# Thermal Performance of AClosed Loop Pulsating Heat Pipe Using Acetone for Plain Tube and Wire Insert

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## Abstract

Electronic device thermal management has long been a fascinating subject to study. All electronic equipment generates excessive heat, which needs to be removed for better performance. Due to their superior heat transfer capability, efficiency, and structural simplicity, heat pipes stand out as the most suitable technological and thermally efficient option. Higher heat flux is crucial in numerous technical applications. Modern heat control for microelectronics can be accomplished with multiphase passive devices. In this paper, the attempt will be to discuss the properties of closed loop pulsating heat pipes (CLPHP), a novel member of the closed passive two-phase heat transfer system family. The goal of the current study is to investigate the relationship between thermal performance and filling ratios and comparative thermal performance analysis of heat pipes for plain tube and wire insert setup. Acetone was used as the working fluid for both setups. The multiturn copper tube has an inner and outer diameter of 2.12 mm and 3.1 mm, respectively. Regarding the CLPHP with insert setup, a wire with a 1 mm diameter is placed inside a copper tube of 3.49 m in length. The heat pipe was divided into three parts: evaporator, adiabatic zone, and condenser. Each CLPHP has an electrically heated evaporator and condenser with a fixed length. Adiabatic zone is made to be insulated so that no heat can be transferred. For experimenting, from 15% filling ratio to 90% filling ratio with a 25% increment, temperatures of the evaporator, adiabatic zone, and condenser were recorded. Results showed how system performance varied with various filling ratios and heat inputs. Heat transfer characteristics of the wire insert in PHP for a closed loop were investigated, and the experimental findings were then compared with those of a PHP configuration using a plain tube while maintaining the other parameters constant. Considering two setups, for 40% and 65% filling ratios in the wire insert setup of Acetone were found to be the most optimum thermal performance. The thermal performance of the CLPHPs is dependent on the conjugation effects of the working fluid, filling ratio, wire effect, and heating power input, according to experimental results for both setups. According to the findings, it may be possible to insert a closed loop pulsing heat pipe into a structure and further analyze the more efficient heat pipe between plain tube and wire insert setup with different filling ratios to increase thermal conductivity to the host substrate.

## Keywords
CLPHP, Multiphase, Filling Ratio, Wire Insert and Thermal Resistance.

## 1. Introduction
Due to ongoing demands for quicker and smaller microelectronic systems, design evolution of heat pipes, a form of passive two-phase thermal control device, has accelerated in the last ten years. One meandering tube is used to create the oscillating heat pipes, also known as pulsing heat pipes (PHPs), which are positioned in between the heat source and the heat sink. The fluid inside the tube is distributed into liquid plugs and vapor slugs due to its diameter being near to the fluid capillary length. Multiple liquid slugs in the evaporator violently vaporize, and several vapors plugs violently condense at the condenser, causing the fluid to oscillate continuously. Both latent and sensible heat are effectively transferred from the heat source to the heat sink as a result. The pulsating/oscillating heat pipe (PHP/OHP) first proposed by Akachi in 1990 which is a new type of efficient heat transfer device. Usually, it consists of an evacuated and filled capillary tube that contains the working fluid.Slugs of liquid with vapor bubbles

intermingled arise as a result of the surface tension of a liquid. The operation of pulsating heat pipes is outlined as, when one end of the capillary tube is heated, the working fluid increases which would increase the vapor pressure. Bubbles in the tube push the liquid towards the condenser. Cooling of the condenser results in a direction of vapor pressure and condensation of bubbles in that section of the heat pipe. The growth and collapse of bubbles in the evaporator and condenser sections, respectively, results in a pulsating motion within the tube. Heat is transferred from the evaporator to the condenser through latent heat and sensible heat transfer of liquid slugs. The active liquid at the surface of the capillary structure vaporizes as a result of heat provided to the evaporator being transferred to the working fluid via conduction. Figure 1 represents typical heat transfer region in heat pipes with temperature differences in different regions. The latent heat of vaporization is transported to the condenser through vaporization, which raises the local vapor pressure in the evaporator and forces vapor to flow there.The vapor moved through the vapor space is condensed at the surface of the capillary structure, releasing the latent heat, because energy is taken at the condenser. Capillary action and bulk forces keep the working fluid in closed circulation. In steady-state operation, a heat pipe can have an extraordinarily high thermal conductance, which gives it an edge over other traditional heat transfer techniques like a finned heat sink. As a result, a heat pipe may convey high heat over a sizable distance with a sizable temperature difference.

