

Short Paper

ENHANCEMENT OF THERMAL PERFORMANCE IN A SINTERED MINIATURE HEAT PIPE

Yuan-Sen Tsai, Yun-Ming Chang, Jui-Hua Chan, Shen-Chun Wu, and Yau-Ming Chen

ABSTRACT

The performance of a sintered miniature heat pipe is enhanced. With the capillary limitation, porosity takes priority over the wick structure parameters that would affect the heat transfer capacity. Since sintered dendritic copper powder has higher porosity, it is used to mix with pore former (Na_2CO_3) in experiments for increasing porosity, and hence enhancing the thermal performance. The results show that, for a heat pipe with a 3mm outer diameter and 200 mm effective length, the heat transfer rate is up to 16.5W and the thermal resistance is $0.9^\circ\text{C}/\text{W}$. In comparison with the unmixed case, the performance increases about 40%.

Key Words: miniature heat pipe, heat transfer enhancement, mixing powder.

I. INTRODUCTION

Heat pipes, originally used in the aerospace industry, are often referred to as superconductors of heat, due to the high heat transfer capacity caused by the phase change mechanism. (Peterson, 1994; Faghri, 1995) Recently, heat pipes have been used in conjunction with sinks and fan units to serve as thermal modules for notebook computers (Kuzmin, 1994; Xie *et al.*, 1998; Nguyen *et al.*, 2000; Lin and Lu, 2000).

The CPU's performance and heat dissipation rate increase progressively. To enhance the efficiency of heat pipes, many efforts have been made to improve the design of thermal modules. (Ali *et al.*, 1999; Kim *et al.*, 2003) However, for a commercial heat pipe with a 3mm outer diameter, its heat transfer capacity is about only 10W. (Ali *et al.*, 1999; Fujikura Ltd., 2000) To satisfy the current requirement, the

diameter of heat pipes is enlarged from 3 to 6 or 8 mm, or two or more heat pipes may be used together to cool a single CPU. Since the space in a notebook computer is constricted, the volume of heat pipes may lead to a degree of difficulty in arranging the various components of a notebook computer. When compromising between performance and size, it is still necessary to enhance the heat transfer capacity of miniature heat pipes.

The types of wick structure include groove, mesh, and sintered powder. Among these types, the sintered powder type is found to have the highest performance (Dunn and Reay, 1994). However, reports about the performance enhancement of sintered miniature heat pipes are rarely found. Seeing that, the present efforts seek to discover the priority of the wick structure parameters. Then, experiments are conducted to enhance the performance of sintered miniature heat pipe by improving the priority parameter.

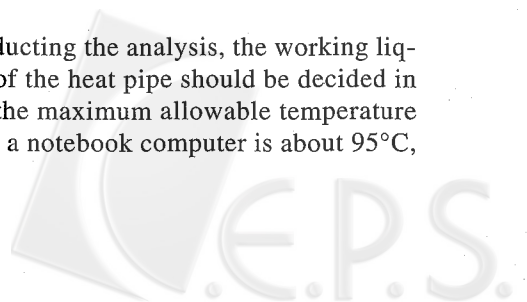
II. THEORETICAL ANALYSIS

Before conducting the analysis, the working liquid and the size of the heat pipe should be decided in advance. Since the maximum allowable temperature of a CPU used in a notebook computer is about 95°C ,

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the operating temperature of the heat pipe in the present study is set between 60 and 80°C. Considering the operating temperature, Merit number and compatibility, water is used as the working liquid. Besides, since the space in a notebook computer is restricted, the present heat pipes are designed with small radius. Here, the outer tube diameter (D_o) and length (L) of heat pipe is $\phi 3 \times 200$ mm, and the pipe wall thickness (t) is set as 0.3 mm.

According to the primary heat transport limitations of the heat pipes, the performance is restricted mainly by capillary limitation. It is the evaporating meniscus in the wick structure pumping the working fluid in a heat pipe; that is, the wick should generate enough capillary force to balance all the various pressure drops in a heat pipe.

