Thermal Performance of the LHP (Loop Heat Pipe) with the Flat Plate Evaporator

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ABSTRACT

The LHP (Loop Heat Pipe) can transfer the small and medium heat dissipation over the short and middle distance. Moreover, it is effective in protecting environment because it doesn’t demand power to transfer the heat. It will be applied to control the temperature of a personal computer, a server and a liquid crystal television of the mechanical industry. The evaporator is 19×95mm flat plate, the vapor tube is φ5×300mm, the condenser is φ3.5×600mm and the liquid tube is φ3.5×300mm. The wick is made from the sintering SUS316 metal. The working fluid is methanol and water. In this paper, we describe the parallel between the thermal performance test result and analysis result of this LHP.

Keywords: LHP (Loop Heat Pipe), Capillary Force, Flat Plate Evaporator

1. INTRODUCTION

The LHP uses the capillary head instead of the mechanical pump to transfer the fluid. It does not have any moving parts and transfer the fluid by the capillary head between the vapor and liquid interface of the wick like a heat pipe (HP). Moreover, vapor and liquid flows in the same direction. It can reduce the loss of the pressure in the wick (very short wick in the evaporator) and can transfer large heat over long distance compared with HP. Therefore, it is reliable and reduced the total weight compared with a mechanical pump system. It can be adapted to the distributed heat sources in order to have a parallel configuration of the evaporator and in order to arrange the layout of the vapor and liquid tubes, too. Moreover, the accumulator put in front of the evaporator can keep the temperature constant varying the heat dissipation of the heat source. The heat transfer capability of LHP, that is limited to the several hundred watts by the capillary force of the wick structure inside the evaporator.

The compact designed LHP can transfer small and medium heat over short or middle distance. Moreover, it is effective in protecting environment because it does not demand power to transfer the heat. It will be better solution to control the temperature of a personal computer, a server, and a liquid crystal television of the mechanical industry.

2. ASPECT OF LHP’s STUDIES

Figure 1 indicates the operation principle of the LHP. The LHP consists of the evaporator, the vapor tube, the condenser and the liquid line. We put the wick to the inside evaporator. The working liquid in the LHP is driven by the capillary force of the wick and the boiling and condensing phenomenon of the liquid. As soon as we apply the heat to the evaporator, the liquid changes to the vapor in the wick structure of the evaporator. The vapor flows to the condenser through the vapor tube. The liquid flows to the evaporator through the liquid tube by the capillary pressure of the wick structure of the evaporator.

We design and make the LHP which heat transfer capability is 100W. Figure 2 shows the test setup of the LHP. We obtain the experimental heat transfer capability of the LHP and evaluate how to use it to control the temperature of a server. We develop the engineering tool that applies to design the LHP. It can calculate the maximum heat transfer capability and operating temperature of the LHP. Figure 3 shows input and output parameters of the engineering tool. We can easy operate it on the personal computer.
3. EXPERIMENTAL SETUP

Figure 4 shows the configuration of the evaporator. The left side is the outer appearance and covered by the heat-insulating material. The right side is the wick structure inside the evaporator. Figure 5 shows the structure of the wick. The wick is made of the SUS mesh wire. The porosity of the wick is 0.75, the minimum pore radius is $0.20 \times 10^{-6}$ m and capillary force is $4 \times 10^6$ N.

Table 1. Specifications of LHP

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator</td>
<td>Outer diameter: $22\text{mm(w)} \times 16.7\text{mm(h)} \times 70\text{mm(l)}$</td>
</tr>
<tr>
<td>Wick</td>
<td>Outer diameter: $20\text{mm(w)} \times 6\text{mm(h)} \times 60\text{mm(l)}$</td>
</tr>
<tr>
<td>Vapor tube</td>
<td>Outer diameter: $5\text{mm}$, Inner diameter: $4\text{mm}$, Length: $250\text{mm}$</td>
</tr>
<tr>
<td>Condenser</td>
<td>Outer diameter: $3.5\text{mm}$, Inner diameter: $2.5\text{mm}$, Length: $600\text{mm}$</td>
</tr>
<tr>
<td>Liquid tube</td>
<td>Outer diameter: $3.5\text{mm}$, Inner diameter: $2.5\text{mm}$, Length: $250\text{mm}$</td>
</tr>
<tr>
<td>Working Fluid</td>
<td>Methanol and water</td>
</tr>
</tbody>
</table>