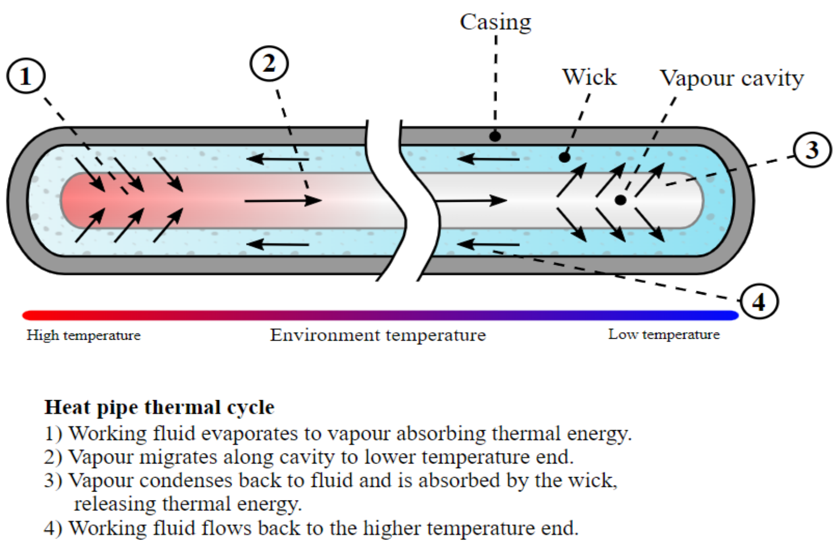


Figure 1. Operation of heat transfer in heat pipes

The tool is first partially filled with a working fluid and partially evacuated. The working fluid then manifests itself clearly inside the tool in the form of liquid-vapor plugs and bubbles in the capillary tubes. The initial plug/bubble distribution in the tubes is not under external control. By means of the liquid-vapor system's pulsing motion, heat is received at one end of this tube bundle and transferred to the other end. Due to internal pressure pulsations, the effectiveness of the performance largely rests on the ongoing maintenance or sustenance of these non-transported. The design of the apparatus assures that fluid transportation does not require an external mechanical power source. The pressure pulsations that drive them are entirely thermally produced. Figure 2 here represents different zones of a heat pipe and classified heat pipes. For the open loop structureone long tube that has been bent numerous times and both of its ends sealed after being filled with the working fluid. The tube ends are not connected to one another. Unlike traditional heat pipes, this one lacks an internal wick structure. For closed loops both of its ends are sealed and filled with liquids.

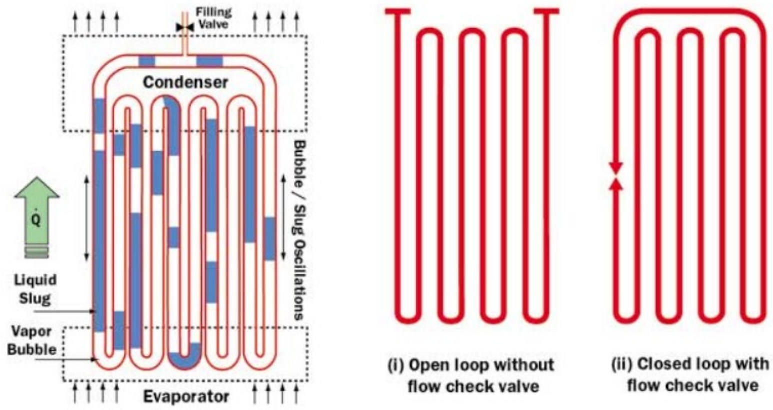


Figure 2. Schematic diagram of pulsating heat pipe

There are some primary design parameters affecting the PHP system dynamics.
• Inner diameter of tube• Input heat flux• Filling ratio of Working fluid• Total number of turns • Device orientation with respect to gravity• Thermo-physical properties of working fluid• Some secondary conditions that influences the operation• Use of control check valve• Rigidity of the tube materials• Material and tube combination• Cross section of tube• Pattern of flow inside the device.

### 1.1 Objectives
The experiment aims at to determine the thermal performance of acetone in heat pipe for efficient heat extraction. For different filling ratios the heat transfer rate differs significantly due to the bubble formation. The efficient heat transfer rate is also compared by the two setups. So, the experimental results show the optimum filling ratio and the efficient setup for greater thermal performance for variation of heat input ranging from 3W to 20W.

## 2. Literature Review
Recent advancements in the field of heat transfer, such as heat pipes, have the potential to increase our knowledge of process identification, passive cooling systems, and efficient heat transfer techniques.

