50% & 80% Ethanol as a working fluid.
2. To examine the performance of CLPHP with 45° and 180° also filling ration 50% & 80% Methanol as a working fluid.
3. To compare the thermal performance of CLPHP with two working fluids i.e., filling ratio 50% and 80%, Ethanol & Methanol at 45° and 180° angles.

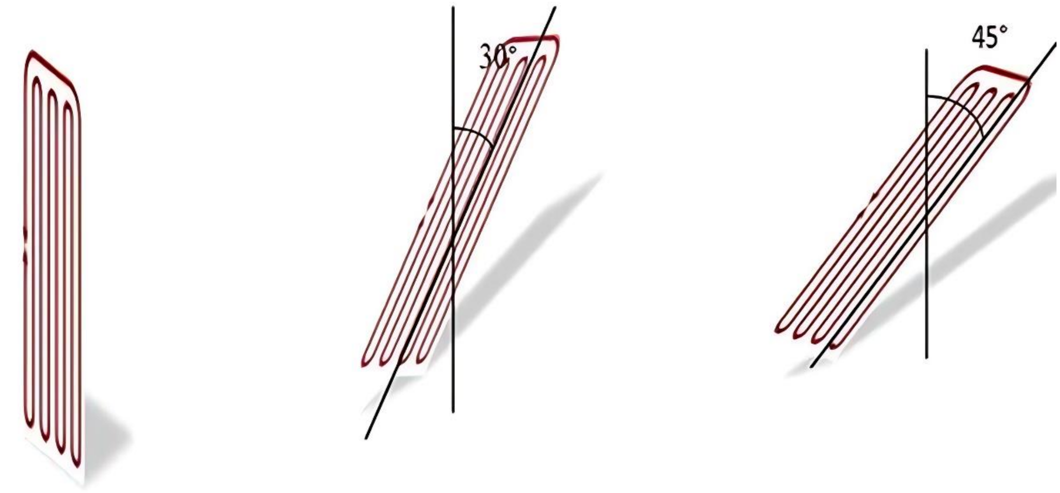


Fig 3.1: Vertical mode (0°) Fig 3.2: 30° Inclination Fig 3.3: 45° Inclination

Figure 1-7 Schematic hypothesis angle of experimental CLPHP

Chapter 2

2 Literature Review

2.1 Closed loop pulsating heat pipe

Pulsating heat pipes are closed, two-phase systems that, like conventional heat pipes, may convey heat without needing additional power. However, they differ dramatically from conventional heat pipes in several critical ways. A typical PHP is a very small, meandering tube containing a partially working fluid. The ends of the tube may be welded together to form a closed loop, or they can be pinched off and left open. The tube is parallel to itself and rotated back and forth. The closed-loop PHP works better in terms of heat transfer, according to researchers. Because of this, the bulk of experimental work uses closed-loop PHPs. In the closed-loop PHP, the working fluid may also be circulated in addition to the oscillatory flow, which enhances heat transfer. Installing a check valve may improve the PHPs' capacity to transport heat by making the working fluid flow in a certain direction. However, doing so is difficult and expensive. The ideal choice is to use PHP structures that are closed-loop and do not have a check valve.

Recently, PHPs were prototyped and examined utilizing a sintered metal wick by Holley and Faghri [10] and [11] [12]. The wick should help with both liquid dispersion and heat transfer. A PHP must have at least one heated area and one cooled space. The evaporators and condensers are often located at the bends of the capillary tube. After emptying, a working fluid is initially partially injected into the tube. The liquid and its vapor will spread throughout the pipe as it slugs and bubbles. As the PHP heats up, the vapor pressure in the bubbles in the evaporator part will increase. This forces the liquid slug toward the condenser part of the heat pipe. As the vapor bubbles approach the condenser, they will begin to condense. When a vapor changes phases, the vapor pressure decreases, which causes the liquid to return to the condenser end. The PHP is set up to have a continuous oscillating flow in this way. Boiling the working fluid will also cause fresh vapor bubbles to form. PHP research is divided into two categories: theoretical and experimental. Regarding the experimental study, the focus has been on characterizing the heat transfer or illustrating the flow pattern in PHPs.

Theoretical studies attempt to mimic the heat transfer and fluid dynamics associated with oscillating two-phase flow numerically and analytically. A thermo-hydraulic coupling strongly controls the performance of a sophisticated heat transfer mechanism called a PHP. It operates as a non-equilibrium heat transfer mechanism. The success of the device's functioning depends on continuously maintaining or sustaining these non-equilibrium conditions within the system. Slugs of liquid and vapor are transferred due to the pressure pulsations generated in the system. The device's inherent architecture thermally drives these pressure pulsations. Therefore, no additional mechanical power source is required for the fluid transfer.

2.2 Emergence of Pulsating Heat Pipe

Conventional heat pipes (CHP) began to gain popularity in the 1960s, and various new geometries, working fluids, and wick structures have been proposed since then [12]. In addition, to address some of the shortcomings of conventional heat pipes, new heat pipe shapes, such as capillary pumped loops and loop heat pipes, have been created during the last 20 years by separating the liquid and vapor fluxes.

The pulsating or oscillating heat pipe (PHP or OHP) is a new kind of heat pipe developed by Akachi et al. in the 1990s & (Khandekar et al., 2002.) . PHP is often employed in electronics cooling because it can disperse the enormous heat fluxes required by next-generation devices. Pumping water or heating air are some other potential applications for PHPs. This review article will describe the operation of pulsating heat pipes, outline recent research and development, and discuss any outstanding issues.

[14]derived the wave equation of pressure oscillation in a PHP based on self-excited oscillation and assuming reciprocal excitation between pressure oscillation and void percentage. By solving the wave equation, they obtained a closed-form solution for the wave propagation velocity.

[15]conducted an experimental analysis of the oscillatory flow in the PHP and found the wave velocity reasonably consistent with Akachi et al. in the 1990s prediction.

The departure of small bubbles is considered the normal flow pattern at the evaporator and adiabatic section, respectively, according to [16], which claims that nucleate boiling and vapour oscillation cause bubble oscillations.

[17]conducted several tests using various PHP settings. He looked at how several factors (such as filling ratio, heat input, number of turns, and orientation) influenced their behaviour. His

experiments gave him a better understanding of the heat and fluid dynamics of PHPs. He stressed the need to select a tube diameter permitting flow oscillations.

[18]also performed some flow visualizations while a PHP was active. They discovered four operating modes that resemble the PHP operating curve, representing the heat pipe's total thermal resistance as a function of input power. The oscillations' amplitude is confined at low heat input, and as heat input rises, the thermal resistance somewhat decreases. A more severe decline in thermal resistance with higher heat input leads to a slug flow pattern. Nevertheless, a preferred flow direction eventually becomes apparent as the heat input rises. The desired flow direction must be chosen, and the flow pattern must be circular rather than slug-like for the thermal.

Little opposition exists, and there is a plateau. However, due to the thermal resistance rapidly increasing as the heat input increases, the evaporator dries up when there is a considerable heat flow.

[18]provided further details in their research using ethanol, water, and R-123. The critical diameter for ethanol and water was substantially larger than the tube diameter, in contrast to the latter, when it was equal to (or even slightly below) the tube diameter. According to their study, the filling ratio and orientation of the PHPs affect how bubbles affect the two-phase oscillating flow that develops at the PHPs' extreme operating limits (i.e., when the PHP is empty or filled with liquid). At high filling ratios (like 95% of liquid) and favorable orientations (like evaporator at the bottom, condenser at the top), the bubbles tend to limit the movement of the two-phase fluid. Even for water at modest filling ratios (approximately 20% to 70%, which really causes oscillations) or even for a critical diameter considerably bigger than the tube diameter (very constrained condition), gravity was a problem. The PHP was discovered to work with R-123 despite having a crucial diameter that was a little bit less than the tube diameter. These results were all explained by accounting for the influence of bubbles on the two-phase flow.

In their article[19]. discusses the effects of CLPHP on them.

Several variables impact HP's thermal performance, including the device's inclination angle, working fluid, the number of turns, and internal tube diameter. The findings of this experiment demonstrated that buoyancy forces affect bubble shape, the internal diameter must be selected with a crucial Bond number within the limit, and performance may be improved by boosting ID and meandering turn numbers. In addition, the performance of CLPHP is significantly impacted by gravity. Finally, different fluids are favorable depending on the working conditions, latent and sensible heat proportions, and flow properties.

[20]examined the spread of vapor plugs in a meandering closed-loop heat transfer system. They observed that a simple flow pattern emerged at high liquid volume percentages. Only two vapor plugs can be located independently in neighboring rounds under these conditions, and one starts to constrict as the other starts to grow. A streamlined numerical solution was also performed, removing any conceivable liquid coating between the tube wall and the vapor stopper under several critical assumptions.

From several angles and with various working fluids,[21] evaluated an open-loop PHP. He evaluated the thermal efficiency of a PHP using working fluids such as water, ethanol, propanol, methanol, and acetone. Under his test conditions, methanol and acetone generated the greatest thermal performance, whereas water produced the worst. Additionally, he discovered that the PHP oscillations are stronger and more frequent when methanol is used in place of water. The low latent heat of methanol, which promotes boiling and nucleation and, as a consequence, fluid flow instability, was thought to be the cause. Finally, he found that horizontal orientation outperformed vertical orientation regarding thermal performance. However, the importance

Unlike ethanol and methanol, water's thermal performance is almost fully independent of orientation, where the ratio of thermal resistances in horizontal and vertical orientation is more than two.

