Manufacturing of the Complex Wick with Double-Layer Bi-Porous Structure and Applying to a Loop Heat

S. C. Wu\textsuperscript{a}, F. C. Lin\textsuperscript{c}, S. H. Chen\textsuperscript{b}, C. C. Yeh\textsuperscript{c}, S. K. Wang\textsuperscript{b}, Y. M. Chen\textsuperscript{c}

\textsuperscript{a} Department of Aviation Mechanical Engineering, China University of Science And Technology, Taipei, Taiwan.
\textsuperscript{b} Department of Mechanical, Energy and Aerospace Engineering, Chung Cheng Institute of Technology, National Defense University, Taoyuan, Taiwan.
\textsuperscript{c} Department of Mechanical Engineering, National Taiwan University, Taipei, Taiwan.

Tel: +886928898124, Fax: +88633895924, E-mail: mimi1210@seed.net.tw

ABSTRACT

The purpose of this study is to develop a complex capillary structure (wick) and to enhance the heat transfer performance of loop heat pipe. We build a manufacturing process of the complex wick. The outer layer of the complex wick is the biporous structure, which possesses large pores working as vapor pathway. The inner layer is the monoporous wick, which provides high capillary force and increases the strength of the outer layer. Experimental results showed: at 85°C as the tolerant temperature of the evaporator wall, the maximum heat load of the complex wick reached 700W (36W/cm\textsuperscript{2}); and the heat transfer coefficient of evaporator reached 116 kW/m\textsuperscript{2}. The minimum thermal resistance of the system was 0.08°C/W. Comparing with the heat transfer performance of the monoporous wick, the complex wick enhanced the maximum heat load in 67% (420W of monoporous wick) and lowered the total thermal resistance in about 100% (0.17°C/W of monoporous wick).

Keywords: loop heat pipe, complex capillary structure, biporous wick

1. INTRODUCTION

Loop heat pipe (LHP) was invented and patented by Maidanik et al. at 1972[1]. The wick only exists in the evaporator and separates the liquid and vapor working fluid. LHP prevents the entrainment limit and has a lower pressure drop in contrast with the conventional heat pipe. The device providing a long heat transport distance and a low thermal resistance is suitable for the electronics-cooling. The schematic of a LHP is shown in Figure 1.

![Figure 1. The Schematic of a Loop Heat Pipe](image)

The key point of the heat transfer enhancement in a LHP lies in the wick. The wick’s research can be discussed with the internal porous parameters and the exterior geometries. It has been reported that the biporous wick promotes heat transfer performance in a traditional heat pipe. For a LHP device, the biporous wick therefore has a high potential for heat transfer enhancement.

In 1987, Koneav et al.[2] investigated the evaporation and boiling heat transfer in the biporous wick. They found the critical heat flux and the heat transfer coefficient were higher than the monoporous wick.

In 1995, North et al.[3] researched the phenomenon of the thin-film vaporization in the biporous structures. It was found that the performance of biporous wick was outstanding at high heat fluxes. As the wick reached the capillary limit, dryout was found in the wick.

In 2002, Cao et al.[4] experimentaly investigated evaporative heat transfer of the copper biporous wick heated under a fin block. The results showed the heat transfer coefficient and the critical heat flux in the biporous wick was better than the monoporous wick.

In 2006, Semenic and Catton [5] reported the powder size of the bidispersed wick was significant for the capillary force.

In 2009, Yeh et al.[6] reported the influence of different pore distribution curves of biporous wicks on the LHP's performance. Experiment
results showed that the heat transfer performance was better than the monoporous wick with about 60% improvement.

In 2011, Wu et al.[7] reported the manufacturing process of the biporous wick and applied to a LHP. The results indicated that the biporous wick effectively enhanced the performance. However, the high porosity caused by the large pores lowered the structural strength of wick. The application of the biporous wick may be limited.

By summarizing the above literatures, the heat transfer performance of the biporous wick is better than the monoporous wick. The large pores in the biporous wick can discharge the vapor smoothly, and reduce the vapor accumulation in the wick. At the high heat flux, the small pore in conventional monoporous wick can not quickly provide sufficient working fluid; and the dryout phenomenon occurs. Increasing the amount of the large pores provides the more vapor pathway in the biporous wick, however, it causes the structural strength weaken.

In 2008, Huang and Franchi[8] developed a complex wick structure which increased the capillary force, permeability and the evaporative performance. However, the manufacturing procedure was not reported in detail.

Based on the foregoing analysis, the purpose of this paper is to propose the concept of the complex wick structure and to employ it in the LHP.

---

2. EXPERIMENTAL METHODS

A LHP consists of an evaporator, vapor/liquid transporting lines, a condenser, and a compensation chamber as shown in Figure 1. The design of wick structure in the evaporator is a crucial point.

---

Figure 2. Complex (Double-Layer) Wick Schematic Drawing

Figure 2 shows the diagram of the complex wick. Outer layer is the biporous structure, which uses the large pore to discharge the vapor during evaporation. Inner layer is the monoporous structure which provides high capillary forces. Moreover, the inner layer also increase the overall structural strength. The heat transfer performance differences of the complex, the biporous, and the monoporous wicks are compared experimentally.
agent to manufacture the outer layer of the complex wick.

