A Review on Pulsating Heat Pipe With Different Working Parameters Affecting The Performance

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Abstract. Every area of engineering is advancing, which is driving up demand for more compact and efficient heat transfer devices. Pulsating heat pipe development results from this (PHP). For managing moderate to high heat fluxes, PHP is a passive two-phase heat transfer device best suited for power electronics and related applications. A tiny diameter tube that is closed end to end to form a loop, is typically used. After being evacuated, the tube is partially filled with a working fluid. The applied heat flux determines the internal flow patterns in a PHP. The thermo-hydrodynamic properties of these devices are highlighted in this work. According to the state of the art, the device has to satisfy at least three thermo-mechanical boundary criteria in order to work as a pulsing heat pipe. Internal tube diameter, applied heat flux, and filling ratio are examples of this. The number of turns and thermo-physical characteristics of the working fluid also have a significant impact on the thermal behaviour. In addition, the report offers a review of previous studies on the use of pulsing heat pipes. Lastly, open questions regarding the process by which PHP operates with various working fluids, validation methods, and applications are explored.

1. Introduction

This study is based on the previous experiment’s experimentation, and the use of that specific data is critical in order to understand and apply this data to the required operating conditions. This study will help you understand the overall working parameters of the PHPs (Pulsating Heat Pipe), as well as the parameters that affect their work efficiency and working principle. Due to their straightforward design, low cost, and superior thermal performance, pulsating heat pipes are growing in popularity and may have many uses. They have so far found commercial niches in the cooling of electronic equipment since their creation in the early 1990s. The research gathered here greatly broadens our understanding of the working fluid phenomena and their impact on pulsing heat pipe thermal performance. While there are still many problems with working fluids and design, these should be overcome with more investigation [1]. In the 526.45 W/m² scenario of a 55% fill ratio of ethylene glycol at a 90° tilt at 600 W with regard to flow of fluids in the PHP operation, the pulsing heat pipe's heat transfer coefficient may be improved [2]. As technology advances in all sectors of engineering, particularly in creating components small and efficient. These characteristics are popular nowadays, and this exhilaration has been notably felt in the electronics and related sectors. Researcher’s efforts to provide more functionality in a smaller package size have resulted in denser circuitry and improved power. [3,4,5] The overall dissipated power isn't the sole issue; heat flow is also a factor. The solution is to create a new material and a new cooling technique in cooling technology principles and methods of application. This resulted in the invention of Pulsating Heat Pipes (PHPs). [6,7,8] PHPs appear to suit all of today's cooling needs. PHPs are particularly appealing heat transfer components because to their simple design, low cost, and outstanding thermal performance. Since their creation in the 90s, they have so far found a market in the cooling of power and microelectronics equipment [9,10,11]. Such heating pipes can override several restrictions associated with traditional heat pipes, such as capillary & entrainment constraints. Despite being defined as a subclass of the extended group of heat pipes. [12,13] Thermo-hydraulic coupling has a distinctly distinctive level of complexity.[14,15] The adiabatic section refers to the segment of the tubes between the evaporator and condenser. The circulating fluid's pressure and thermal capacity are selected such that they fall in between evaporator and condenser temperatures. As a result of heat being absorbed inside the evaporator and released in the condenser, the fluid is converted to vapour. The produced vapour is moved to the condenser portion, in which it condenses. To the evaporator part, the liquid is returned. [16,19] Latent heat, which necessitates a complicated study, is primarily responsible for the heat transfer between that of the tube wall & a vapour plug as
well as in the lateral area between the plug & slug. [20,21] The predictive validity analysis, which was done for only the horizontal operation and vertical operation, shows that the uncertainty at high heat loads is repeatable and independent of the prior level of heat power input. Nevertheless, when the PHP is operated vertically at start-up heat input levels, the disparities are larger. This phenomenon has been seen at various filling ratios, with 0.5 being the most effective.

2. Working principle of the PHP's:-

The PHP’s working is related to following principles

a. Thermodynamic Principle
b. Fluid Dynamic Principle
c. Heat Transfer Principle

Principle of Thermodynamic:

As the heat is raised in the evaporator area, vapour bubbles form after some time, and these bubbles are condensed in that condenser section, where the heat is dropped. The behaviour of the bubbles in the PHP’s can change as the temperature rises and falls. This may not be the exact cycle process, but it is still unknown [10].