[22]used a high-speed video to observe the oscillatory flow in a closed-loop PHP. For methanol and water, several oscillation modes were discovered. The working fluid was water, which highlighted the processes of vapor plug break-up and coalescence, particularly near tube U-bends. They concluded that the capillary pressure is not constant in the bends, leading to a localized buildup of liquid based on an analytical model. They further said the methanol used as the working fluid's low surface tension prevents coalescence or break-up. When compared to water, the liquid plugs are, therefore, longer.

In their article published at[23]. offer an experimental study on the operational restrictions of closed-loop pulsing heat pipes (CLPHPs). The three operational orientations looked at were vertical bottom heated, horizontal heated, and vertical top heated. The effects of inner diameter, operating orientation, filling ratio, and heat input flux on thermal performance and performance limits were examined. The CLPHPs were operated until a performance threshold was achieved, indicated by extreme evaporator overheating (dry-out). After that, rather high heat loads may be managed. An experimental examination on two closed-loop pulsing heat pipes (CLPHPs) examined the effects of inner diameter, filling ratio, operational orientation, and heat load on thermal performance and performance limitation in the form of evaporator dry-out. CLPHPs have their best thermal performance and maximum performance limit in the vertical bottom heat mode with a 50% filling ratio. As the inner diameter decreases, performance changes brought on by different heat modes (i.e., the gravity effect) become extremely slight or insignificant.

This work examined the operational limit of closed-loop oscillating heat pipes with check valves (CLOHP/CV) concerning the inner diameter and inclination angles. Using copper tubes with an ID of 1.77 and 2.03 mm and ten turns, R123 was used as the working fluid. Five equal lengths with inclination angles of 0, 20, 40, 60, 80, and 90° comprised the evaporator, adiabatic, and condenser sections. The critical temperature increased when the inner diameter changed from 1.77 to 2.03 mm, according to [24]In addition, the critical temperature increased from 0 to 90 degrees of inclination.

[25]quantitatively investigated oscillatory flow and heat transfer in a small U-shaped channel. The U-shaped tube's two sealed ends served as the heating components. The condenser part was located in the middle of the U-shaped canal. The U-shaped duct was placed vertically, with two sealed ends (heating parts) at the top. The impact of several non-dimensional factors on PHP performance was also investigated. Empirical correlations were found between the oscillation's amplitude and circular frequency.

[26]found that heat transmission in a PHP is primarily brought about by the interchange of heat, with sensible heat accounting for over 90% of the heat transfer from the evaporator to the condenser. The oscillation of liquid slugs was the primary effect of evaporation and condensation on the performance of PHPs. At the same time, latent heat had less effect on the overall quantity of heat transfer.

In an experiment, [27]showed that with an input power of 30–50W at the same charge volume, the temperature difference between silver Nano-fluids and DI-water decreased by 0.56–0.65°C.

Base water and spherical Al_2O_3 particles with a diameter of 56 nm were used in an experiment by [28]The highest thermal resistance was reduced by 0.14 °C/W (or 32.5%) compared to pure water when the power input was 58.8W at a 70% filling ratio and 0.9% mass fraction.

The current use of heat pipe technology has significantly advanced due to heat pipes being reduced in size. The American and Japanese heat pipe industries have conducted research on the use of heat pipes, even with a diameter of 2 mm, for cooling the laptop PC and CPU.

The small heat pipe has recently shown a startling effect when used to disperse heat and keep computers and other electrical gadgets at a consistent temperature. Therefore, a thorough investigation is crucial for the little heat pipe's further growth and performance improvement.

Using a full-sized PHP, this article will first assess some experimental data. The impacts of fluid and tube sizes, as well as orientation, will get particular emphasis. We will then discuss the results of an experimental investigation of the oscillating flow in a single tube of a single liquid plug under adiabatic conditions (purely hydrodynamic aspect) and under non-adiabatic conditions to help us analyze the results obtained at the system scale (thermal effects due to heating of the test-section).

Chapter 3

3 Materials And Methods

3.1 Depiction of different types of Apparatus

- Pulsating heat pipe
- Working fluid
    - Methanol
    - Ethanol
- 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.

3.2 Description of Different types of Apparatus

3.3 Working Fluid:

3.3.1 Methanol:

Methanol, commonly known as methyl alcohol, wood alcohol, wood naphtha, or wood spirits (sometimes abbreviated MeOH), has the chemical formula CH_3OH. Methanol was originally known as "wood alcohol" because it was predominantly generated as a byproduct of the destructive distillation from wood. Modern methanol is produced directly from hydrogen, carbon dioxide, and monoxide in an industrial catalytic process.

Methanol, the most basic form of alcohol, is a colorless, light, flammable liquid with a characteristic odor similar to that of ethanol (drinking alcohol). In contrast to ethanol, methanol is poisonous and not recommended for human intake. It is a denaturant for ethanol used as an antifreeze, solvent, fuel, and polar liquid at room temperature. It is also utilized in the transesterification process that produces biodiesel.

Methanol is naturally formed in the anaerobic metabolism of many bacterial species and is usually present in the environment at trace levels. Methanol vapor is thus only very little present in the environment. However, over many days, sunshine breaks down the methanol in the atmosphere into carbon dioxide and water.

Methanol burns when exposed to oxygen, even in the open air, producing carbon dioxide and water

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

Methanol properties:

Table 1 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

The most common names for ethanol are alcohol or spirits, also known as ethyl alcohol and drinking alcohol. It serves as the primary form of alcohol in alcoholic beverages created when yeast ferments sugars—one of the first neurotoxic psychoactive substances.

Human drug usage for enjoyment. It may result in alcohol intoxication if ingested in sufficient amounts. Ethanol is used as the active fluid, an antiseptic, a fuel, and a solvent in modern (post-mercury) thermometers. It is a volatile, colorless, flammable liquid with a strong chemical odor. Its chemical name, CH_3CH_2OH, is frequently shortened to C_2H_5OH or C_2H_6O.

Ethanol properties:

Table 2 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/m³
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

3.4 Visual Picture of Experiment

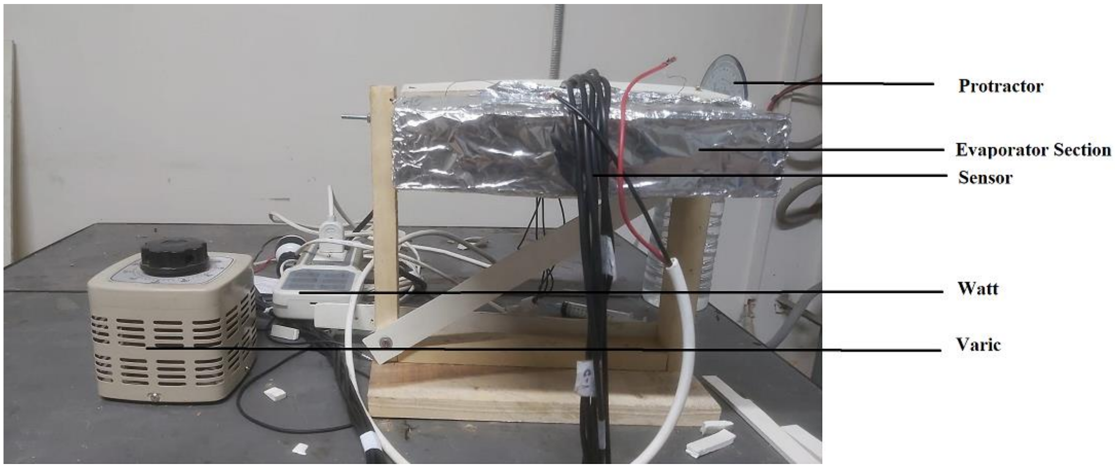


Figure 3-1 Experiment Set-up

3.5 Experiment CLPHP

A closed-loop pulsating or oscillating heat pipe is a metallic tube of capillary dimensions coiled in a serpentine pattern and linked end to end. It is divided into three sections:

3.5.1 Evaporator section

This part of the heat pipe is where the working fluid absorbs heat and evaporates. It is located on the bottom part of the heat pipe. The heat pipe is heated by a nichrome wire linked to the variac. Nichrome wire should not be linked to the copper tube directly since it is an excellent conductor of electricity, and doing so might cause a short circuit. As a result, a copper tube is maintained separately from a mica layer surrounding the Nichrome wire. The mica tape thus acts as a heat conductor for the copper tube. The evaporative side of our experiment was also thermally insulated using asbestos tape to provide greater heat sealing. In this way, the heat loss was reduced.

3.5.2 Condenser Section

The heat from the working fluid is rejected at the pipe's condenser section. In this part, the working fluid condenses and rejects a small quantity of heat absorbed from the evaporator section. This part of the experiment is on the heat pipe's top segment.

3.5.3 Adiabatic Section

Between the condenser and evaporator portions lies the adiabatic section. There is minimal heat transmission between the fluid and the surroundings because the fluid's liquid and vapor phases travel in opposite directions here. Glass wool and foam tape are used to cover the insulated portion.