Grover (1966) provided limited theoretical analysis and presented experiments on stainless steel heat pipes with a wire mesh wick and sodium as working fluid. Lithium and silver were also mentioned as working fluids.Today's major improvements in manufacturing techniques,computerized modeling, and increased research have demonstrated that heat pipe technology can inexpensively and successfully address many of the important difficulties and issues in heat transfer and thermal management. A typical PHP is a small meandering tube that is partially filled with a working fluid. The tube is bent back and forth parallel to itself, and the ends of the tube may be connected in a closed-loop or pinched off and welded shut in an open loop. It is widely acknowledged that closed-loop PHP has superior heat transfer performance. M. Arab (2012) investigated extra-long PHP with conventional thermosyphon in applying solar water heaters. The effect of adiabatic length is also studied in the experimental investigation.

The characteristics of working fluids, which are in charge of improving heat transport, may promote thermal performance. Higher conductivity hybrid nanofluids could improve the PHP's thermal performance. M.Zupar (2020) carried out numerical and experimental experiments to evaluate PHP's functionality. With a heating power of 10-100W and a filling ratio of 50% and 60%, experimental assessments were conducted.

Experimental research has been conducted on a variety of CLPHPs to examine the effects of various influencing factors, including internal diameter, operating inclination angle, working fluid, and a number of bends. S. Khandekar (2009-2020) looks at a CLPHP parametric study. It is evident that various liquids are advantageous in various operating circumstances.

Thermo-physical properties of surfactant solution have positive impact on the thermal performance of the PHP. Thermal performance of CLPHP with various alcohols and surfactant solutions were investigated by D. Bastakoti (2018).

The efficiency of heat pipes was shown to rely on a number of variables, including energy input, working fluid types, and filling ratio. Working fluids such as acetone, methanol, and deionized water were tested. Methanol performed better thermally(2013) when filled at a fill ratio of 45%. As an active fin array, a number of pulsating heat pipes arranged in a straight line between cells would remove heat from the source.

Influence of different operating parameters such as applied heat flux to the evaporator section, filling ratio of working fluid, heat pipe inclination, nanoparticle concentration and response time on the thermal performance and efficiency of heat pipe was also experimentally studied. Results showed that using the nanoparticles leads to the reduction in temperature distribution and enhances the thermal performance of heat pipe.

On two closed loop PHP, performance factors such the temperature difference between the evaporator and condenser, thermal resistance, and the overall heat transfer coefficient were assessed. For a given working condition, the filling ratio must be tuned to ensure maximum thermal performance and minimal thermal resistance. The PHP was built using a copper tube with a 1080 mm length and 3 mm diameter. Variable working fluid fill ratios of 15%–90% (in steps of 20%) and heat load (10–100W) were taken into consideration. The testing results show that PHP performs better at a fill ratio of 60% for different heat inputs due to its reduced thermal resistance and higher heat transfer coefficient.As heat input increases, the thermal resistance of closed loop pulsing heat pipes decreases. The thermal resistance decreases gradually at lower heat inputs (QS 30 W), but more quickly at larger heat inputs (QS 30 W). The thermal resistances have the results of $R_{acetone}<R_{methanol}<R_{ethanol}<R_{water}$.

At high FR, the bubbles tend to limit two phase fluid motion. Working fluids with high boiling point temperature and high latent heat require higher power loads for the phase change, which can be important when PHP is intended to dissipate high heat fluxes at high temperatures.

In 2004, some researchers investigated the thermal performance of gold nano-fluids in meshed heat pipes. The circular meshed heat pipe had a length of 170 mm and an outer diameter of 6 mm. The heat pipe thermal resistance ranged from 0.17 to 0.215 °C/W. The measured results showed that the thermal resistance of the heat pipes with nano-fluids was lower than that of pipes containing pure water. Recently, they demonstrated that a nano-fluid consisting of silver nano-particles in DI-water enhanced grooved heat pipe thermal performance.Similar research by Park et al. in another recent study revealed similar findings. Additionally, their findings demonstrated that the thermal performance of a silver nano-fluid heat pipe was superior to that of a traditional heat pipe. The outcome will be contrasted with silver nanoparticles dispersed in DI water at a 10 nm size.