Principle of Fluid Dynamic:

A capillary tube's fluid flow is made up of moving liquid slugs, vapour plugs. The slugs as well as plugs begin to disperse in the half-filled tube. Because of the surface tension with forces outweigh gravitational forces, the liquid slugs can completely bridge the tube. At the interaction of solids, liquids, and vapours, surface tension creates a partial thickness region on that both of ends on each slug. Plugs of a working fluid in that when a vapour phase separate the slugs. A thin film of liquid dragging from of the slug surrounds the vapour plug.

Principle of Heat Transfer:

As the fluid slugs fluctuate, they enter the PHP's evaporator section. Sensible heat gets transferred to the slug as its temperature rises, and as the slug returns to the PHP's condenser final moment, it gives its heat to the environment. The differential pressure that drives the oscillating flow is generated by latent heat transfer. Heat transfer occurs in the thin liquid film due to phase change.

![Fig 1 : Working of heat pipe and list of the part description [1]](image)

3. The Parameters affecting Performance Of PHP's:

The various parameters affecting the PHP’s directly or indirectly are Geometrical parameters, Operating parameters, Properties of fluid being used.
Geometrical/Design Parameters: Tube material and its dimensions of the tube (radius and length):

The radius of the pipe is very essential and plays a significant part in the choosing PHP’s. The internal dimensions of that pipe effects the PHP’s more directly. The larger the dimensions of the pipe in the lesser thermal sheet resistance and it is used to increase the conductivity (Thermal).

The calculation of the diameter can be done using this formulae below

\[ D_m = 2 \sqrt{\frac{\sigma}{g(\rho_{liq} - \rho_{vap})}} \]

Where:
- \( \sigma \) = Surface tension (fluid) (N/m);
- \( g \) = acceleration of gravity (N/m²);
- \( \rho_{liq} \) = fluid density (kg/m³);
- \( \rho_{vap} \) = vapor density (kg/m³);

The compatibility of the fluids is very important because if they are no compatible the efficiency of the PHP may decrease and this may cause and the failure of the PHP or the corrosion is caused due to their non-compatibility. And also if there any non-condensable gases are formed and the molecular reaction leads to corrosion this corrosion is caused by the reaction may lead to internal damage of the PHP.

There are different fluids and different pipe materials that can be made into pipes. From the given table below you can identify the compatibility of the fluid with required material to be used to make heat pipes. As this table helps us understand the compatibility between fluid and material of the tube.

<table>
<thead>
<tr>
<th>Table-1 [12]</th>
<th>Compatibility of working fluid with tube material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube Material</td>
<td>Working Fluid</td>
</tr>
<tr>
<td>Copper</td>
<td>RU</td>
</tr>
<tr>
<td>Aluminium</td>
<td>GCN</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>GNT</td>
</tr>
<tr>
<td>Nickel</td>
<td>MC</td>
</tr>
</tbody>
</table>

RU- recommended by past successful usage; RL- recommended by literature; MC- may compatible GNC- generation of gas all temperatures;

Orientation in the heat pipes:

Orientation is nothing but the way you position the tube in the PHP. The angular measurements are used here in-order to find the best position required for the process. This angle is based on the evaporator section position to the horizontal of that section. For any work the satisfactory performance in when the angle is in between 50-65.

Number Of Turns:

The turns of the tube is very important to the PHP this determines the area of the PHP, and the size of the setup should be used as the number of turns increases the more the chance of better performance. From the experiments conducted in the past this conclusion has been consider. This condition can be considered for both horizontal mode and vertical mode.

The Design (Evaporator & Condenser) section:

The modelling of the Evaporator section & condenser section play’s a very major role in the working and efficiency of the PHP’s. We know that the area of condenser should be greater that of the area that of the evaporator for avoiding the dry out condition. The below graph-1 shows the relation between the evaporator length & critical heat flux. We can observe that as the As the evaporator's length is extended, the critical flux drops.
Bend Effect:

The geometry of the U-turns are there. As we discussed, the effectiveness of heat pipes is impacted by curvature. The bends are 180 and 90 degrees the loss of pressure is more. This bends creates a lot of problems when they are in the horizontal position and the heat loss is very less. If the orientation of the pipes changes the better the performance of the pipe will be an also the pressure loss is decreased.