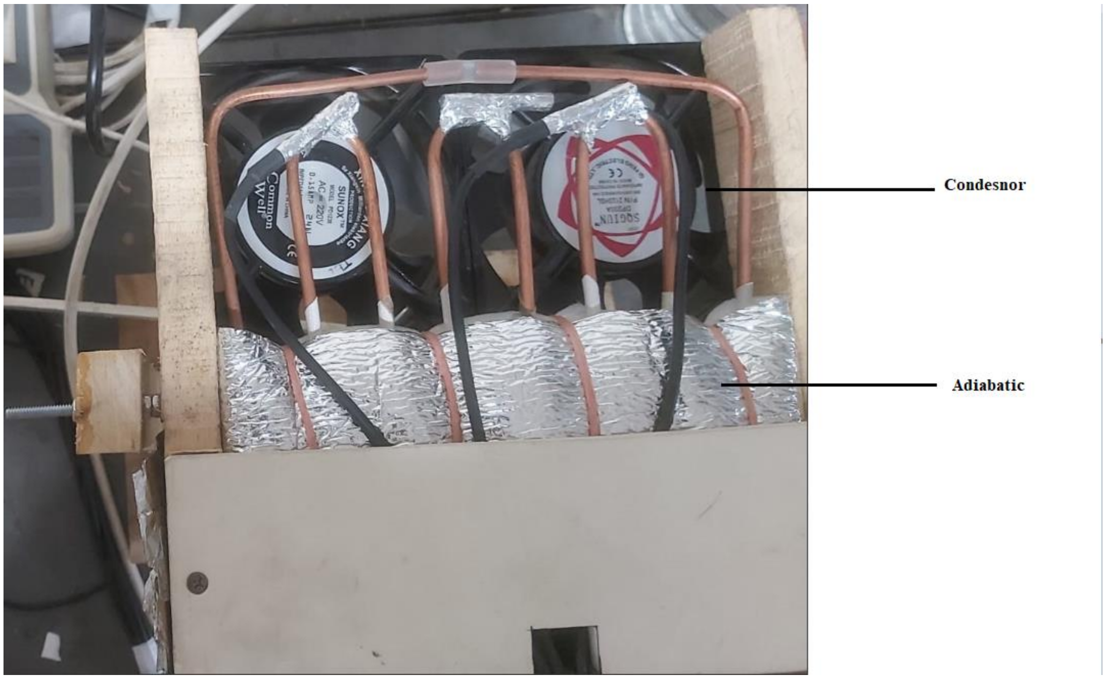


Figure 3-2 Condenser & Adiabatic Section

Table 3 CLPHP Parameters

Parameters	**Condition**
Inner diameter	2.65 mm
Total length	1925 mm
Length of evaporator section	50 mm
Length of adiabatic section	100 mm
Length of condenser section	60 mm
Material	copper
Turn	4
Distance between 2 heat pipes	20mm

3.6 Experimental Procedure

Obtain the size and design of a closed loop pulsing heat pipe (CLPHP).

Set up a heating source, such as a hot plate, to provide the CLPHP-regulated heat input.

Set up flow meters, pressure gauges, and temperature sensors to track the CLPHP's performance.

Ensure that the experimental setup has a dependable power source.

Preparation for CLPHP:

Use a suitable solvent to clean the CLPHP and remove any pollutants thoroughly.

Carefully put the CLPHP together, ensuring each part is attached and sealed.

Install the flow meters, pressure gauges, and temperature sensors at the appropriate places along the CLPHP.

50% Fill Ratio Experiment:

Fill the CLPHP to a filling ratio of 50% (i.e., the working fluid takes up 50% of the internal volume) by adding methanol or ethanol.

Connect the power source and heating source to the CLPHP.

Increase the heat input to the CLPHP gradually while keeping an eye on the flow rate, pressure, and temperature.

Keep track of the performance information, such as the flow rate, pressure drop, wall, evaporator, and condenser temperatures.

Run many tests while varying the heat input and assessing the behavior of the CLPHP under various operating circumstances.

80% Fill Ratio Experiment:

Remove the old operating fluid from the CLPHP and replace it with either methanol or ethanol to reach an 80% filling ratio.

Replicate the Filling Ratio at 50% experiment's stages while tracking and documenting CLPHP performance information.

45-degree angle experiment:

Adjust the CLPHP configuration such that it is 45 degrees above the horizontal.

Reach the required filling ratio (50% or 80%) and fill the CLPHP with the selected working fluid.

The same steps should be followed, with the heat input being progressively increased and performance data being recorded.

180-degree angle experiment:

Set the CLPHP configuration to be vertical and at a 180-degree angle.

While maintaining the required filling ratio, fill the CLPHP with the working fluid.

Increase the heat input, monitor the CLPHP's performance, and record the results.

Data Evaluation:

Compare the performance of the CLPHP at various filling ratios and angles as you analyze the data gathered. Analyze the CLPHP's flow behavior, pressure drop, and heat transfer properties under each experimental circumstance. Interpret the facts, form conclusions, and note patterns or noteworthy discoveries. Consider temperature distribution, heat transfer efficiency, and operational stability.

3.7 Precaution

When experimenting, the following variables were taken into account:

All other sources that may affect heat transmission were shut off throughout.

The sensor (DS18B20 sensors) used in the experiment must be properly inspected before taking the temperature.

The fluid injection must be precise since the fill ratio impacts how well the heat pipe works.

Measurements should be taken only when a temperature achieves a stable state or a consistent value. The silicon tube should always be properly sealed since condenser condensation may sometimes create leaks. CLPHP.

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Chapter 4

4 Results & Discussions

In this chapter, we will illustrate our findings visually and briefly explain the effect.

Origin Pro generated fascinating statistical visual graphs.

4.1 Steady Condition of All Data

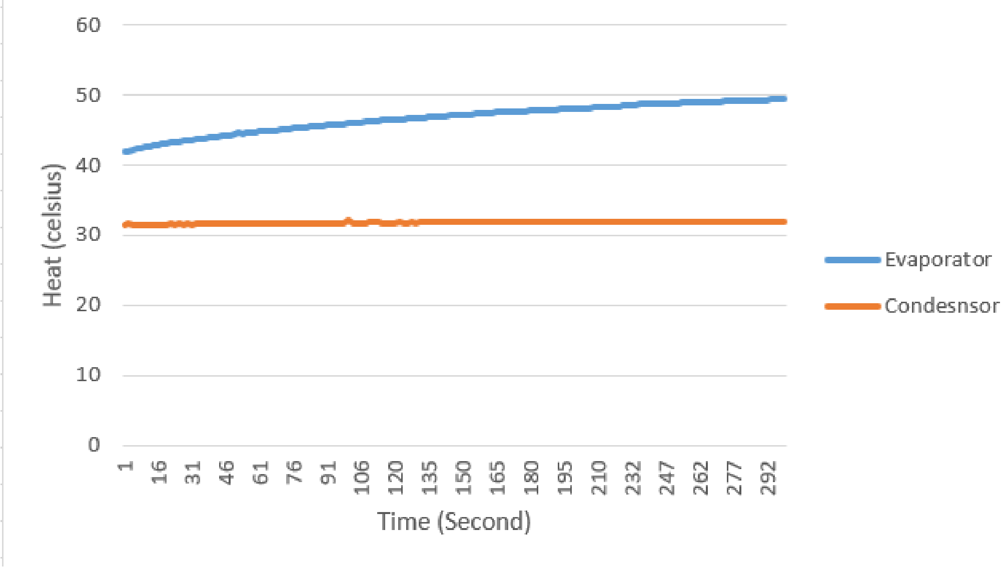


Figure 4-1 Steady condition data

In this graph representing that the steady condition archive in our experiment. To examine the behavior of the CLPHP, data collection entails monitoring numerous parameters, including temperature, pressure, flow rate, and heat transfer coefficient. Ensuring the instrument enters a stable condition before collecting any measurements is essential to acquire reliable and precise data. Achieving a steady state in a CLPHP entails that the flow rate, temperature, and pressure of the working fluid have stabilized and that there has been little change over time. As a result, the heat transfer process is more predictable, and the device's performance is easier to analyze when the CLPHP is in a steady state. Data that are consistent and reliable may be obtained when the CLPHP is not in a stable state during data collection. For instance, getting precise and important data could be challenging because of the large fluctuations in the observed temperatures, pressures, and flow rates. A steady state must be established and maintained to collect data in a closed-loop pulsating heat pipe.

