Effect of Powder Sizes on Heat Transfer Characteristics of Miniature Sintered – Wick Heat Pipe

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Abstract

The objective of this study is to experimentally and numerically determine the effect of powder sizes on the void fraction, which subsequently affects the heat transfer characteristics, of miniature sintered–wick heat pipe usually applied in the notebook computer. The powder size of the wick is a profound influence on the heat transfer performance, as well as the economic aspect, of the heat pipe. By using computer program to simulate the void fraction of the sintered wick made of two sizes of metal powder, and accordingly the mixture fraction of such metal powder, the optimum throughput heat transfer of the miniature heat pipe can be predicted. The inputs of the simulation program are size specification, the thickness of copper powder and powder fraction. The heat transfer characteristics of the heat pipe will be determined by firstly obtaining the void fraction of such sintered wick. Then the heat transfer rate will be calculated from the void fraction. The optimum void fraction can be solved as the point at which the void fraction and heat rate are appropriate on the basis of economic consideration. In order to validate such calculation, the experiments have been conducted with several kinds of metal powders. The wick employs the copper powder with range of diameter of 150 - 212 and 250 - 297 micron respectively by wick molding with sintering process. The miniature heat pipe with outside diameter of 6 mm and the total lengths of 200 mm was used. The wick thickness was fixed of 0.46 mm. Water was used as a working fluid. From the result, the heat transfer performance at normal state of the heat pipe with powder fraction of 1 : 3 has found to be as high as 25 W which is quite closed to the predicted one.

Key words: heat transfer characteristics, miniature sintered, wick, heat pipe

1. Introduction

Heat pipe is heat transfer device which transfer heat from high temperature heat source to low temperature heat sink by latent heat working fluid inside a closed container. Because heat resistance inside heat pipe is very low, it is an efficient heat transfer device and popular in engineering application such as heat recovery device, spot cooling, electronic cooling and CPU cooling. Heat pipe consists of 3 parts. The first one is container which keeps working fluid and wick inside. The second one is working fluid which transfers heat from evaporator section to condenser section. The last one is wick to transport working fluid from condenser section to evaporator section by capillary force. From experimental study by [1], it was found that powder size and void fraction had profound influence on thermal performance of heat pipes. The type of wick structure was presented by [2], [3]. They found that structure type of sintered wick produced higher capillary force than the type of groove or mesh, as shown in Figure 1. The simulation model was presented by [4], it was found that void fractions obtained by using three powder sizes are lower than that using one or two powder sizes. This is because when the various powder sizes are used, the empty space can be filled with the smaller powder, thus the void fraction is low. No systematic investigations have been carried out concerning the parametric study of powder sizes and mixture ratio on the void fraction of sintered wick structure for miniature heat pipes. Therefore the present study attempted to investigate the thermal performance of miniature heat pipe with sintered copper powder wick. By this research will focus on effect of powder size of the sintered wick made of made of two sizes of spherical copper powder as well as the mixture fraction of such copper powder. The interesting problem is how to estimate the powder fraction and void fraction which affect heat transfer characteristics of miniature sintered − wick heat pipe. Moreover, this study can be employed as basic data to design CPU cooling system of the portable computer.

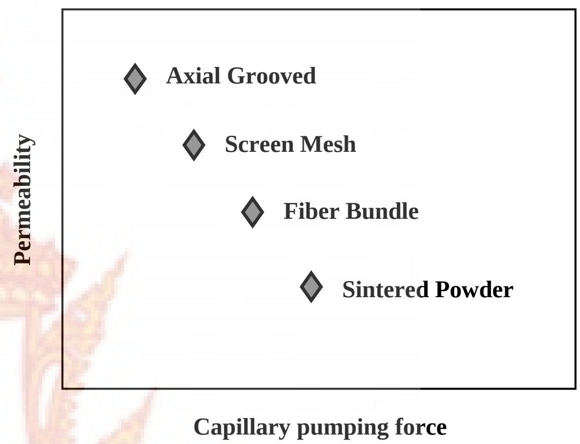
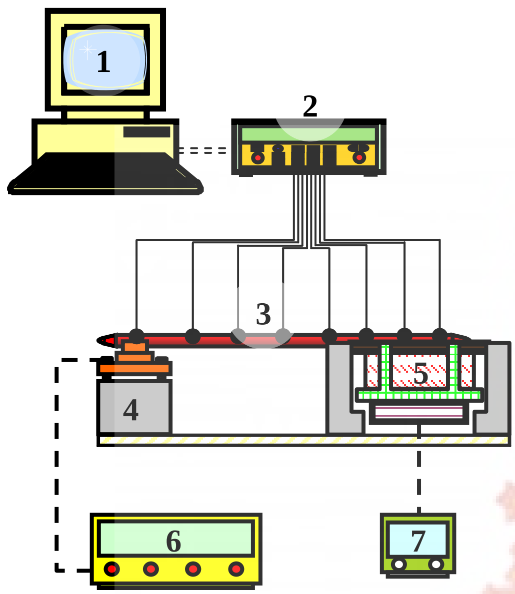