Figure 6 shows the schematic of the test setup. The normal size of the LHP is $400\text{mm} \times 200\text{mm}$. The outside diameters of the evaporator is $22\text{mm(w)} \times 16.7\text{mm(h)} \times 70\text{mm(l)}$. The outside and inside diameters of the vapor tube are $5\text{mm}$ and $4\text{mm}$. The outside and inside diameters of the condenser and the liquid tube are $3.5\text{mm}$ and $2.5\text{mm}$.

Figure 7 shows the functional diagram of the test setup. We apply heat to the lower side of evaporator by the heater. We measure several temperatures of the LHP by the thermocouples. The air fan cools the condenser. The data logger and personal computer measure the temperature, pressure, voltage and current.
4. EXPERIMENTAL TECHNIQUE

4.1. Outline of Experiment

The object is to obtain the fundamental performance of the LHP with the flat plate evaporator. We change the liquid volume inside the LHP at the experiment in order to grasp the optimum liquid volume. We increase the heat of the flat plate evaporator at the optimum liquid volume experiment. We examine the thermal resistance, temperature distribution and thermal performance of the LHP.

First, we use the methanol as a working fluid. We put the heat to the evaporator from 20W to 160W and reduce the heat from 160W to 20W with 10W interval. Table 2 shows the test parameter. We use the water as a working fluid. Next, we put the heat to the evaporator from 20W to 160W and reduce the heat from 160W to 20W with 10W interval. Table 3 shows the test parameter.

<table>
<thead>
<tr>
<th>Table 2. Test Parameter (methanol)</th>
</tr>
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<tbody>
<tr>
<td>Sampling time (sec)</td>
</tr>
<tr>
<td>Amount of Working fluid (ml)</td>
</tr>
<tr>
<td>Heat Input(W)</td>
</tr>
<tr>
<td>Position</td>
</tr>
<tr>
<td>Wick</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Test Parameter (water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling time (sec)</td>
</tr>
<tr>
<td>Amount of Working fluid (ml)</td>
</tr>
<tr>
<td>Heat Input(W)</td>
</tr>
<tr>
<td>Position</td>
</tr>
<tr>
<td>Wick</td>
</tr>
</tbody>
</table>

4.2. Thermal Resistance

We explain the definitions of the dry-out and the maximum heat transfer capability. The dry-out point will be defined the point in which the temperature between the condenser and evaporator will be begun an upward trend. In addition, the heat input at that point will be defined the maximum heat. We can calculate the thermal resistances of the LHP by the following equations.

Thermal resistance (overall) :

$$R_{TTR} = -\frac{T_{TTR} - T_{con}}{Q}$$

Thermal resistance (evaporator) :

$$R'_{TTR} = -\frac{T_{TTR} - T_{Sat}}{Q}$$

Thermal resistance (condenser) :

$$R''_{TTR} = -\frac{T_{Sat} - T_{con}}{Q}$$

5. EXPERIMENTAL RESULT

Figure 8 shows the test result of methanol. The maximum heat transfer capability is 160W with 9, 10 and 11ml methanol. The overall thermal resistance decreases as well as increasing the heat input and reaches 0.37K/W at 160W heat condition.

![Figure 8. Thermal resistance vs Heat Input (Methanol)](image)

Figure 9 shows the test result of water. The maximum heat transfer capability is 110W with 9ml water. The overall thermal resistance decreases as well as increasing the heat input and reaches 0.53K/W at 110W heat condition.
6. CONSIDERATION

6.1. Theoretical Thermal Resistance

We consider the overall thermal resistance of the LHP that is consisted of the thermal resistance of the evaporator wall, the wick structure and condenser wall.