4.2 Ethanol 50% Filling Ratio Angle 45°

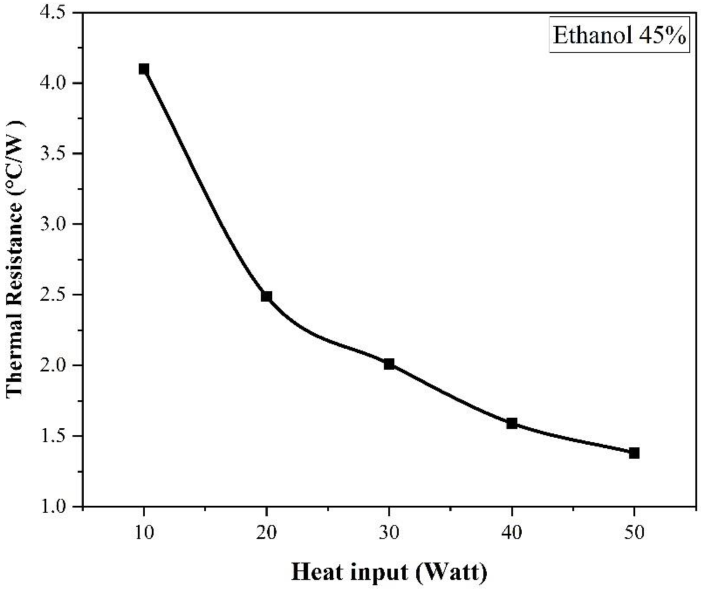


Figure 4-2 Ethanol 50% Thermal Resistance vs Heat input (watt)

In this graph shows in 50% filling ratio in CLPHP Angle° 45 degree shows initial thermal resistance in 10 Heat input (watt) in 4.3 C°/w and lower goes 1.4 C°/w. Based on the provided graph, it illustrates the thermal resistance of a heat pipe in a closed loop pulsating heat pipe (CLPHP) at a 45-degree angle. The filling ratio is 50%. At a power input of 10 Heat input (watt)s, the first thermal resistance was measured to be 4.3 °C/W, showing a temperature increase per power unit. The heat pipe's thermal resistance reduces when the power input is lowered. For example, the heat resistance lowers to 1.4 °C/W for a reduced power input. The lower temperature increase for the given power input suggests that the heat pipe is more effective at dispersing heat.

The graph demonstrates that, generally, when the power input drops, the heat pipe's thermal resistance lowers from an initial value of 4.3 °C/W to a lower value of 1.4 °C/W. This suggests that, for a given amount of power input, the heat pipe becomes more efficient in transferring heat away, resulting in a lesser temperature rise.

4.3 Ethanol 50% Filling Ratio Angle 180°

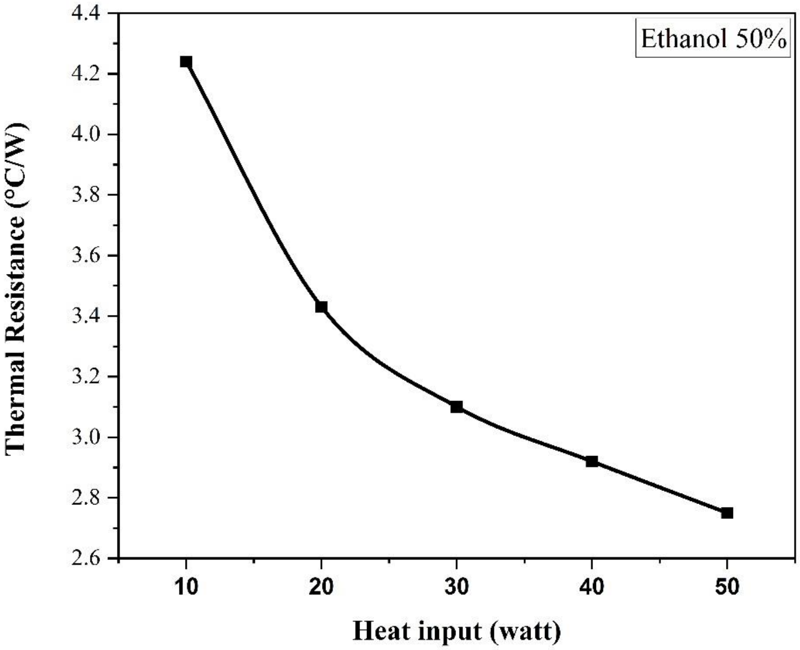


Figure 4-3 Thermal Resistance Vs Heat input (watt)

Based on the given graph represents the thermal resistance of a heat pipe with a filling ratio of 50% in a Closed Loop Pulsating Heat Pipe (CLPHP) at an angle of 45 degrees. The initial thermal resistance at a power input of 10 Heat input (watt)s is recorded as 4.3 °C/W, indicating the temperature rise per power unit. As the power input is reduced, the thermal resistance of the heat pipe decreases further. At a lower power input, the thermal resistance drops to 2.8 °C/W, higher than the previously mentioned value of 1.4 °C/W.

This indicates that the heat pipe is less efficient in dissipating heat at the lower power input than in the previous scenario. The increase in thermal resistance implies that the temperature rise per unit of power input is greater, suggesting that the heat transfer capability of the heat pipe has reduced. In summary, the graph shows that as the power input decreases, the thermal resistance of the heat pipe reduces from an initial value of 4.3 °C/W to a lower value of 2.8 °C/W. However, the latter value is higher than the 1.4 °C/W mentioned in the previous graph, indicating the heat pipe's reduced heat transfer efficiency at the lower power input.

4.4 Ethanol 80% Filling Ratio Angle 45°

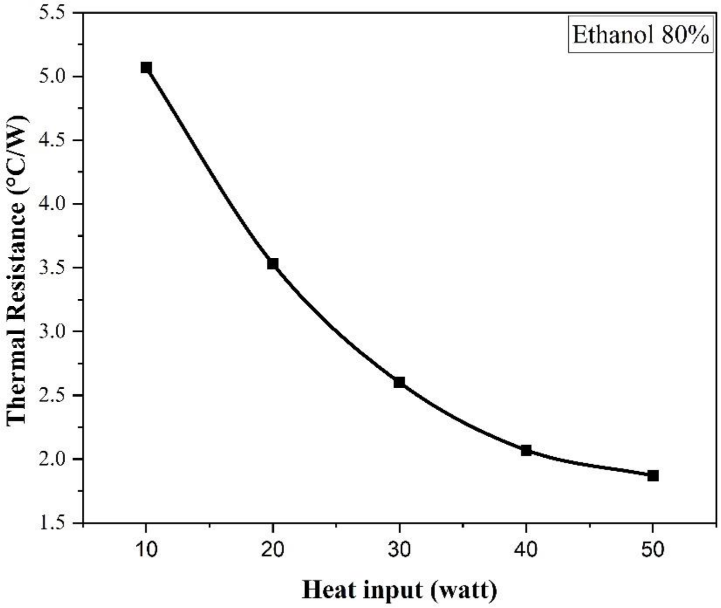


Figure 4-4 Thermal Resistance Vs Heat input (watt) Ethanol

Based on the provided graph illustrates the thermal resistance of a heat pipe in a closed loop pulsating heat pipe (CLPHP) at a 45-degree angle. The filling ratio is 80%. The initial thermal resistance, which measures the temperature increase per power unit, is measured as 5.2 °C/W with a power input of 10 Heat input (watt)s. The heat pipe's thermal resistance falls even more when the power input is lowered. The thermal resistance decreases to 1.8 °C/W with reduced power input, which is greater than the figure of 1.4 °C/W previously reported in the earlier graph.

This shows that, compared to the earlier situation, the heat pipe is marginally less effective at dispersing heat at the lower power input. A modest decrease in the heat transfer capacity of the heat pipe is implied by the rise in thermal resistance, which means that the temperature rise per unit of power input is larger than previously. Although the thermal resistance has grown since the previous graph, it is still lower than the beginning value of 5.2 °C/W, which is important to remember. As a result, the heat pipe is still more effective at dispersing heat at the lower power input than at the higher power input. The graph demonstrates that, in general, when the power input lowers, the heat pipe's thermal resistance falls from an initial value of 5.2 °C/W to a lower value of 1.8 °C/W. The latter result still shows an enhanced heat transfer efficiency relative to the initial thermal resistance, even if it is higher than the 1.4 °C/W shown in the preceding graph.

4.5 Ethanol 80% Filling Ratio Angle 180°

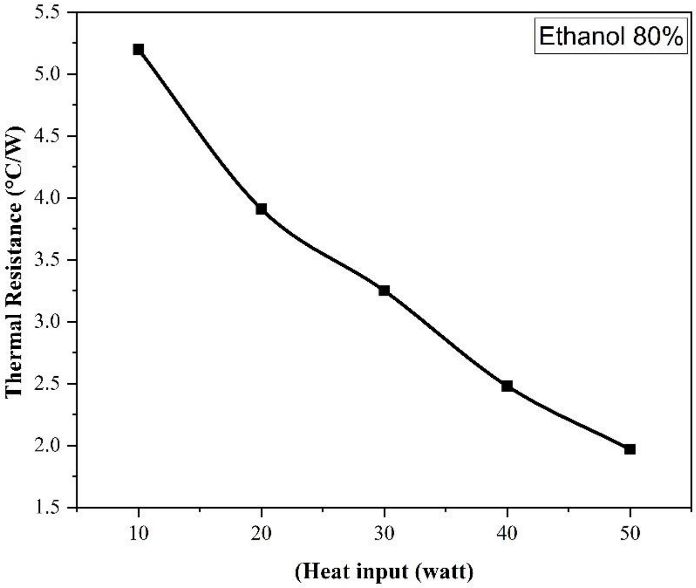


Figure 4-5 Thermal Resistance Vs Heat input (watt) FR 80% Angle 180°

Based on the provided graph illustrates the thermal resistance of a heat pipe in a closed loop pulsating heat pipe (CLPHP) at a 45-degree angle. The filling ratio of the heat pipe is 80%. The initial thermal resistance, which measures the temperature increase per power unit, is measured as 5.3 °C/W with a power input of 10 Heat input (watt)s. The heat pipe's thermal resistance falls even more when the power input is lowered. The thermal resistance increases from the previously indicated value of 1.8 °C/W in the last graph to 2.0 °C/W with a lower power input. This shows that, compared to the prior case with a 50% filling ratio, the heat pipe is marginally less effective at dispersing heat at the lower power input. A modest decrease in the heat transfer capacity of the heat pipe is implied by the rise in thermal resistance, which means that the temperature rise per unit of power input is larger than previously. The thermal resistance is larger at the first power input of 5.3 °C/W than at the beginning value of 4.3 °C/W in the preceding graph, which is an essential distinction to notice. This means that, even with the same power input, the heat pipe with an 80% filling ratio is less efficient at dispersing heat than the heat pipe with a 50% filling ratio.