(Filling ratio) Filling Ratio:

The amount fluid is filled in the pipelines in relation to capacity of HP (heat pipe) is called filling ratio. The minimal filling ratio is determined from the experimental data. The filling ratio is varied in between 0%-100%. The true working range of the PHP is in between 20-80% fill ratio. This may differ in the changing of the fluid occurs. If the bubble are increased the more we have the freedom of the pulsating in the heat pipes. That the sensible heat is also decreased as the degree of freedom increases.

Filling ratio (100%):

Here there are very less bubbles are formed, as there is no air to form bubbles and movement of the bubbles are not happened. And there is minimal flow to through the pipes. This causes the seize of the fluid in the pipes as the movement of the, fluid is not happening. So, the heat rejection also decreased, and the performance of the PHP is decreased. So, This type of fill ratio effects a huge deal in this type of filling ratio.

The below graph helps you understand the performance of the heat pipe at different operating temperatures.
Filling ratio (0%):

Here the ratio of fluid is very less, the amount of fluid kept in the pipes is very minimal to form a very few slugs and to form a evaporator dry out. This very unstable in this condition this may lead to damage of the equipment due to the amount of water present in the HP(Heat pipe). This type of procedure is very is ineffective and very unstable in the operating conditions.

Dry-out Condition:

This factor restricts heat pipe operation. When the entire working fluid has vaporised and there's no more liquid inside this evaporator section, this is referred to as dry out. The condition has occurred. This condition happens when the pipe has a very small filling ratio and a large heat input. Heat transfer occurs completely due to conduction when the dry out condition is reached.

4. Properties in the Working Fluid:

The requirement of a working fluid is also very essential in the performance of the PHP, it is also one of the most important parameters. To select a perfect working fluid we have to know the properties of the fluid to be used in the heat pipes. And information helps us to understand the lifespan of the pipes and the heat transfer using this information. The temperature range of the working fluids are provided below in the table 2. The characteristics that are taken into account at the time of choosing the working fluid are Thermal stability, vapor pressure, Wettability, higher latent heat & higher thermal conductivity, low vapor viscosity, freezing point.

<table>
<thead>
<tr>
<th>Working Fluid</th>
<th>Melting point (°C)</th>
<th>Boiling point (°C)</th>
<th>Useful range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>-271</td>
<td>-261</td>
<td>-271 to -269</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-210</td>
<td>-196</td>
<td>-203 to -160</td>
</tr>
<tr>
<td>Ammonia</td>
<td>-78</td>
<td>-33</td>
<td>-60 to 100</td>
</tr>
<tr>
<td>Acetone</td>
<td>-95</td>
<td>57</td>
<td>0 to 120</td>
</tr>
<tr>
<td>Methanol</td>
<td>-98</td>
<td>64</td>
<td>10 to 130</td>
</tr>
<tr>
<td>Ethanol</td>
<td>-112</td>
<td>78</td>
<td>0 to 130</td>
</tr>
<tr>
<td>Heptane</td>
<td>-90</td>
<td>98</td>
<td>0 to 150</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>100</td>
<td>30 to 200</td>
</tr>
</tbody>
</table>

5. Conclusion:

Pulsating heat pipes are becoming increasingly popular due to simple design, low cost, and superior heat performance, and they may find widespread applicability. In the cooling of electrical devices, they have discovered market segments since their invention in the early 1990s. The work presented here contributes significantly to our understanding to the phenomena & effects of the working fluid, that regulate the heat pipelines' heating effectiveness when they pulse. Many unresolved issues concerning working fluids as well as design remain, but further research should be capable of addressing these obstacles.

References
8. Ji Li b, Chenxi Li a, Thermal characteristics of a flat plate pulsating heat pipe module for onsite cooling of high power server CPUs. Thermal Science and Engineering Progress (2022).