Manufacturing and Testing of the Liquid Grooves Wick on the Heat Transfer Performance in Loop Heat Pipe with Flat Evaporator

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Keywords: Loop heat pipe with flat evaporator, Acetone, Wick, Liquid groove.

Abstract. It's the first idea that make liquid grooves on the surface of the wick next to the compensation chamber. By this, the absorbing surface area of working fluid increased and thereby reduce the flow resistance of loop heat pipe with flat evaporator. Results indicated that heat transfer performance increases in the wick structure with liquid grooves on the surface, of which the critical heat load (dryout heat load) reached 175W and the thermal resistance was 0.77 °C/W. Comparing with the structure without liquid groove under 100 °C, the typical operating temperature of electronic devices, our design increased the heat load by 50%. As the reason, wick structure with liquid groove has a great potential to improve the performance of loop heat pipe.

Introduction

Loop heat pipe with flat evaporator (FLHP) is a passive two-phase heat-transfer device with capillary pump and it can be used in aerospace, energy, electronic cooling etc. Capillary pump is provided by the wick structure from the evaporator. The wick structure can also separate the evaporator from the vapor discharge room and the liquid replenishment room (compensation chamber), so that the heat transfer performance in loop heat pipe with flat evaporator is affected by the wick structure.

In this study, we developed the wick structure and tried to improve the performance in loop heat pipe with flat evaporator. As the reason, we searched many papers that discuss about wick structure and listed as below:

In 1996, Gernert [1] operated the loop heat pipe with Nickel wick structure and elucidated that increase the surface area might be helpful for the performance in loop heat pipe. In 2007, Launay [2] conducted a literature review of loop heat pipe and pointed out that the performance of loop heat pipes with evaporator is determined by the design of wick structures and compensation chambers in the evaporator. In 2009, Wu [3] manufactured the polymer polystyrene as a wick structure for heat leakage of loop heat pipe. The experimental data shows that the polymer possesses a low thermal conductivity and is able to suppress the heat transfer to the compensation chamber effectively. In 2014, Wu [4] investigated the effects of increasing the number of grooves on a wick's surface and found the best number of vapor grooves on the surface area. Wu pointed out that increasing the surface area of the vapor emissions can reduce thermal resistance and improve heat transfer performance.

From reviewing the above literature, there is no study or design aiming at refining the liquid grooves. Therefore, we proposed a design about wick structure with liquid grooves (Figure. 1-b) and the initial experiment that the number of the liquid grooves was five. This design can not only reduce the flow resistance but increase the surface area for absorbing working fluid therefore improving the performance in the loop heat pipe with flat evaporator.

In this paper, we choose the polymer materials-Polytetrafluoroethylene (PTFE), which has low thermal conductivity and low manufacturing temperature, as the wick structure to reduce heat leakage.
Since PTFE is hydrophobic, water can’t be used as working fluid, plus this study targets at applying on electronic devices, we choose acetone instead of water. The main purpose of this paper is to improve the performance in loop heat pipe with flat evaporator by using wick with liquid grooves.

**Experimental Principles and Methods**

**Wick Manufacturing Process**

According to sintering experience from Wu [6], we chose PTFE with particle size range from 500-700 µm as wick structure and the temperature of sintering furnace was set to be 375 ºC for 30 minutes.

**Wick Properties Measurements**

The parameters of wick structure was measured and taken SEM pictures after manufacturing. Parameters included effective aperture ($R_C$), permeability ($K_W$), and porosity ($\varepsilon$). The measuring device was designed based on ASTM E128-99 for measuring the effective aperture and permeability, and porosity was calculated by Archimedes principle.

**FLHP Heat Transfer Performance Testing**

Except for the evaporator is made out of aluminum alloy, the main material of the system is stainless steel. Thermal testing of FLHP is shown in Figure. 2. In this study, we recorded and monitored the temperature by T-type thermocouples, with error within ±0.2 ºC. The power source was used to supply current to the heat source ($Q$). In order to test the effect of the liquid grooves wick structure on the heat transfer performance in FLHP, the total thermal resistance of the system is determined using Eqs. (1)

$$R_{tot} = \frac{T_{evap} - T_{cin}}{Q}$$  \hspace{1cm} (1)

($Q$ is the input heat load; $T_{evap}$ is the evaporator wall temperature; $T_{cin}$ is the condenser inlet temperature.)