As a result, the graph demonstrates that the thermal resistance of the heat pipe with an 80% filling ratio falls with decreasing power input, going from an initial value of 5.3 °C/W to a lower value of 2.0 °C/W. Nevertheless, the latter result still shows an enhanced heat transfer efficiency relative to the initial thermal resistance, even if it is slightly higher than the 1.8 °C/W shown in the preceding graph. However, the heat pipe with an 80% filling ratio has a larger initial thermal resistance than the heat pipe with a 50% filling ratio, which is an essential point to remember.

4.6 Compare all data of Ethanol

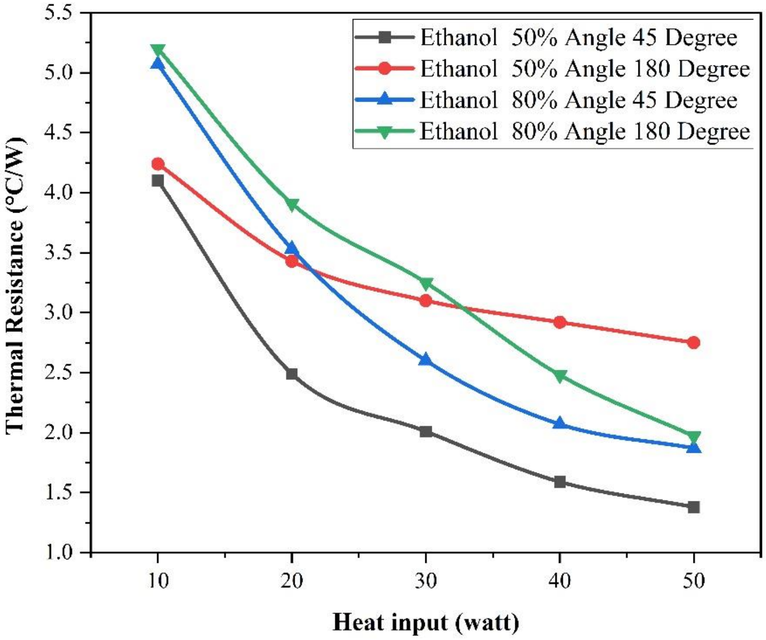


Figure 4-6 Thermal Resistance Vs Heat input (watt) Ethanol All

According to the facts given, it seems that the thermal performance of a heat pipe in ethanol at a 180-degree angle may be summarized as follows: The heat pipe exhibits extremely promising low thermal resistance with an initial power input of 20 Heat input (watt)s. Inferring effective heat transmission means that the temperature increase per power input unit is minor. However, after this initial boost in power input, the thermal resistance begins to climb. This is most likely the result of a condition known as "dry out," in which the working fluid (in this example, ethanol) is inadequate to transmit the heat efficiently. When a heat pipe experiences dry-out circumstances that impair heat transmission effectiveness, a continuous liquid phase cannot be maintained over the pipe's whole length. The heat pipe's performance declines when it enters a condition of dried out, according to the growing thermal resistance. As a result, the temperature rise per input power unit rises, indicating a decreased capacity to disperse heat properly. In conclusion, the heat pipe in ethanol with an 50% filling ratio initially exhibits good thermal performance at 20 Heat input (watt)s. Beyond this level, however, the power input causes the heat pipe to degrade due to dry-out conditions, leading to lower heat transfer efficiency & also Ethanol 50% Filling ratio in angle 45° shows greater lower thermal resistance.

4.7 Methanol 50% Filling Ratio Angle 45°

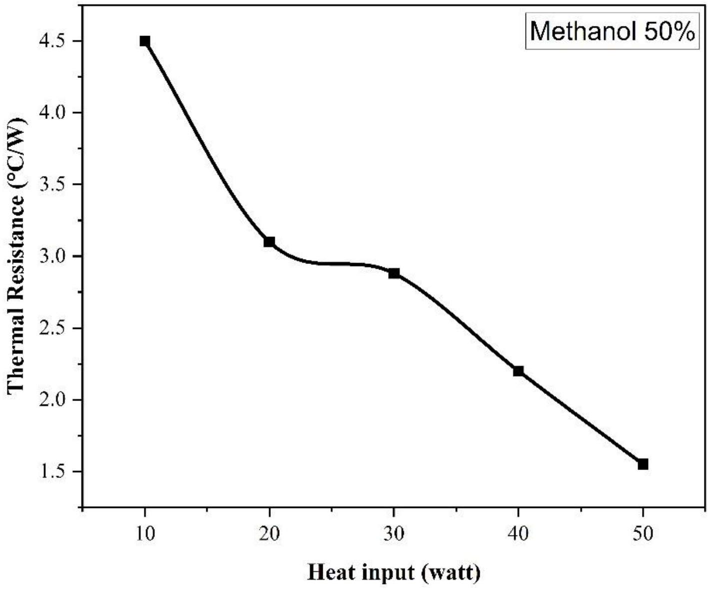


Figure 4-7 Thermal Resistance Vs Heat input (watt) Methanol

Based on the given graph, represents the thermal resistance of a heat pipe with a 50% filling ratio in a Closed Loop Pulsating Heat Pipe (CLPHP) using Methanol as the working fluid. The heat pipe is inclined at an angle of 45 degrees.

At an initial power input of 10 Heat input (watt)s, the heat pipe exhibits a thermal resistance of 4.5 °C/W. This means that for each heat input (watt) of power input, the temperature of the heat pipe rises by 4.5 degrees Celsius.

As the power input decreases, the thermal resistance of the heat pipe reduces. For example, the thermal resistance drops to 1.5 °C/W at a lower power input. This lower value indicates that the heat pipe becomes more efficient in dissipating heat as the power input decreases.

The decrease in thermal resistance suggests that the heat pipe exhibits better heat transfer capability at lower power inputs. This means that for the same amount of power input, the temperature rise of the heat pipe is smaller, indicating improved heat dissipation.

The graph shows that the heat pipe with a 50% filling ratio using Methanol as the working fluid and inclined at 45 degrees initially has a thermal resistance of 4.5 °C/W at 10 Heat input (watt)s. However, as the power input decreases, the thermal resistance reduces to 1.5 °C/W, indicating better heat transfer performance and a smaller temperature rise for a given power input.

4.8 Methanol 50% Filling Ratio Angle 180°

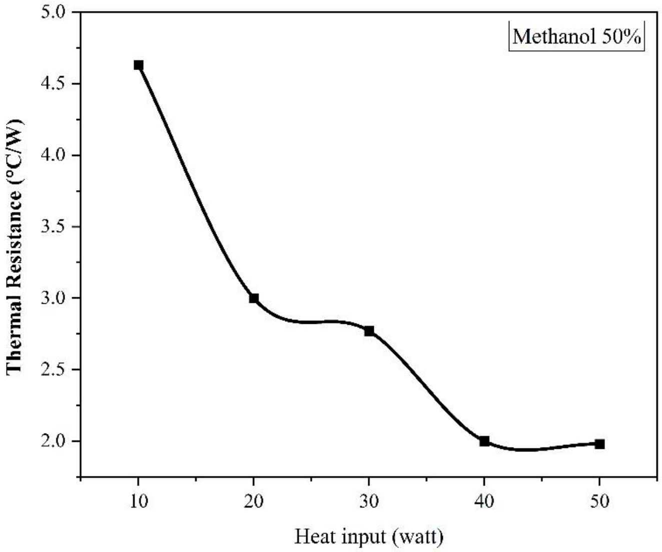


Figure 4-8 Thermal Resistance Vs Heat input (watt) Methanol FR 50% Angle 180°

In this graph shows thermal resistance is initially high and that is 4.6 and lowest 1.8. in 30 heat input (watt) it shows steady almost cause due to possible dry-out incident or pressure leakage i.e., because we use silicon tube for coupling the both end of pipe.