## 3. Experimental Methods

The nickel-chromium wire that was wrapped outside the evaporator portion was heated in order to heat the evaporator section. Copper tube makes up the portion of the evaporator. Copper's conductivity is well known. Due to the wires' close proximity to the copper tubes while the current is flowing, there is a possibility of a short circuit. In order to prevent the issue, the heater was electrically insulated. If a short circuit occurs, the reading will be incorrect. Glass wool was used to insulate the evaporator area in order to reduce heat loss. After that, a wooden block put vertically to ensure appropriate pulsation supported the heat pipe. An AC thermostat was used to regulate the evaporator's input heating power. Schematic Diagram of the experimental setup of CLPHP is shown in figure 3:

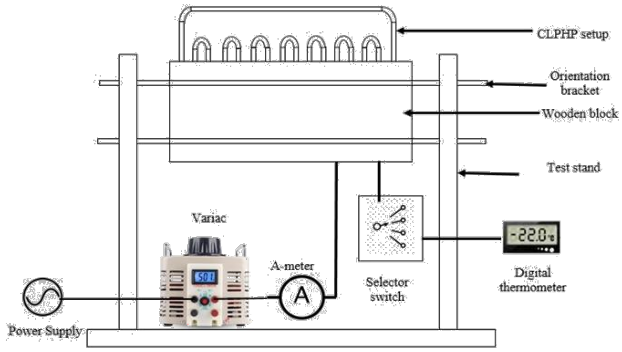


Figure 3. Schematic diagram of the experimental setup

A capillary tube of copper was used for the construction. Two separate Closed Loop PHP were constructed for the experiment. A long copper wire was placed inside the tube. Wire inserted was a plain copper wire. First one is the plain capillary means no inserts inside the tube. It's a basic structure of CLPHP experiment. A copper tube of 2.1 mm was constructed for the experiment. There is no insert inside the pipe bends. U shape bends are made with 8 turns for this structure. Three main sections were identified and read during the experiment: evaporator (50 mm), adiabatic zone(100mm) and condenser(50mm).Figure4 displays a schematic view of the configuration. To measure the temperatures, nine points of the k-type thermocouple are fitted. All thermocouple and CLPHP connection points were covered with heat tape to prevent inadvertent heat sources from being used to measure the temperature. To avoid short circuits, the evaporator area is covered with heat tape. Nickel-chromium wire is wrapped around the evaporator portion of the heat source coil. Current will flow through nickel-chromium wire with a high resistance, producing a lot of heat. The adiabatic and evaporator components are surrounded by glass wool with a 1-inch thickness for optimal setup insulation.

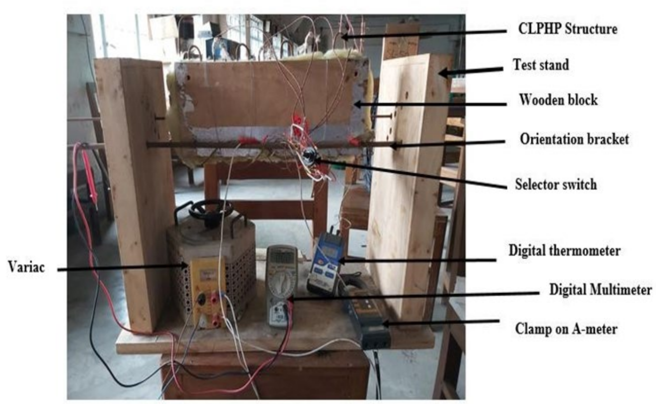


Figure 4.Setup of CLPHP (Plain Tube)

The second one figure 5 has a wire insert but is built with proportions that are identical to plain tube CLPHP. In this instance, a straight 0.7 mm copper wire was put within the heat pipe. This construction has a total of eight turns. The condenser portion of the structure is the remaining portion, and the evaporator part is 50 mm tall, 100 mm tall, and 100 mm wide. Heat tape is used to cover the evaporator area to prevent short circuits. The heat source coil's nickel-chromium wire is wrapped in the evaporator section. High heat will be produced as current passes through nickel-chromium wire that has a high resistance. For proper setup insulation, glass wool with a 1-inch thickness surrounds the adiabatic and evaporator parts. The setup is then positioned between wooden block and electrical connections with connections. Figure 5 represents here the setup for wire insert pulsating heat pipe. The setup is quite similar to plain tube setup.