Figure 1 Capillary and Permeability of various wick structure

2. Experimental setup

The miniature heat pipes were made of the copper tube with inside diameter of 5.32 mm, outside diameter of 6 mm. The lengths of heat pipe was 200 mm. The sintered wicks were made from sphere copper powder of two sizes. The wick employed the copper powder with the diameter range of 150-212 and 250-297 micron. The mixing powder fraction were 1:0, 3:1, 1:1, 1:3 and 0:1, respectively. The working fluid used was water. The inclination angle was 0 degree (from horizontal plane). The experimental setup is schematically shown in Figure 2.



No.	Name
1	Computer
2	Data logger
3	Heat pipe
4	Heater
5	Heat sink
6,7	DC power supply

Figure 2. Schematic diagram of experimental apparatus

The evaporator section of heat pipe was heated by the electric heater. The temperature was controlled by DC-current heat source (Instek, GPR-7550D). The condenser section of heat pipe was cooled by copper groove, which was attached with the cooling fan. The cooling fan was controlled by DC-current heat sink with 6.8 voltage. Eight K-type thermocouple probes were installed along the heat pipe to measure the temperature distribution of heat pipe. They were 1 point in evaporator section, 3 points in adiabatic section and 4 points in condenser section. After that heat was supplied to evaporator section continuously by adjusting power was increased to 10 W. When the steady state was reached, temperatures were recoded. After that, the power was increased until it reached the steady state. The experimental results were recorded again and this was repeated until the heat pipe experienced the dry out phenomenon.

3. Results and discussion

3.1 Temperature distribution along length of heat pipe

Figure 3 shows the relation between distance along the length of the heat pipe from evaporator section to condenser section and wall temperature of the heat pipe with outside diameter of 6 mm. The length of each section is 15 mm, 100 mm and 70 mm respectively. It can be found from the study that, when the mixing ratio of the sphere copper powder (with the two ranges of diameter of 150-212 and 250-297 micron) was varied as 3:1, 1:1, and 1:3 (consequently the void fraction was varied as 39.88%, 37.91%, and 36.16%), the temperature of heat pipe in each part during steady state operation. The temperature distribution at distance 22.5 mm of evaporator section was fairly uniform : at 30 W of heat load the temperature was 49.74 ^{o}C. At 80 mm distance the temperature was 49.71 ^{o}C of adiabatic section, and at 185 mm distance the temperature was 48.53 ^{o}C of condenser section, respectively. These results show a near constant temperature for the evaporator section and condenser section of about 1.21 ^{o}C. This trend was identical for every heat load test. Moreover, these results are compared with Klinbun et al., (2008) and it can be found that the trends in both studies are fairly closed.

Temperature along the heat pipe surface exhibited the acceptable temperature difference (between evaporator section and condenser section) within the range of 1-3°C. This follows the regulation law of the customers.

3.2 Effect of heat load on thermal resistance

Thermal resistance is another important parameter to convince the thermal performance of the wicked heat pipe. The data to be shown belong to heat pipe with an outside diameter of 6 mm, length of 200 mm and wick thickness of 0.46 mm. Water was used for the working fluid. When the mixing ratio of the sphere copper powder (with the two ranges of diameter of 150-212 and 250-297 micron) was varied as 3:1, 1:1, and 1:3 (consequently the void fraction was varied as 39.88%, 37.91%, and 36.16%), It was found, the thermal resistance was reduced, as in case of the void fraction of 36.166%, from 0.069 °C/W to 0.03875 °C/W when the heat load was increased from 10 W to 40 W. Thermal resistance will decrease continually when heat load is increased. Thermal resistance is calculated from $R_t = \Delta T/Q$. Therefore, (R_t) will continually decrease when the thermal heat load is increased as long as the temperature difference between evaporator and condenser section (ΔT) remains unchanged. At a higher heat load, the thermal resistance increased from 0.03875 °C/W to 0.144 °C/W when heat load was increased from 40 W to 55 W. This is because the dry out occurred at the evaporator section which occurred from the efficiency of the heat sink is not high enough to transfer the increased heat, and the vapor pressure in the evaporator section is too large. At this pressure, the vapor will not condense the flow of fluid decreases and the evaporator section dries out as shown in Figure 4. The surface temperature was accordingly increased.