4.9 Methanol 80% Filling Ratio Angle 45°

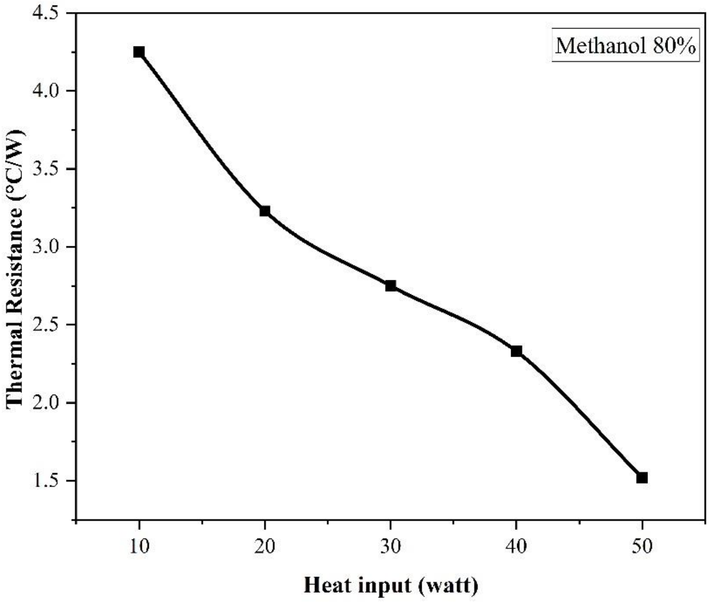


Figure 4-9 Thermal resistance Vs heat input (watt) Methanol 80% FR angle 45°

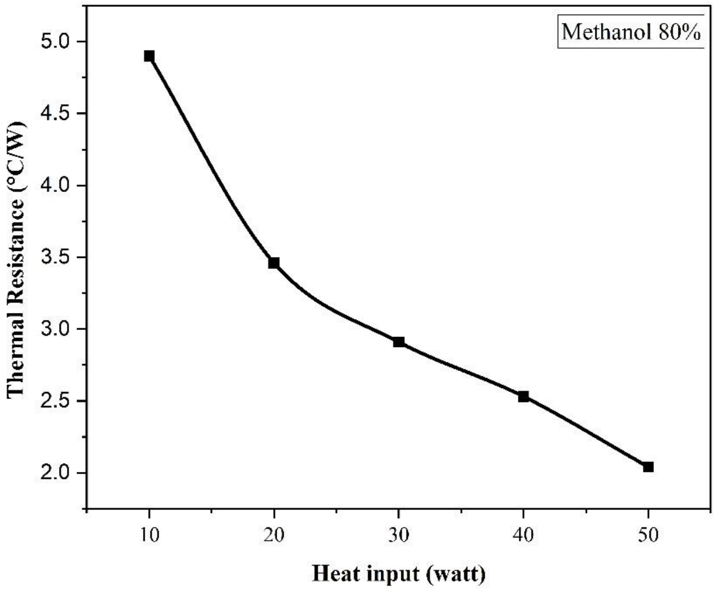
The thermal resistance of a heat pipe with an 80% filling ratio in a Closed Loop Pulsating Heat Pipe (CLPHP) utilizing methanol as the working fluid is shown based on the graph provided. The heat pipe is 45 degrees from the horizontal.

The heat pipe displays 4.35 °C/W of thermal resistance with an initial power input of 10 Heat input (watt)s. This shows that the heat pipe's temperature increases by 4.25 degrees Celsius for every Heat input (watt) of incoming electricity.

The thermal resistance of the heat pipe decreases with decreasing power input. For example, the heat resistance lowers to 1.5 °C/W for a reduced power input. This lower figure shows that the heat pipe becomes more effective at dispersing heat as the power supply declines.

The reduction in thermal resistance indicates that the 80% filling ratio heat pipe has better heat transfer performance at lower power inputs. As a result, the heat pipe's temperature increase is less for a given amount of power input, suggesting improved heat dissipation.

4.10 Methanol 80% Filling Ratio Angle 180°



The thermal resistance of a heat pipe with an 80% filling ratio in a Closed Loop Pulsating Heat Pipe (CLPHP) utilizing methanol as the working fluid is shown based on the graph provided. A 180-degree inclination is included in the heat pipe.

The heat pipe displays 5.0 °C/W of thermal resistance with an initial power input of 10 Heat input (watt)s. This shows that the heat pipe's temperature increases by 5.0 degrees Celsius for every Heat input (watt) of incoming electricity.

The thermal resistance of the heat pipe decreases with decreasing power input. For example, the heat resistance lowers to 2.0 °C/W with reduced power input. This lower figure shows that the heat pipe becomes more effective at dispersing heat as the power supply declines.

The reduction in thermal resistance indicates that the 80% filling ratio heat pipe has better heat transfer performance at lower power inputs. As a result, the heat pipe's temperature increase is less for a given amount of power input, suggesting improved heat dissipation.

4.11 Compare all data of Methanol

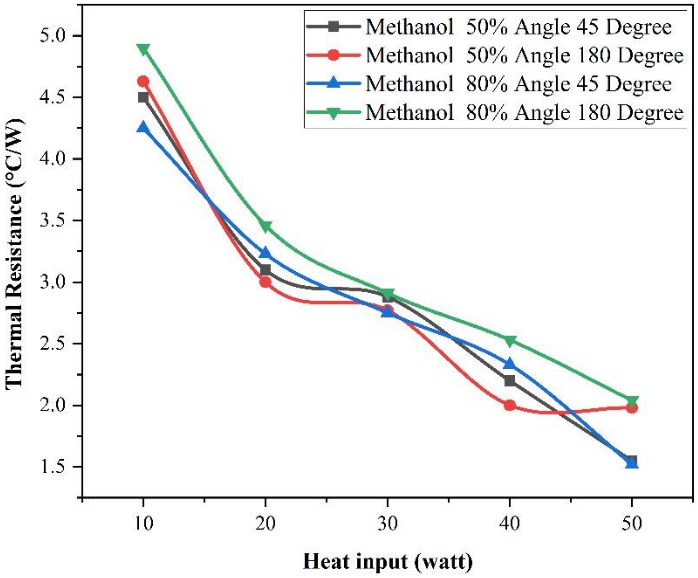


Figure 4-10 Methanol all data Compares

45-degree angle and 50% filling ratio of methanol in CLPHP

Thermal resistance was first measured at 10 Heat input (watt)s: 4.5 °C/W

1.5 °C/W is a lower thermal resistance.

Methanol in CLPHP at a 45-degree angle with an 80% filling ratio:

At 10 Heat input (watt)s, the initial heat resistance is 4.3 °C/W.

1.8 °C/W is a lower thermal resistance.

The heat pipe with an 80% filling ratio displays lower initial thermal resistance than the one with a 50% filling ratio, according to our comparison of the two circumstances. The initial thermal resistance of the heat pipe with an 80% filling ratio is 4.4 °C/W, but the heat pipe with a 50% filling ratio begins with a higher value of 4.5 °C/W.

Additionally, when the power input is reduced, the thermal resistance of both heat pipes lowers. For example, while the heat pipe with an 80% filling ratio achieves 1.8 °C/W, the one with a 50% filling ratio only reaches 1.5 °C/W.

In conclusion, compared to the heat pipe with a 50% filling ratio, the Methanol heat pipe with an 80% filling ratio at a 45-degree angle exhibits reduced initial thermal resistance and a slightly greater thermal resistance at lower power inputs.

Chapter 5

5 Conclusions

We may infer the following conclusions from the presented data for the Closed Loop Pulsating Heat Pipe (CLPHP) with various parameters, such as the number of turns, evaporator length, adiabatic length, condenser length, and working fluids:

50% loading ratio ethanol:

Thermal resistance at an angle of 45 degrees is 1.38 °C/W.

The thermal resistance rises to 2.75 °C/W at an angle of 180 degrees, suggesting decreased heat transmission effectiveness.

80% loading ratio ethanol:

Thermal resistance at an angle of 45 degrees is 1.87 °C/W.

The heat resistance marginally rises to 1.97 °C/W at an angle of 180 degrees.

50% loading ratio methanol:

Thermal resistance at an angle of 45 degrees is 1.55 °C/W.

The heat resistance rises to 1.98 °C/W at a 180-degree tilt.

80% filling ratio methanol:

Thermal resistance at a 45-degree angle is 1.52 °C/W.

The heat resistance rises to 2.04 °C/W at a 180-degree tilt.

These similarities allow us to draw the following conclusions:

First, higher filling ratios often show reduced thermal resistance, which indicates more effective heat transmission.

Among the studied situations, ethanol at an 50% filling ratio and a 45° angle exhibits the highest performance, with a heat resistance of 1.38 °C/W. This design offers the lowest resistance, suggesting effective heat dissipation.

Ethanol exhibits the lowest performance with an angle of 180 degrees and a 50% fill ratio, with a thermal resistance of 2.75 °C/W. This combination produces the greatest thermal resistance and lowest heat transfer efficiency.

The working fluid selection also influences the performance of the heat pipe. For example, given comparable filling ratios and orientations, ethanol displays lower thermal resistance than methanol.

The angle's effect on heat resistance varies depending on the filling ratio and working fluid. While the thermal resistance in certain situations, such as with ethanol at an 80% filling ratio, is equivalent between 45 and 180 degrees, it rises dramatically at that temperature in other situations, such as with ethanol at a 50% filling ratio.

Generally, ethanol at an 80% fill ratio and a 45-degree angle produces the optimum overall performance. The working fluid used, the filling ratio, and the orientation influence the heat pipe's thermal resistance and transmission effectiveness.

And Shows Methanol 50% angle 45° greater lowest thermal resistance. In [9]Shows 40% to 60% optimal and angle 90° but our optimal show in 180° So, this might cause the number of lower turns and possible dry-out condition and hypothetically this could be the case because the liquid phase has a greater dynamic viscosity than the vapor phase, which results in higher frictional surface shear stress, and because the body force impact of horizontal operation mode does not serve to increase fluid motion as it does in bottom heat mode.

