



Investigating the effect of powder-mixing parameter in biporous wick manufacturing on enhancement of loop heat pipe performance



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ABSTRACT

This study investigated the use biporous wick with two pore sizes to enhance the performance of loop heat pipe (LHP). In the manufacturing process of a biporous wick, this paper varied the mixing ratio between high polymer PMMA, which was used to make large pores, and nickel powder, which was used to make small pores. This paper used PMMA as the sacrificial material to form large pores; the pore size and content of PMMA was varied, with powder sizes of 177–210 μm , 250–297 μm and 350–420 μm , and contents of 30 vol%, 35 vol%, and 40 vol%. After mixing with nickel powder and the sintering process to produce the biporous wick, the product was put into LHP for performance testing and measurements. Experimental results indicated that a higher content of PMMA particles corresponds to better performance, but beyond a maximum and optimal content the performance worsens; results also indicated that larger powder size leads to better vapor transport and evaporation, but beyond a certain point the large pores can cause weakened structure. Therefore, we found that 250–297 μm and 35 vol% was the optimal PMMA powder diameter and content, respectively; under these parameters, the maximum LHP heat load was 800 W, the thermal resistance was around 0.095 $^{\circ}\text{C}/\text{W}$, the evaporator heat transfer coefficient was 131 $\text{kW}/\text{m}^2 \text{C}$, and the porosity was 86%. Compared with using a monoporous wick, the wick performance was enhanced by about 130%, reducing the LHP thermal resistance by about 60% and, for the first time, to less than the order of $10^{-2} \text{ }^{\circ}\text{C}/\text{W}$.

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1. Introduction

Loop heat pipe (LHP) was first invented by Maydanik et al. [1] and later patented in the United States. LHP uses liquid–vapor phase change mechanism and lets vapor escape from the evaporator through the capillary structure, effectively enhancing heat transfer performance and distance as well as decreasing the thermal resistance.

Fig. 1 shows a schematic of the design; LHP is composed of an evaporator, a condenser, a compensation chamber, a vapor line, and liquid line. The evaporator includes a wick; the other components are simply smooth pipes. When heat enters the system through the evaporator, the heat is transferred to the working fluid on the wick's surface. The vapor then escapes through the grooves on the wick's surface, while at the same time the high capillary force of the wick allows the vapor line to pump the operation of

the entire system. The most important part of the LHP is the design of the wick in the evaporator; heat enters through the evaporator's wall to the working fluid on the wick surface, where liquid–vapor phase change occurs to transfer the heat to the rest of the system for cooling. Therefore, the performance of the wick directly impacts the overall performance of the LHP.

A traditional LHP uses a monoporous wick, but at high heat load, boiling occurs within the capillary structure, causing the formation of vapor film, causing thermal resistance to rise and finally drying phenomenon. Therefore, using a biporous wick can let the working fluid be transported through small pores and vapor escape through large pores, solving the vapor film problem.

Application of biporous wick to LHP was first suggested by North and Maydanik [2]; however, no related conclusion was provided. Chen et al. [3] investigated the effect of the biporous wick material on boiling heat transfer and found that the biporous wick results in significant improvements. Semenic and Catton [4] pointed out the importance of the connectivity of the pores and the combination of large and small pore diameters in the manufacturing process of biporous wick, thereby allowing vapor to escape

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Nomenclature

A	heating area (mm^2)	V_r	volume percent (vol%)
h_e	evaporator heat transfer coefficient ($\text{W}/\text{m}^2\text{°C}$)	V_p	volume of PMMA (cm^3)
Q	heat load (W)	V_w	total volume of wick (cm^3)
R_{LHP}	LHP total thermal resistance ($\text{°C}/\text{W}$)	W_f	mass of wick saturated with working fluid (g)
T	temperature (°C)	W_w	mass of dry wick (g)
T_v	vapor temperature (°C)	ε	wick porosity (%)
$T_{c,in}$	condenser inlet temperature (°C)	ρ	density (kg/cm^3)
T_{evp}	evaporator wall temperature (°C)		

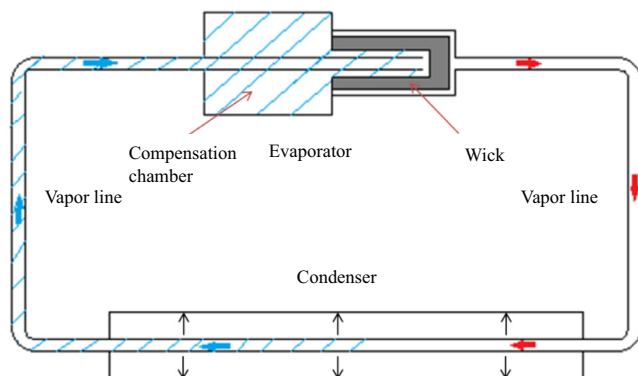


Fig. 1. Schematic of the LHP.