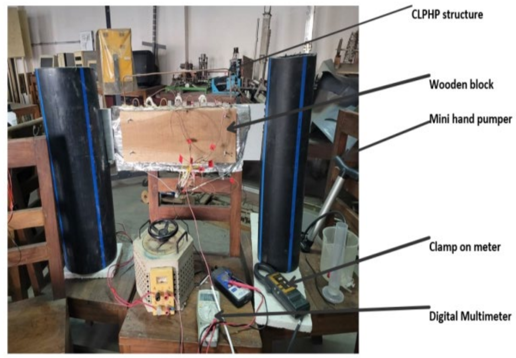


Figure 5. Setup of CLPHP (Wire Insert)

## 4. Data collection

Nine points are selected in each setup for the experiment: 3 points in evaporator section, 3 in adiabatic section and rest of the points are condenser section. Temperatures of all of the points are recorded and voltage and current are measured for each reading for 15%, 40%, 65% and 90% filling ratios for Acetone. Here Figure 6 represents different points of the heat pipe for measuring temperatures of different zones. Average temperature of each zone is calculated for measuring thermal resistance.

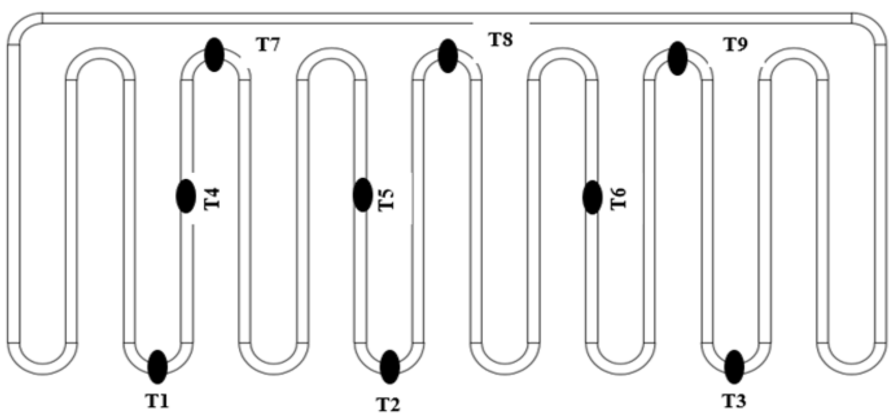


Figure 6.Selected points on CLPHP for temperature measurements

**Necessary Formulas:**

Heat Input Q= V*I*cos θ

Here, V= Input voltage from the variac output,

I= Electric current,

cos θ= Power factor= 0.8

Average temperature of evaporator, $T_e = \frac{T1+T2+T3}{3}$

Average temperature of adiabatic zone, $T_a = \frac{T4+T5+T6}{3}$

Average temperature of condenser, $T_c = \frac{T7+T8+T9}{3}$

Thermal resistance, $R = \frac{Te-Tc}{Q}$

Resistance can be written as:

$$R = \frac{Te-Tc}{Qinput}$$

Here,

$T_1$, $T_2$ and $T_3$ = Temperatures at evaporator region

$T_4$, $T_5$ and $T_6$ = Temperatures at adiabatic zone
$T_7$, $T_8$ and $T_9$ = Temperatures at condenser region
$T_e$ = Average temperature of evaporator
$T_a$ = Average temperature of adiabatic zone
$T_c$ = Average temperature of condenser
$R_a$ = Thermal resistance of the adiabatic zone
$R_c$= Thermal resistance of the condenser zone
Temperature records for all of the filling ratios are shown below in the tables with calculated thermal resistance.
For Acetone, Table 1 to Table 8 represents variation of thermal resistance for different filling ratios of Acetone and heat input for both in plain tube and wire insert setup. The variational graphs for thermal resistance are plotted based on these data.

Table 1. Data (WF: Acetone, FR: 15%) on plain tube CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc(˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.91 | 47.07 | 43.67 | 41.80 | 1.35 | 15% Acetone |
| 2 | 7.83 | 51.80 | 47.37 | 45.43 | 0.81 | 15% Acetone |
| 3 | 12.23 | 57.47 | 50.40 | 47.73 | 0.80 | 15% Acetone |
| 4 | 14.11 | 66.40 | 59.03 | 55.63 | 0.76 | 15% Acetone |
| 5 | 16.13 | 66.37 | 58.10 | 55.17 | 0.69 | 15% Acetone |

Table 2.Datafor (WF: Acetone, FR: 40%) on plain tube CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc(˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 5.28 | 35.90 | 33.10 | 32.23 | 0.69 | 40% Acetone |
| 2 | 7.83 | 43.37 | 39.73 | 38.00 | 0.69 | 40% Acetone |
| 3 | 11.89 | 54.90 | 48.97 | 46.93 | 0.67 | 40% Acetone |
| 4 | 13.06 | 64.90 | 58.53 | 53.50 | 0.87 | 40% Acetone |
| 5 | 14.56 | 65.33 | 58.17 | 53.33 | 0.82 | 40% Acetone |