To estimate the maximum heat transfer capacity, the equation expressed below is established through analyzing the pressure drops in all sections of the working fluid circulation, (Chan, 2001)

$$Q \leq \frac{2\sigma r_{cap} + \rho_l g D_v \cos \psi \pm \rho_l g L \sin \psi}{[\mu_l / KA_w \lambda \rho_l + C(f_v Re_v) \mu_v / 2(r_{h,v})^2 A_v \rho_v \lambda] L_{eff}} \quad (1)$$

All the symbols in the equation are explained in "Nomenclature". Here, according to prior studies, the meniscus radius of sintered spherical powder is $r_{cap} = 0.21d$ (Tien and Rohani, 1974), and the permeability of sintered spherical powder wick is $K = r_s^2 \epsilon^2 / 37.5(1-\epsilon)^2$ (Chi, 1976). From Eq. (1), the key factors affecting performance are the wick structure parameters.

The wick parameters include wick thickness, powder diameter and porosity. According to Lai's study, (Lai, 2000) the suitable wick thickness for a heat pipe with 3 mm outer diameter would be 0.5 mm. Hence, only powder diameter and porosity are analyzed here, and their effects on heat transfer capacity are revealed in Fig. 1.

As shown in the figure, the maximum heat transfer rate increases effectively with increasing porosity. Although the heat transfer capacity would also increase with increasing powder diameter, while the porosity is low, even though the powder diameter increases substantially; the maximum heat transfer capacity increases only a little. Hence, porosity is considered the key factor among the wick parameters. Higher porosity, which means more and more pores are found in the wick, would make the working fluid flow toward the evaporator more easily and hence increase the heat transfer capacity. Seeing that, this paper seeks to promote the porosity of the sintered powder wick in order to enhance the thermal performance of the heat pipe.

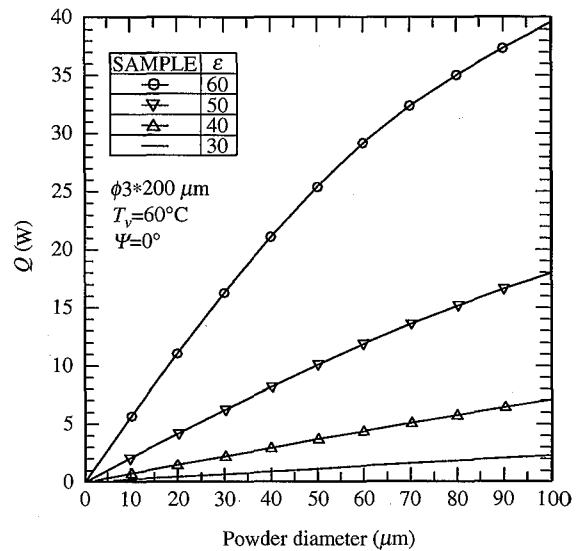


Fig. 1 Effect of porosity and powder diameter on heat transfer capacity

III. EXPERIMENTAL APPARATUS AND PROCEDURES

To increase the porosity of the sintered wick, in the present study, a pore former is mixed with copper powder. Here, dendritic powder is selected, because it has higher porosity than spherical powder. (Lai, 2000; Chan, 2001) Since the wick structure thickness is thin, the pore former must have a diameter either the same as or smaller than copper powder diameter for fear of breaking the wick structure. On the other hand, the chemical reaction between the pore former and the other materials should be also under consideration. Here, sodium carbonate (Na_2CO_3) is used as the pore former, since it has a suitable particle size (about 60~250 μm). During the sintering process, no chemical reaction between sodium carbonate and copper powder will happen. Besides, sodium carbonate can be dissolved easily by an acid solution. That is, sodium carbonate will not affect the structural strength of the wick and is easy to clean.