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Appendix

Calculation of filling Ratio

Let, V = Internal volume of the heat pipe

= 100% Fill Ratio

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

= $\frac{3.1416 \times 2.60_i^2 \times \{(205+(2\times 230)+(6\times 210)\}}{4}$ mm^2

= 10220 mm^2

≈ 10.20 ml

= 10.20 ml (100%)

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, 5.1 ml, and 8.12 ml of working fluids were employed to evaluate the properties of heat transfer, yielding respective ratios of 50%, and 80%.

Calculation of Heat Input

Let, Q = Power Input (Heat Input)

= V.I. Cos θ

In our experiment 10W~50W power was used for the reading at the interval of 10W. The power was achieved through the voltage variation mentioned in following table:

Calculation of Thermal Resistance

Let, R_{th} = Thermal Resistance

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

= $\frac{T_e - T_C}{Q}$ C°/W

Micro-controller Code

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

#define HEAT INPUT (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,Heat input (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) / HEAT INPUT (WATT);
  float coeffi = HEAT INPUT (WATT) / (0.0062203 * (eva - con));


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

Steady condition data table

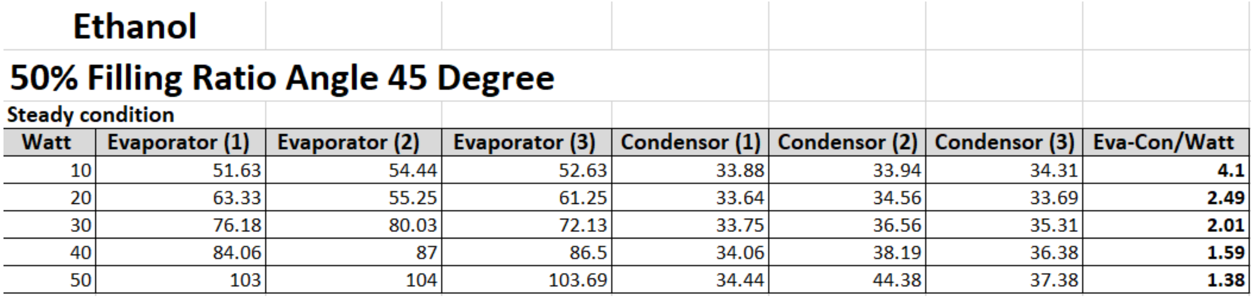
Sec	Evaporator (ΔT_e)	Condenser (ΔT_c)
1	41.88	31.49
3	42.02	31.63
5	42.17	31.48
7	42.32	31.5
9	42.46	31.54
10	42.56	31.52
12	42.71	31.52
14	42.83	31.5
16	42.94	31.54
18	43.02	31.56
20	43.1	31.52
22	43.21	31.58
23	43.31	31.56
25	43.43	31.6
27	43.48	31.56
29	43.56	31.6

Sec	Evaporator (ΔT_e)	Condenser (ΔT_c)
31	43.64	31.56
33	43.75	31.6
35	43.83	31.58
37	43.88	31.62
38	43.98	31.62
40	44.04	31.64
42	44.1	31.64
44	44.19	31.62
46	44.29	31.64
48	44.33	31.66
50	44.39	31.64
51	44.64	31.71
53	44.54	31.69
55	44.6	31.69
57	44.69	31.69
59	44.75	31.71
61	44.81	31.71
63	44.85	31.71
64	44.94	31.71
66	44.96	31.73
68	45.02	31.71
70	45.08	31.71
72	45.16	31.71
74	45.25	31.73
76	45.27	31.73
78	45.35	31.71
79	45.39	31.75
81	45.46	31.75
83	45.52	31.73
85	45.56	31.75
87	45.62	31.77
89	45.68	31.77
91	45.72	31.77
92	45.75	31.77
94	45.83	31.79
96	45.87	31.79
98	45.93	31.79
100	46	32.12
102	46.06	31.77
104	46.12	31.79
106	46.15	31.79

Sec	Evaporator (ΔT_e)	Condenser (ΔT_c)
107	46.21	31.79
109	46.25	31.81
111	46.33	31.81
113	46.35	31.81
115	46.42	31.79
117	46.46	31.79
119	46.5	31.79
120	46.54	31.79
122	46.58	31.81
124	46.62	31.79
126	46.66	31.79
128	46.73	31.81
130	46.77	31.79
132	46.81	31.83
133	46.85	31.81
135	46.87	31.81
137	46.93	31.83
139	46.95	31.83
141	47.02	31.83
143	47.04	31.83
145	47.12	31.87
147	47.12	31.81
148	47.16	31.85
150	47.19	31.81
152	47.23	31.85
154	47.27	31.83
156	47.31	31.83
158	47.4	31.83
160	47.38	31.85
161	47.44	31.87
163	47.5	31.85
165	47.54	31.87
167	47.56	31.83
169	47.6	31.85
171	47.62	31.83
173	47.65	31.83
175	47.69	31.85
176	47.71	31.83
178	47.75	31.85
180	47.79	31.85
182	47.81	31.87

Sec	Evaporator (ΔT_e)	Condenser (ΔT_c)
184	47.85	31.83
186	47.87	31.83
188	47.89	31.85
189	47.96	31.87
191	47.98	31.85
193	48	31.83
195	48.06	31.85
197	48.08	31.85
199	48.1	31.87
201	48.12	31.85
203	48.14	31.85
204	48.21	31.85
206	48.21	31.85
208	48.23	31.87
210	48.29	31.87
212	48.33	31.85
214	48.33	31.87
216	48.37	31.85
217	48.41	31.85
219	48.44	31.85
221	48.48	31.89
223	48.48	31.87
225	48.5	31.85
227	48,54	31.89
229	48.54	31.89
231	48.58	31.85
232	48.6	31.89
234	48.65	31.91
236	48.69	31.89
238	48.69	31.87
240	48.71	31.89
242	48.73	31.87
244	48.75	31.89
245	48.79	31.89
247	48.79	31.89
249	48.83	31.87
251	48.88	31.9
253	48.9	31.9
255	48.92	31.91
257	48.94	31.89
258	48.96	31.89

Sec	Evaporator (ΔT_e)	Condenser (ΔT_c)
260	48.98	31.91
262	49	31.89
264	49.01	31.89
266	49.02	31.91
268	49.06	31.91
270	49.08	31.91
272	49.1	31.91
273	49.14	31.91
275	49.14	31.91
277	49.17	31.91
279	49.17	31.91
281	49.19	31.98
283	49.23	31.93
285	49.25	31.93
286	49.29	31.91
288	49.27	31.95
290	49.31	31.91
292	49.31	31.93
294	49.37	31.95
296	49.37	31.93
298	49.37	31.93
300	49.39	31.89

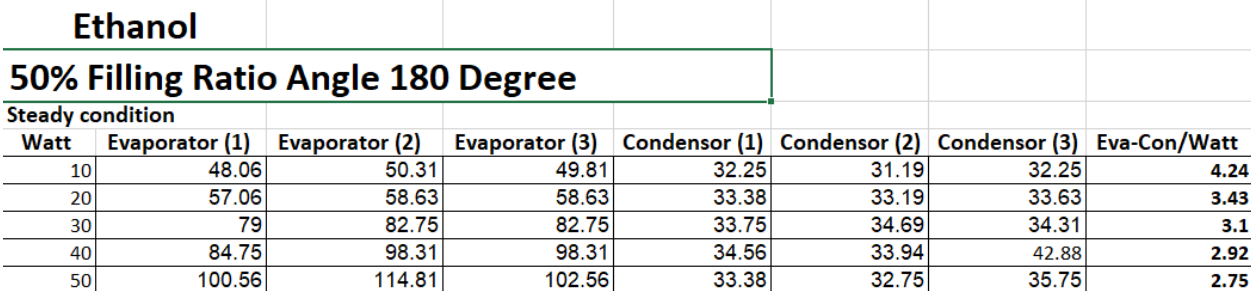


Ethanol

50% Filling Ratio Angle 45 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	51.63	54.44	52.63	33.88	33.94	34.31	**4.1**
20	63.33	55.25	61.25	33.64	34.56	33.69	**2.49**
30	76.18	80.03	72.13	33.75	36.56	35.31	**2.01**
40	84.06	87	86.5	34.06	38.19	36.38	**1.59**
50	103	104	103.69	34.44	44.38	37.38	**1.38**

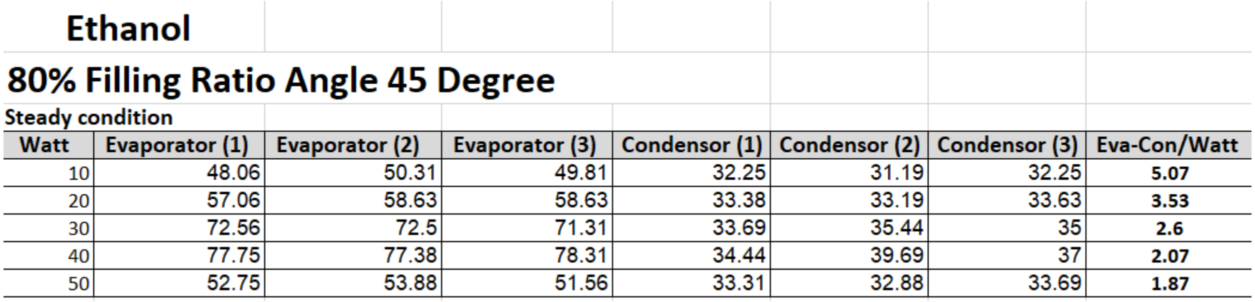


Ethanol

50% Filling Ratio Angle 180 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	48.06	50.31	49.81	32.25	31.19	32.25	**4.24**
20	57.06	58.63	58.63	33.38	33.19	33.63	**3.43**
30	79	82.75	82.75	33.75	34.69	34.31	**3.1**
40	84.75	98.31	98.31	34.56	33.94	42.88	**2.92**
50	100.56	114.81	102.56	33.38	32.75	35.75	**2.75**