Table 3. Datafor (WF: Acetone, FR: 65%) on plain tube CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc(˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.6 | 38.33 | 35.90 | 34.40 | 1.09 | 65% Acetone |
| 2 | 7.9328 | 47.47 | 42.50 | 40.30 | 0.90 | 65% Acetone |
| 3 | 11.808 | 58.30 | 52.23 | 48.43 | 0.84 | 65% Acetone |
| 4 | 14.8672 | 66.07 | 58.47 | 53.60 | 0.84 | 65% Acetone |

Table 4. Data for (WF: Acetone, FR: 90%) on plain tube CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc(˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.6 | 36.40 | 34.50 | 33.37 | 0.84 | 90% Acetone |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | 8.04 | 47.90 | 43.30 | 40.97 | 0.86 | 90% Acetone |
| 3 | 12.284 | 62.27 | 55.60 | 52.07 | 0.83 | 90% Acetone |
| 4 | 14.867 2 | 65.13 | 60.67 | 53.30 | 0.80 | 90% Acetone |

Table 5.Data for (WF: acetone, FR: 15%) on wire insert CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc (˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.44 | 32.97 | 31.13 | 29.87 | 0.90 | 15% Acetone |
| 2 | 7.36 | 43.40 | 39.87 | 38.10 | 0.72 | 15% Acetone |
| 3 | 12.14 | 54.30 | 49.43 | 45.63 | 0.71 | 15% Acetone |
| 4 | 14.62 | 63.87 | 57.20 | 54.10 | 0.67 | 15% Acetone |

Table 6.Data for (WF: acetone, FR: 40%) on wire insert CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc (˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.61 | 31.23 | 29.97 | 30.07 | 0.32 | 40% Acetone |
| 2 | 6.68 | 37.93 | 36.80 | 35.83 | 0.31 | 40% Acetone |
| 3 | 11.97 | 47.80 | 43.63 | 44.27 | 0.30 | 40% Acetone |
| 4 | 14.76 | 53.07 | 48.93 | 49.07 | 0.27 | 40% Acetone |
| 5 | 21.49 | 60.87 | 54.00 | 55.13 | 0.27 | 40% Acetone |

Table7.Data for (WF: acetone, FR: 65%) on wire insert CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc (˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.23 | 31.47 | 30.27 | 29.63 | 0.45 | 65% Acetone |
| 2 | 7.01 | 35.97 | 33.87 | 33.10 | 0.33 | 65% Acetone |
| 3 | 9.79 | 41.47 | 38.33 | 37.50 | 0.32 | 65% Acetone |
| 4 | 14.54 | 46.57 | 42.70 | 41.43 | 0.28 | 65% Acetone |
| 5 | 21.82 | 59.07 | 53.33 | 51.50 | 0.28 | 65% Acetone |

Table8. Data for (WF: acetone, FR: 90%) on wire insert CLPHP

| SI No. | Q(W) | Te (˚C) | Ta (˚C) | Tc (˚C) | R (˚C/W) | Identification |
|---|---|---|---|---|---|---|
| 1 | 3.28 | 34.33 | 33.17 | 32.07 | 0.69 | 90% Acetone |
| 2 | 6.07 | 37.43 | 35.47 | 34.70 | 0.45 | 90% Acetone |
| 3 | 9.42 | 42.60 | 39.70 | 38.73 | 0.41 | 90% Acetone |
| 4 | 14.76 | 57.13 | 50.70 | 51.27 | 0.40 | 90% Acetone |
| 5 | 22.47 | 60.77 | 54.27 | 53.17 | 0.34 | 90% Acetone |

## 5. Results and Discussion

Several graphical explanations are made to find out the optimum thermal performance for variation of the filling ratios and setups in the following.

## Effect of Filling Ratio on thermal resistance with different heat input

For Acetone, with the effect of filling ratios thermal resistance of Acetone decreases for all of the heat inputs. For lower heat inputs, as the filling ratio increases thermal resistance of the liquid reduces drastically for wire insert setup and plain tube setup. Figure shows that minimum thermal resistance was achieved for 15W heat input at 90 percent filling ratio. Gradient in thermal resistance vs filling ratio is higher in lower heat input than higher heat input. With the increase of heat input, thermal resistance is lower because more bubbles form as the heat input increases and the flow regime changes from slug to annular flow. As the filling ratio and heat input increases bubble formation reaches to an optimum position, so the gradient of thermal resistance to filling ratio remain almost constant at 65% and 90% filling ratio. From figure 7, thermal resistance of Acetone decreases with increase of filling ratios for all of the heat inputs. And for 12W and 15W thermal resistance is found to be lowest for 90 percent filling ratio.