The outer layer had a biporous pore size distribution. The nickel powder was mixed with the pore forming agent. The mixture was filled into a mold and then was sintered. The pore forming agent worked as a sacrificial layer which was soften and vaporized at the high temperature during the sintering process. Therefore, two different pore radii in outer layer wick were formed after the sintering. For the inner layer, the conventional monoporous wick was utilized. After changing the central rod, refilled and then was sintered. The detailed procedure is shown in Figure 3.

The evaluations of the heat transfer performance are the evaporator wall temperature, the total thermal resistance and the heat transfer coefficient of evaporator. In this work, the evaporator temperature was limited under 85°C as a tolerant temperature which is based on the consideration of the electronic-cooling application. The total thermal resistance of the system and the heat transfer coefficient of evaporator are determined by the below equation (1) for estimating the evaporator heat transfer coefficient was ±1.4~9%.

\[
R_{\text{total}} = \frac{T_s - T_{\text{sink}}}{Q_{in}}
\]  

(1)

\[
h_e = \frac{Q_{in}}{A_{ev}(T_e - T_s)}
\]  

(2)

3. RESULTS AND DISCUSSIONS

Figure 4 is the actual sample of the complex wick. The SEM pictures of the outer layer and the inner layer are also shown. From this figure, it can be obvious found that the different pore radii on the surfaces of the inner layer and the outer layer.

Evaporator was heated under a copper saddle which was embodied with the heaters connected with a DC power supply. The heating surface area was 2010 mm². A tubular condenser was used in this test. The temperature of water coolant was set at 10°C. Calibrated (deviation in ± 0.2°C) K-type thermocouples were set up for temperature measurement. The data of the thermocouples were instantaneously recorded by an Yokogawa MX-100 acquisition device. \( R_{\text{total}} \) is LHP total thermal resistance, \( T_e \) is the evaporator wall temperature, \( T_{\text{sink}} \) is sink temperature determined by the temperature of water coolant, \( Q_{in} \) is input heat load, and \( A_{ev} \) is the heat exchanging area. \( h_e \) is the evaporator heat transfer coefficient, and \( T_s \) is the vapor temperature. The uncertainty analysis was through the recommendations of Kline and McClintock[9]. The involved uncertainty presented in the equation (1) for estimating the total thermal resistance of the system was ±2.5%; and the uncertainty of the evaporator heat transfer coefficient was ±1.4~9%.

Table 1 depicts the geometric parameters of the evaporator and the condenser. In this work, the heat transfer coefficient of evaporator are considered of the electronic-cooling application. The evaporator temperature was limited under 85°C as a tolerant temperature which is based on the consideration of the electronic-cooling application. The total thermal resistance of the system was ±2.5%; and the uncertainty of the evaporator heat transfer coefficient was ±1.4~9%.
It is higher than the heat transfer performance of the biporous wick in about 16.5% and has an enhancement of 66% compared with the monoporous wick. The experimental results shown that the performance of the complex wick is better than the monoporous and the biporous wick.

Figure 5. The Evaporator Temperature of Three Test Samples

By exploring the difference among these wicks, the main factors are that the biporous wick can quickly remove the vapor, and the monoporous wick can continuous supply work liquid to make the wick wetted. The complex wick possessing the advantages of monoporous ans biporous wick. The evaporative surface area is increased in the outer layer and the structural strength is also improved by the inner layer, as well as the capillary force. Therefore, the complex wick can enhance the heat transfer performance than the monoporous wick and the biporous wick.

Figure 6 shows the total thermal resistance depending on the applied heat loads. It indicates that the operating characteristics of three samples attain to the constant thermal resistance zone from the variable thermal resistance zone. It is a general operating characteristic of a LHP. This characteristic is resulted from the increasing utilization of the condenser under an increasing heat load.

As the applied heat load increases during in (a), (b), and (c) regions shown in Fig. 6, the complex wick structure has a better heat transfer performance among the three samples. At (b) region, the lowest thermal resistance of the monoporous wick is 0.17°C/W, the biporous wick is 0.12°C/W, and the complex wick is 0.08°C/W, respectively. Form Fig. 5, under the tolerant evaporator wall temperature 85°C, the maximum heat load reaches 700W in the complex wick structure, which is the best performance compared with the monoporous and the biporous wicks.

Figure 6. The Thermal Resistances of Three Test Samples

4. CONCLUSIONS

In this study, an innovative wick is developed for the LHP’s evaporative heat transfer enhancement. The performance difference of the complex, the monoporous, and the biporous wicks are compared. The main conclusions are summarized as followings:

1) The complex wick structure manufactured and applied in the LHP’s evaporator can overcome the structural weaknesses at high heat load. The procedure of the complex wick was reported.

2) The testing result showed that the maximum heat load of the complex wick reached 700W, the minimum thermal resistance was 0.08°C/W, and the heat transfer coefficient of evaporator reached 116 kW/m² as the tolerant temperature was set at 85°C.

3) The heat transfer enhancements of the complex wick was significant in contrast with the monoporous wick. Comparing with the monoporous and the single-layer biporous wick, heat maximum heat load of the complex wick increased 67% and 15%, respectively. The minimum thermal resistance decreased in 100% and 50%.

REFERENCES