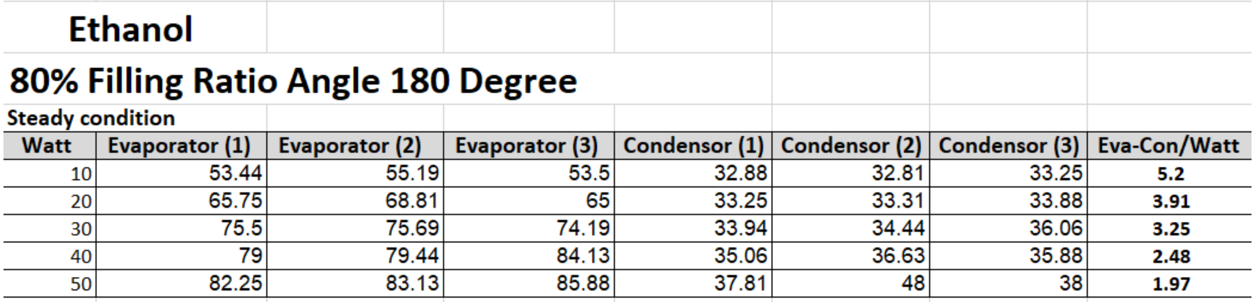


Ethanol

80% Filling Ratio Angle 45 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	48.06	50.31	49.81	32.25	31.19	32.25	**5.07**
20	57.06	58.63	58.63	33.38	33.19	33.63	**3.53**
30	72.56	72.5	71.31	33.69	35.44	35	**2.6**
40	77.75	77.38	78.31	34.44	39.69	37	**2.07**
50	52.75	53.88	51.56	33.31	32.88	33.69	**1.87**

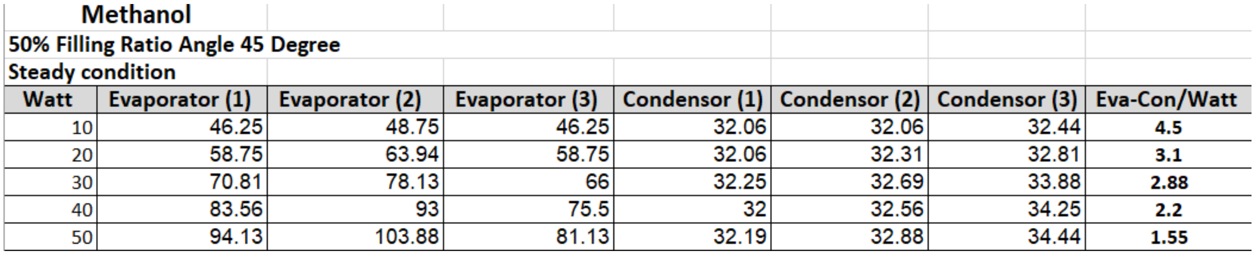


Ethanol

80% Filling Ratio Angle 180 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	53.44	55.19	53.5	32.88	32.81	33.25	**5.2**
20	65.75	68.81	65	33.25	33.31	33.88	**3.91**
30	75.5	75.69	74.19	33.94	34.44	36.06	**3.25**
40	79	79.44	84.13	35.06	36.63	35.88	**2.48**
50	82.25	83.13	85.88	37.81	48	38	**1.97**

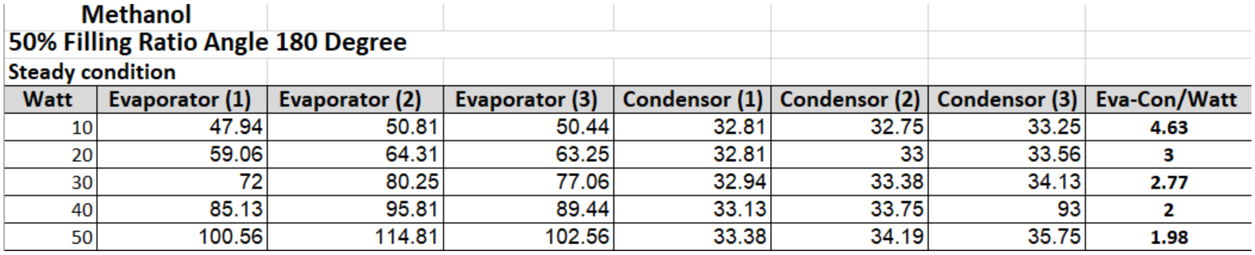


Methanol

50% Filling Ratio Angle 45 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	46.25	48.75	46.25	32.06	32.06	32.44	**4.5**
20	58.75	63.94	58.75	32.06	32.31	32.81	**3.1**
30	70.81	78.13	66	32.25	32.69	33.88	**2.88**
40	83.56	93	75.5	32	32.56	34.25	**2.2**
50	94.13	103.88	81.13	32.19	32.88	34.44	**1.55**

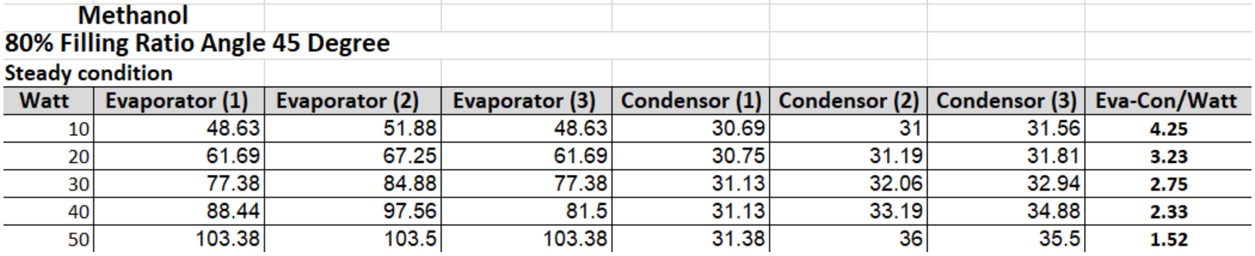


Methanol

50% Filling Ratio Angle 180 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	47.94	50.81	50.44	32.81	32.75	33.25	**4.63**
20	59.06	64.31	63.25	32.81	33	33.56	**3**
30	72	80.25	77.06	32.94	33.38	34.13	**2.77**
40	85.13	95.81	89.44	33.13	33.75	93	**2**
50	100.56	114.81	102.56	33.38	34.19	35.75	**1.98**

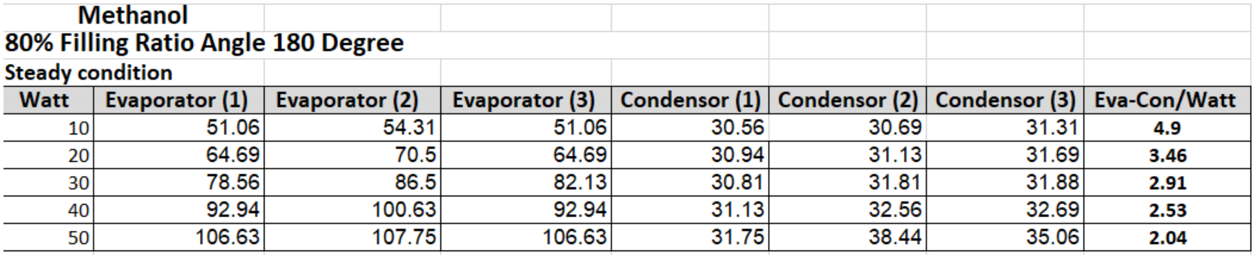


Methanol

80% Filling Ratio Angle 45 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	48.63	51.88	48.63	30.69	31	31.56	**4.25**
20	61.69	67.25	61.69	30.75	31.19	31.81	**3.23**
30	77.38	84.88	77.38	31.13	32.06	32.94	**2.75**
40	88.44	97.56	81.5	31.13	33.19	34.88	**2.33**
50	103.38	103.5	103.38	31.38	36	35.5	**1.52**



Methanol

80% Filling Ratio Angle 180 Degree

Steady condition

Watt	Evaporator (1)	Evaporator (2)	Evaporator (3)	Condensor (1)	Condensor (2)	Condensor (3)	Eva-Con/Watt
10	51.06	54.31	51.06	30.56	30.69	31.31	**4.9**
20	64.69	70.5	64.69	30.94	31.13	31.69	**3.46**
30	78.56	86.5	82.13	30.81	31.81	31.88	**2.91**
40	92.94	100.63	92.94	31.13	32.56	32.69	**2.53**
50	106.63	107.75	106.63	31.75	38.44	35.06	**2.04**