Since the suitable wick thickness is 0.5 mm, if the powder diameter is larger than 100 μm, the powder number in the radial direction would be less than five and might affect the structure of the wick. Hence, the copper powder with a diameter of 75 μm is chosen.

Before being filled into the pipe, both copper powder and sodium carbonate are sieved to assure the desired particle size, and then mixed together in different weight ratios. Here, a V-type mixer is used, and the demand weight ratios of pore former are 5%, 10%, 20% and 40%, respectively.

Then, the conjunction of copper tube and powder is sintered at 850°C for 30 minutes in a reduction

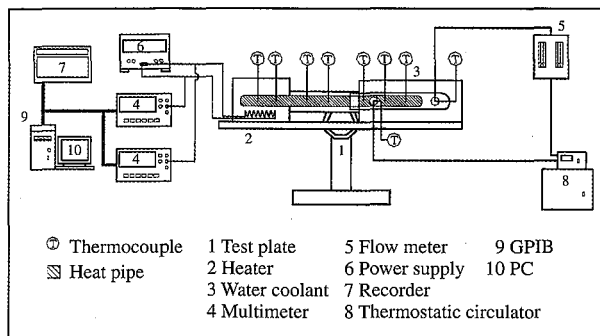


Fig. 2 Schematic of the performance testing system

atmosphere in the furnace. After being cooled, the copper tube is attached to the vacuum and filling system, and then evacuated to the pressure of 1×10^{-4} Torr. When the desired vacuum condition is achieved, a small amount of distilled water is injected into the copper tube. Through repeated tests, the optimal volume is found to be 120% of the vacant space within the wick (Huang, 2000). Then, by pinching the filling end and welding it, the copper tube is sealed, and a miniature heat pipe is ready. More detailed information about the fabrication procedures can be seen in Chan's study (Chan, 2001).

The performance of the heat pipe is tested by the testing system shown in Fig. 2. Here, AC power (6) applied to the heater (2) is controlled through a LabView program and measured with a multimeter (4). The condenser section is placed in a water coolant (3) which is connected to a thermostatic circulator (8). Here, the size of the heater is 50×50 mm; the water coolant is 110 mm in length and 15 mm in diameter. The temperature data are taken by recorder and then transferred to the computer (10) through a GPIB card (9). For heat insulation, both the evaporator and the adiabatic section are covered with asbestos. Seven calibrated T -type thermocouples are installed along the length of the heat pipe to measure the temperature distributions.

The test procedures include changing the power input to the heat pipe and the temperature of cooling water. By measuring the heat brought by water coolant, the maximum heat transfer capacity of heat pipe is decided. The equation is:

$$Q = \dot{m} C_p (T_{out} - T_{in}) \quad (2)$$

Besides, the respective average temperature of evaporator and condenser are also recorded to calculate the system thermal resistance, and the equation is:

$$R = (T_{e,avg} - T_{c,avg}) / Q \quad (3)$$

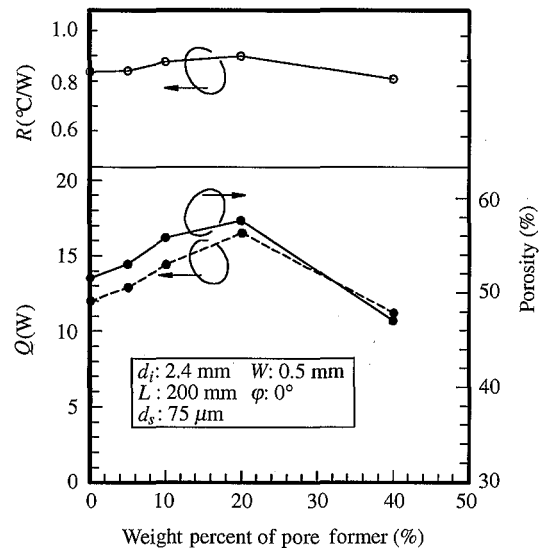


Fig. 3 The effect of mixing ratio on heat transfer rate, porosity and thermal resistance

The error analysis is conducted according to relative uncertainty analysis (Cotter, 1984). Through the analysis, for both maximum heat transfer capacity and thermal resistance, the uncertainty is estimated to be 7.2% and 7.8%, respectively (Chan, 2001).