3.3 Effect of void fraction on heat transfer characteristics

Figure 5 show the effect of void fraction on heat transfer. The following experimental data belong to the heat pipe with 6 mm outside diameter and 200 mm length and wick thickness of 0.46 mm. When the mixing ratio of the sphere copper powder (with the two ranges of diameter of 150-212 and 250-297 micron) was varied as 3:1, 1:1, and 1:3 (consequently the void fraction was varied as 39.88%, 37.91%, and 36.16%), it was noticed that at the void fraction was increased from 36.16% to 39.88%, the heat transfer will decrease from 25 W to 20 W. Since heat transfer depends on the thermal resistance of wick material, a small void fraction offers improved thermal conductivity because of the greater fraction of copper powder fraction to working fluid, where the thermal conductivity of copper powder is greater than that of the thermal conductivity of working fluid. In contrast, a large void fraction has less copper powder but more working fluid, so heat transfer decline and thermal resistance is increased. From in Figure 5, at small void fraction the heat transfer performance was found to be 24 Watts which is comparatively high for our collaborative private sector. This value is also pretty closed to the predicted value from our simulation program. This means that our simulation program can be validated.

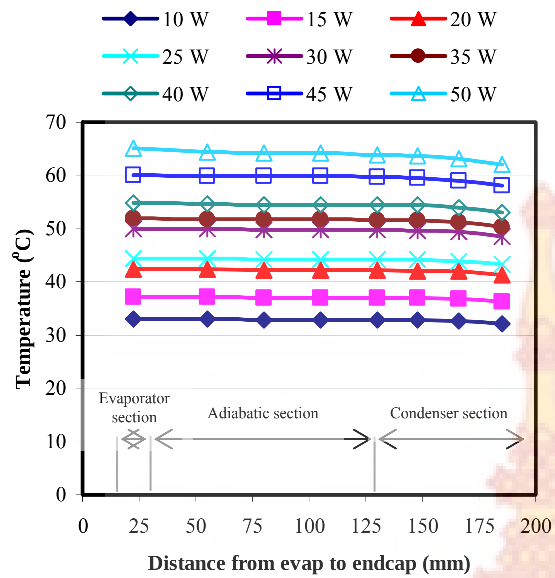


Figure 3. Temperature distribution along the heat pipe from evaporator section to condenser section

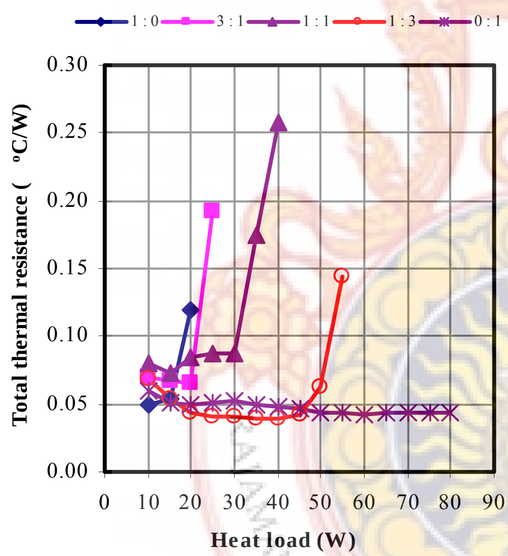


Figure 4. Effect of heat load of heat pipe and thermal resistance

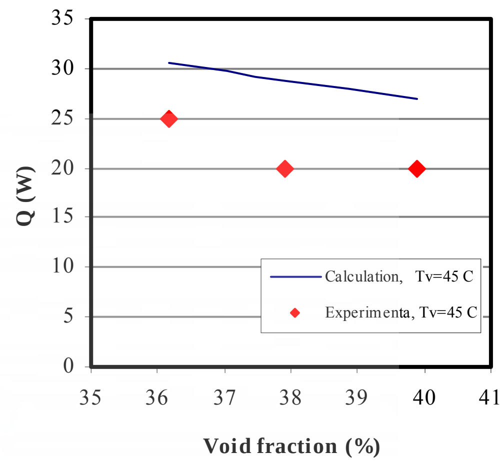


Figure 5. Effect of void fraction on heat transfer

4. Conclusions

The effect of void fraction on heat transfer characteristics of miniature sintered – wick heat pipe has been investigated in this study in order to validate our previously established simulation program. It was found that, the temperature distribution along the heat pipe surface (with the controlled void fraction of 36.16%) exhibited the acceptable temperature difference (between evaporator section and condenser section) within the range of 1-3°C. The total thermal resistance was found as low as 0.03875 °C/W and the heat transfer performance was found to be 24 Watts which is comparatively high for our collaborative private sector. Moreover, this study can be employed as basic data to design CPU cooling system of the portable computer.

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6. References

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