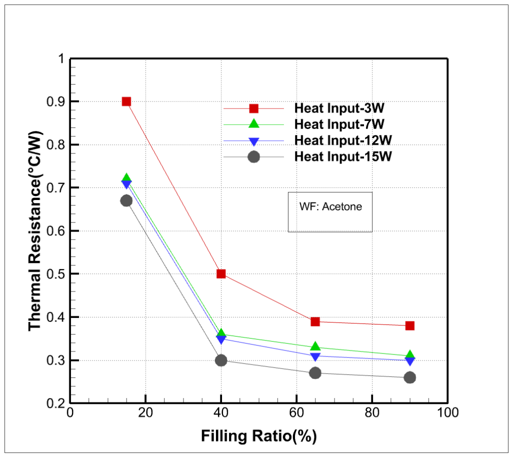


Figure 7. Thermal Resistance variation with filling ratios on wire insert CLPHP (WF: Acetone)

## Effects of heat input on thermal resistance of Acetone

Thermal resistance is inversely proportional to the heat input and proportional to the temperature difference of the evaporator and condenser. With greater temperature difference between the evaporator and condenser at constant heat input, thermal resistance of the liquid will increase. For Acetone, with higher filling ratio thermal resistance decreases initially. It's because, as the filling ratio increases more liquid is available to form vapor so that latent heat can be transferred from the evaporator to condenser. But as the filling ratio increases thermal resistance doesn't increase because liquid is filled with most of the volume. Less space is available for movement of the liquid-vapor slugs, so the pulsation action is not efficient. Khandekar also experienced such phenomenon. Less degrees of freedom inside the CLPHP does not provide sufficient agitation to the bubble formations from the nucleation sites to a desired quantity. Inadequate bubbles can't move well to the condenser section so overall thermal performance drops. Optimum value of thermal resistance is found for 40 percent and 65 percent filling ratios. Figure 8 shows variation of thermal resistance with heat input for various filling ratios. From the graph, both for 40 percent and 65 percent filling ratios, thermal resistance is lower. 15 percent filling ratio shows a peak value of resistance at low heat input but eventually the resistance falls with increasing heat input.

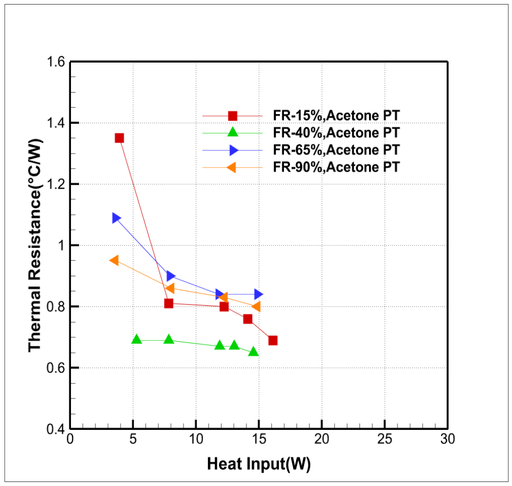


Figure 8. Thermal Resistance variation with different heat input for different filling ratios for Plain Tube Setup

For wire insert setup, Acetone shows a significant decrease in thermal resistance for all of the filling ratios and heat inputs. For 15 percent filling ratio, thermal resistance is higher than other filling ratios. For 40 percent and 65 percent filling ratio, sufficient bubble formation causes a steady and spontaneous decrease of thermal resistance with heat input. With 90 percent filling ratio, though the thermal resistance is lower than plain tube setup, resistance is more than other filling ratios. Minimum thermal resistance was obtained at higher heat inputs. Here, figure 9 shows the thermal resistance pattern for wire insert setup which can be comparable with plain tube setup. The resistance variational pattern is almost similar for all of the filling ratios unlike plain tube setup. Minimal thermal resistance is achieved for 40 percent and 65 percent filling ratios.