IV. RESULTS AND DISCUSSION

In the present study, the first attempt at enhancing the performance of the heat pipe by adding pore former is made. Here, sodium carbonate powder is used to mix with dendritic copper powder and a comparison is conducted to investigate the effect of mixing weight ratio. The results are shown in Fig. 3.

As the mixing ratio increases from 0 to 20%, the porosity also increases from 51.6% to 57.7%. The porosity decreases when the mixing ratio increases further to 40%. It is because the increase of pore former decreases the weight ratio of copper powder relatively, and the sintered wick may shrink or slump. Consequently, the wick structure will be destroyed and its porosity will be lower than even an unmixed one.

When the mixing weight ratio is 20%, for a heat pipe with 3 mm outer diameter and an effective length of 200 mm, the maximum heat transfer capacity is 16.5W. Compared with the unmixed case, the performance is enhanced about 40%. Under the same geometry size, the present heat pipe approaches the best performance in the authors' knowledge. The present experimental results also show that the increase in thermal resistance is negligible when compared with the increase of heat transfer capacity.

It is necessary to check the experimental results,

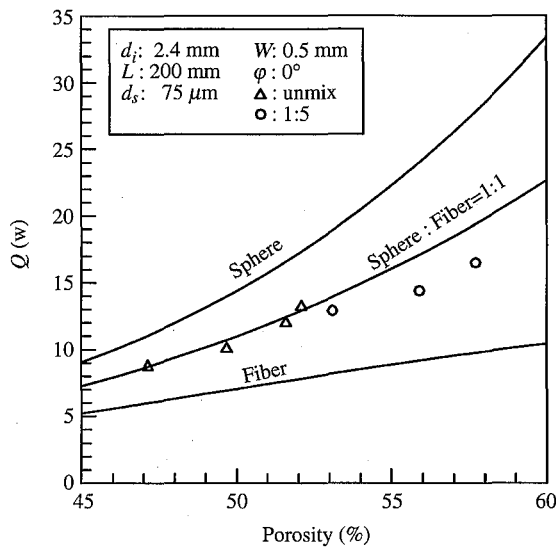


Fig.4 Comparison between the experimental results and predicted values

however, because no experimental formula for dendritic powder is found in the literature. In present paper, by using the equations proposed for both spherical and fiber powder and adjusting their proportions to unity (1:1), a modified prediction algorithm fitting the experimental results is established. (Fig. 4) Here, the meniscus radius and permeability of fiber powder are given according to the experimental formula mentioned in the literature (Lai, 2000; Brunswick Corporation, 1979).

As shown, the modified theoretical prediction agrees well with the unmixed condition. Whereas, for the mixed case, the pores generated by both copper powder and pore former are not the same as those formed by copper powder only, and larger deviations may be found.

V. CONCLUSIONS

In this study, the heat transfer performance of a sintered miniature heat pipe was enhanced successfully. Experiments were conducted to mix dendritic copper powder with pore former to enhance porosity further. Conclusions are listed as follows:

1. This study successfully uses sodium carbonate powder as a pore former and finds the optimal mixing ratio 20% to promote porosity. For the present heat pipe with 3 mm outer diameter, the heat transfer rate achieved 16.5W and the thermal resistance was 0.9°C/W. In comparison with an unmixed pipe, the performance is enhanced about 40%.
2. By synthesizing the experimental formulas of both spherical and fiber powder, a modified prediction equation was established to give a prediction on

the performance of a heat pipe, which used sintered dendritic copper powder as wick structure.