The ambient temperature was maintained at 25 ºC, and the condenser water jacket temperature at 10 ºC to assist the FLHP condenser operation. The power source provided the heat source by using the power supply to simulate the heat energy in the FLHP. The error analysis is based on the relative inaccuracy analysis proposed by Moffat [8]. The total thermal error was within ± 5% ~ 9%.
Results and Discussions

Wick Properties and SEM Measurement Results

Figure 3 shows the image of the sizes of PTFE particle and the SEM of wick properties under 100x and 2000x magnification. The images shows that the effective pore size is 4.75µm, the porosity is 43% and the permeability is $2.4 \times 10^{-12}$ (m²), indicating a good wick structure.

LHP Performance Testing Results

Figure 4 and 5 summarize the performance of the FLHP with the evaporator wall temperature and the total thermal resistance results.

Figure 4 shows the relationship between the temperature of the evaporator wall and the heat load which square represents the heat transfer performance of the wick without liquid grooves and circle denotes that for the wick structure with liquid grooves. According to the Figure 4, the initial temperature of the wick structure with liquid grooves was already lower than the wick structure without liquid grooves. The Figure 4 shows that the linear slope of the wick structure without liquid grooves is steeper than the one with liquid grooves. The linear slope refers to the temperature of the evaporator wall, rising fast, which means that the heat transfer performance was reduced. In the case of wick structure with liquid grooves, the critical heat load can reach to 175 W, the heat flux of 28W/cm², and the lowest total thermal resistance of 0.77°C/W. Assume that the temperature is set to 100 °C, the heat load of the wick structure with liquid grooves can reach of 75W. Because of the
liquid grooves can reduce the flow resistance, comparing with those without, the heat transfer performance was enhanced by 50 %

![Figure 4](image.png)

**Figure 4.** FLHP with the evaporator wall temperature and the heat load.

![Figure 5](image.png)

**Figure 5.** FLHP with the evaporator wall temperature and the total thermal resistance results.

Figure 5 shows that the relationship between total thermal resistance and heat load. Same as Figure 4, the initial thermal resistance of the wick structure with liquid grooves was already lower than those without. The wick structure without liquid grooves initially had a deep drop at the variable resistance region (i) and changed into constant thermal resistance region (ii) when it reached the load of 90W. The critical heat load was 150W. However, the wick structure with liquid grooves will be in the constant thermal resistance region and at a stable state at 120W. The wick structure with liquid grooves will dry out when it approached to 175W. The lowest total thermal resistance of wick structure without liquid grooves is 0.9. With the liquid grooves, the flow resistance can be reduced and the heat leakage can also be suppressed and delayed, and so the lowest total thermal resistance of wick structure with liquid grooves can reach of 0.77°C/W.

Based on the above result, this study gave the idea of a wick structure with liquid grooves. And the wick surface of liquid side can increase the contact area of the working fluid and the flow resistance is reduced to extend the heat transfer operation of the FLHP and thus breaks the limit of the heat transfer performance. This design has development potential in the future.
Conclusion

In this study, the liquid grooves on the wick structure surface for replenishing the working fluid were designed successfully. The conclusions from this study are as follows:

1. Successfully design and manufacture the liquid grooves of wick structure and the measurement of wick structure is as follow:
   - The effective pore diameter is 4.75 µm, the porosity is 43% and the permeability is $2.4 \times 10^{-12}$ (m$^2$)

2. The testing of LHP performance showed that the critical heat load of the FLHP with liquid grooves wick structure can reach of 175W, the heat flux of 28W/cm$^2$ and the lowest total thermal resistance of approximately 0.77 °C/W. When the temperature of the evaporator wall limited at 100°C. The critical heat load of liquid grooves can reach of 75W, comparing with the wick structure without liquid grooves, the maximum heat load increased by 50%.

Based on the above results, designing liquid grooves has great potential for improving the performance of the loop heat pipe with the flat evaporator.

Acknowledgement

Sincerely thanks for the Ministry of Science and Technology’s help. The project number is MOST-104-2221-E-157-008.

References