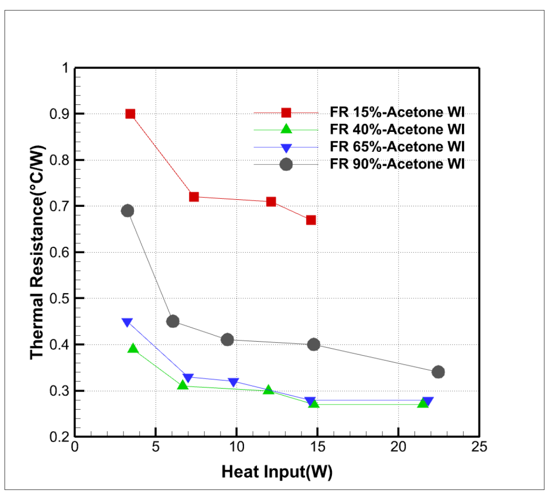


Figure 9.Thermal Resistance Variation with Heat Input for Wire Insert setup for different filling ratios

## Effect of Filling ratio on Evaporator Temperature

Evaporator temperatures are higher for filling ratios of 15%. This occurs because acetone has a lower boiling point and 15% more space to be a vapor, which allows the pulsating process to take place as intended. In comparison to 40% and 65% fill ratios, 90% fill ratios appear to have higher evaporator temperatures. For Wire insert acetone working fluid, the temperature distribution of the evaporator for various filling ratios is illustrated in Figure. Another intriguing finding is that, even though the evaporator temperature is higher for 15% filling ratios, the rate of thermal resistance decrease with heat input is not as high as it is for other fill ratios. For 40% and 65% filling ratios, pulsating movement is preferred. Figure 10 shows the comparison of evaporator temperature with heat inputs for wire insert. Increasing pattern is seemed for all of the filling ratios though at higher filling ratios and higher heat input evaporator temperatures are lower than lower filling ratios.

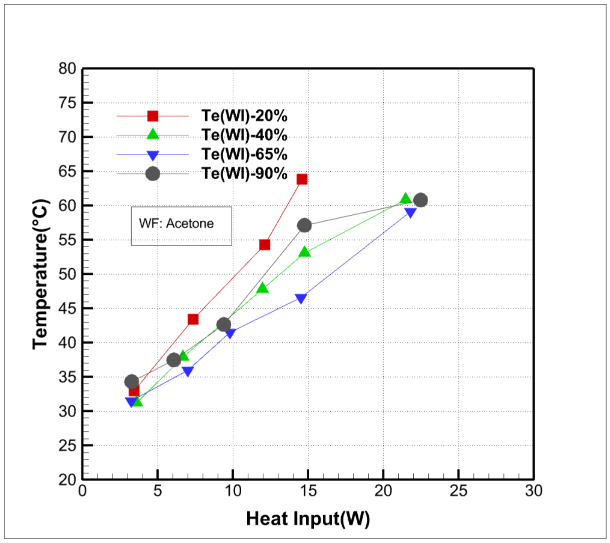


Figure 10.Variation of Evaporator Temperature with Heat Input for different filling ratios in wire insert setups

### Proposed Improvements

The present study proves that heat transfer enhancement is done for wire insert CLPHP than plain tube CLPHP. A certain number of recommendations have been given for further study:

1. Working fluid flow characteristics can be considered for further studies. Different liquids, nano fluids, composite of two liquids can be used for future studies.
2. Geometric shapes and sizes, number of turns, wire diameter, pipe diameter can be changed for further experiment.The overall experimental work can be simulated numerically by a comprehensive mathematical modelling with suitable numerical model scheme so that the effect of bubble dynamics can be visualized.
3. Experimental studies can be done with inclination of the heat pipe and effect of inclination on thermal performance can be observed.

## 6.Conclusion

Results for various filling ratios and settings are investigated through this research of the experiment. For higher heat input both for plain tube and wire insert setup, thermal resistance is found to be lower than plain tube setup for the efficient heat transfer in wire insert setup. In lower heat input, thermal resistance is higher due to the lower heat transfer from evaporator to condenser. The similar pattern for the thermal performance metrics with filling ratios and heat inputs is observed for both settings. But for wire insert setup, thermal resistance is found lower than plain tube setup both with heat input at evaporator and filling ratio. As the filling ratio increases from 15% to 90%, initially thermal resistance drops faster but beyond 65% filling ratio, thermal resistance doesn’t seem to change too much. The evaporator temperature rises with heat input for both plain tube and wire insert configurations. Another finding from the experiment is that, in contrast to greater filling ratios, evaporator temperatures rise for lower filling ratios. Pulsating action is more prominent for 65% and 90% filling ratios. According to the experiment, the ideal filling ratios for acetone are 40% and 65%, and the wire insert design provides the best thermal resistance for all heat inputs as well as overall thermal performance.

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