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NOMENCLATURE

A	area
C	constant
C_p	specific heat at constant pressure
d	diameter
eff	effective
f	friction factor
g	gravity
in	inner
K	wick permeability
L	length
l	liquid
m	mass
out	outer
Q	heat transfer rate
r_{cap}	meniscus radius
R	thermal resistance
Re	Reynolds number
$r_{h,v}$	hydraulic radius of vapor flow pass
r_s	pore radius
T	temperature
v	vapor
w	wick
ε	porosity
λ	latent heat of vaporization
μ	absolute viscosity
ρ	density
σ	surface tension
Ψ	angle

REFERENCES

- Ali, A., DeHoff, R., and Grubb, K., 1999, "Advanced Heat Pipe Thermal Solutions for Higher Power Notebook Computers," *Technical Paper*, Thermacore Inc, Lancaster, PA, USA.
- Brunswick Corporation, 1979, *Product Data*, Deland, FL, USA.
- Chan, J. H., 2001, "Heat Transfer Enhancement of Sintered Miniature Heat Pipe," *Master Thesis*, National Taiwan University, Taipei, Taiwan, ROC.
- Chi, S. W., 1976, *Heat Pipe Theory and Practice*, McGraw-Hill, New York, USA.
- Cotter, T. P., 1984, "Principles and Prospects for Micro Heat Pipes," *Proceedings of the 5th International Heat Pipe Conference*, Tsukuba, Japan,

- pp. 328-335.
- Dunn, P. D., and Reay, D. A., 1994, *Heat Pipes*, Pergamon, Oxford, UK.
- Faghri, A., 1995, *Heat Pipe Science and Technology*, Taylor and Francis, Washington, DC, USA.
- Fujikura Ltd, 2000, "Fujikura Thermal Technology Global Support," *Product Data*, Kyoto, Japan.
- Huang, W. H., 2000, "Fabrication and Performance Testing of Sintered Miniature Heat Pipe," *Master Thesis*, National Taiwan University, Taipei, Taiwan, ROC.
- Kim, K. S., Won, M. H., Kim, J. W., and Back, B. J., 2003, "Heat Pipe Cooling Technology for Desktop PC CPU," *Applied Thermal Engineering*, Vol. 23, No. 9, pp. 1137-1144.
- Kuzmin, G., 1994, "Oasis Cooling Packing Technology for Notebook Computers," *Proceedings of Electro'94 International Conference*, Boston, MA, USA, pp. 829-835.
- Lai, C. C., 2000, "The Impact of Wick Structure Parameters on the Performance of Sintered Miniature Heat Pipe," *Master Thesis*, National Taiwan University, Taipei, Taiwan, ROC.
- Lin, W. K., and Lu, C. C., 2000, "The Improvement of the Thermal Module System for the Notebook Computer," *Master Thesis*, National Tsing-Hua University, Hsinchu, Taiwan, ROC.
- Nguyen, T., Mochizuki, M., Mashiko, K., Saito, Y., Sanciuc, I., and Boggs, R., 2000, "Advanced Cooling System Using Miniature Heat Pipes In Mobile PC," *IEEE Transactions on Components and Packaging Technology*, Vol. 23, No. 1, pp. 86-90.
- Peterson, G. P., 1994, *An Introduction to Heat Pipes*, Wiley, New York, USA.
- Tien, C. L., and Rohani, A. R., 1974, "Analysis of the Effects of Vapor Pressure Drop on Heat Pipe Performance," *International Journal of Heat and Mass Transfer*, Vol. 17, No. 1, pp. 61-67.
- Xie, H., Ali, A., and Bhatia, R., 1998, "The Use of Heat Pipes in Personal Computers," *Proceedings of I-Therm'98, The 6th Intersociety Conference on Thermal Phenomena in Electronic Systems*, Seattle, WA, USA, pp. 442-448.

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