at high heat load through the large pores. Yeh et al. [5,6] first listed the manufacturing process of the biporous wick, using Na_2CO_3 particles to form the large pores; they changed the Na_2CO_3 particle diameter and content, immersing the sintered wick in water to dissolve the Na_2CO_3 particles to form large pores; after testing, the particle diameter and content was found to directly effect the performance of the LHP, yet this method still presents limitations on maximizing the diameter and content of large pores. Wu et al. [7] investigated the manufacturing process of biporous wick in LHP; PMMA was first used for wick manufacturing as sacrificial layer for large pore formations. After sintering, performance testing indicated that, compared with using monoporous wick, heat transfer performance was enhanced by 50%. However, the manufacturing process of the biporous outer layer was not clearly listed.

From the above literature, it is clear that biporous wick can effectively solve problems encountered when using a monoporous wick. However, there are little reports on the manufacturing process of biporous wick; few reports using Na_2CO_3 washing process pointed out limitations on forming larger and higher contents of large pores in the manufacturing process. There are also very few studies on LHP performance enhancement, and the most important parameters (large pore-forming PMMA particle's size and content) still need further investigations. Therefore, this paper investigates the powder-mixing parameters (pore-forming agent's particle size and content), using PMMA as pore-forming agent, in the biporous wick manufacturing process to enhance LHP performance.

2. Biporous wick manufacturing process

This study follow the method used in [8] and used high polymer particles for mixing to form large pores. After mixing the polymer particles with nickel powder, the mixture was sintered to form the capillary structure. Following Tracey [9], the nickel powder used was manufactured by Inco, with type-255 as the main component; the diameter was around $3\ \mu\text{m}$, and the shape was spherical. The

polymer used was PMMA, with density $1.19\ \text{g}/\text{cm}^3$, melting point $140\ \text{°C}$; once the sintering temperature is beyond PMMA's melting point, the particles began to evaporate, leaving behind large pores in the wick.

Fig. 2 shows the manufacturing process of biporous wick. First, the chosen nickel powder and PMMA particles were mixed according to adjusted proportion. Then, the mixture was poured into the mold, which had 12 grooves on the outer surface. After setting the sintering temperature and time, with rising temperature rate $10\ \text{°C}/\text{min}$ to $700\ \text{°C}$ constant temperature, the mold was placed into the oven [10]. During the sintering process, hydrogen gas was added to act as atmospheric gas during the cooling process. After sintering was finished, the manufactured wick was removed from the mold. Since PMMA vapor is slightly toxic, a cooling trap was placed in the oven to cool the PMMA vapor, preventing PMMA vapor from escaping into the atmosphere.

Concerning the structure of biporous wick, Semenic and Catton [4] as well as Yeh et al. [6] especially suggested that, in order to allow vapor to easily escape, the larger and more numerous the large pores the better; design of the large pores significantly effects the performance of the biporous wick, of which the most important parameters are the pore-forming agent (PMMA) size and content choices. The following explains how the parameters are chosen:

Pore-forming agent diameter: $350\text{--}420\ \mu\text{m}$, $250\text{--}297\ \mu\text{m}$, $177\text{--}210\ \mu\text{m}$.

Semenic and Catton [4] suggested larger large pores the better to let vapor escape, but since the washing process of Na_2CO_3 particles causes problems difficult to solve, this paper uses single-sintering process to manufacture the wick, with no washing process afterwards, successfully eliminating the problem encountered by Yeh et al. while also increasing the wick's structural strength [5]. Using the largest diameter range suggested by Yet [5], $125\text{--}149\ \mu\text{m}$, as baseline, after preliminary testing, when the pore-forming agent particle diameter is larger than $500\ \mu\text{m}$, the biporous wick can no longer be formed by sintering. Therefore, the pore-forming agent diameter ranges chosen for this study are $350\text{--}420\ \mu\text{m}$, $250\text{--}297\ \mu\text{m}$, and $177\text{--}210\ \mu\text{m}$.

Pore-forming agent content: 40 vol%, 35 vol%, 30 vol%.

Yeh et al. [6] stated that the higher content of PMMA particles the can increase the evaporation area; in their paper, the content is 20 vol%, and after preliminary testing, we found that when the content reaches 45 vol%, biporous wick loses structural strength. Therefore, 40 vol% is the maximum content for this study, with 40 vol%, 35 vol%, and 30 vol% as tested parameters. After deciding the volume percent of PMMA to be used in wick, Eq. (1) was used to calculate the respective weights of nickel powder and PMMA particles needed. The volume ratio V_r was first determined, then the volume of PMMA V_p can be calculated and converted into corresponding weight. Subtracting V_r from V_w gave the volume of nickel powder to be used; after converting it into corresponding weight, the amount of nickel powder was measured out, and the mixing process could begin.

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