We can indicate the thermal resistance of the external wall of the evaporator by the following equation.

\[ R_e = \frac{l}{Ak_e} \]  

We can calculate the effective thermal conductance of the wick structure inside the evaporator by the following Maxwell’equation.

\[ K_w = \frac{1}{L} \left[ k_x + k_y + \left( 1 - \varepsilon \right) \left( k_x - k_y \right) \right] \]  

We can indicate the effective thermal resistance of the wick structure inside the evaporator by the following equation.

\[ R_w = \frac{l}{Ak_w} \]  

We can indicate the thermal resistance of the external wall of the condenser by the following equation.

\[ R_c = \frac{\ln(r_{out} / r_{in})}{2\pi k_c L} \]  

Table 4 shows the theoretical thermal resistance and experimental result

<table>
<thead>
<tr>
<th></th>
<th>Methanol</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Thermal Resistance</td>
<td>0.248</td>
<td>0.157</td>
</tr>
<tr>
<td>Evaporator</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>Wick</td>
<td>0.238</td>
<td>0.147</td>
</tr>
<tr>
<td>Condenser</td>
<td>0.00023</td>
<td>0.00023</td>
</tr>
<tr>
<td>Experimental Result</td>
<td>0.37</td>
<td>0.53</td>
</tr>
</tbody>
</table>

The thermal resistance of the wick is higher than another thermal resistance. In order to improve the performance of the LHP, it is necessary to reduce the thermal resistance of the wick. The experimental result of the methanol is identical to the theoretical thermal resistance. The experimental result of the water is larger than the theoretical thermal resistance. It is possible that another parameter expect for the wick raises thermal resistance of the LHP.

6.2. Impact of the Operating Pressure

The working fluid inside the evaporator evaporates and the pressure inside the evaporator rises. The pressure difference between the evaporator and the condenser occurs. The vapor moves from the evaporator to the condenser by this pressure difference. Figure 10 shows the relation between the saturation pressure and temperature. The saturation pressure of 100deg. water is fortieth part of a methanol. The saturation pressure of cold water is lower than that of cold methanol. Thermal resistance of the LHP becomes low because of the little pressure difference between the evaporator and the condenser.

7. CONCLUSIONS

The following results were obtained from this study.
The optimum volume of methanol in the LHP is 11ml and it is 45% of the LHP volume.

The maximum heat transfer capability is 160W and the minimum thermal resistance is 0.39K/W with 11ml methanol.

The fluid with high saturation vapor pressure is needed in order that the LHP operate stability.

NOMENCLATURE

- $R_{ec}$: Thermal resistance (overall)
- $R'_{ec}$: Thermal resistance (evaporator)
- $R''_{ec}$: Thermal resistance (condenser)
- $T_{eva}$: Evaporator temperature (K)
- $T_{con}$: Condenser temperature (K)
- $T_{sat}$: Saturation temperature (K)
- $Q$: Heat input (W)
- $R_e$: Thermal resistance of the evaporator
- $R_c$: Thermal resistance of condenser
- $A$: Evaporator area ($m^2$)
- $k_e$: Thermal conductivity of the evaporator
- $l$: Evaporator length ($m$)
- $R_w$: Thermal resistance of wick
- $k_w$: Thermal conductivity of the wick ($W/(m\cdot K)$)
- $k_l$: Thermal conductivity of the liquid ($W/(m\cdot K)$)
- $k_s$: Thermal conductivity of the material ($W/(m\cdot K)$)
- $\varepsilon$: Porosity of the wick
- $r_{out}$: External diameter ($m$)
- $r_{in}$: Internal diameter ($m$)
- $k_c$: Thermal conductivity of the condenser ($W/(m\cdot K)$)
- $L$: Condenser length ($m$)

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REFERENCES


