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# The performance of the novel vapor chamber based on the leaf vein system

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ABSTRACT

With the upgrade of the miniaturization of the electronic equipment, heat in per area increases dramatically, which leads to the strong need for a high efficient device of heat dissipation. As the result of the nature evolution, leaf vein system is an excellent structure for heat and mass transfer but has not been widely studied. Based on the leaf vein system, a conceptual structure is designed to form the wick of a vapor chamber, in which the leaf-vein-like fractal network and the micro fin-pins are used to simulate the leaf vein network and mesophyll tissue respectively. In the experiment, the leaf-vein-like structure is manufactured by chemical etching, and two different vapor chambers (diameter is 90 mm, the evaporator and condenser have the same wick structures) with and without strength boiling are compared concerning their cooling performances. The experiment result shows that when the diameter of the heating rod is 35 mm, the vapor chamber can perform good temperature uniformity and small thermal resistance with the input power $Q \leqslant 90$ W. When the deionized water is used as the working fluid, the thermal resistance of the vapor chamber is smaller than 0.3 °C/W.



## 1. Introduction

With the miniaturization, high capacity or process speed of the electronic equipments, such as the computer, LED screen or light, the heat dissipation becomes a very challenging work faced by thermal engineers because of the dramatic increase of heat per area. Many engineers are committed to the developing work of cooling device. Up to date, the heat pipe [1] is still widely used as an efficient cooling equipment, but in some circumstances, it is found difficult to undertake the cooling task with the continuous improvement of the electronic equipment. Because of the advantage of heat dissipation by the whole plane, as a more efficient cooling device, the vapor chamber (flat heat pipe) is more and more used in electronic equipment cooling. In the vapor chamber, the heat from the electronic equipment is conducted to the working fluid by the evaporator, and the working fluid evaporates into the gas fluid first, then changes into liquid and releases the heat when it arrives at the condenser, and finally the heat is taken away by forced cooling. Recent reports from different researchers show that methodologies on changing the micro structure of the wick and the overall structure of the vapor chamber have significant effect on improving the heat transfer coefficient [2–10].

Zhang et al. [3] designed a straight microchannel radiating from the center to form the wick of a vapor chamber, and obtained that the best liquid charge ratio (volume fraction of the working fluid) is 40.4% through numerical and experimental methods to evaluate the thermal performance. Cao and Gao [11] fabricated a vapor chamber in which the wick is composed of micro grooves with triangle cross section and analyzed its thermal resistance under different conditions, but found that the vapor chamber has worse temperature uniformity when the liquid charge ratio is 60%. Chen et al. [12] designed a rectangular vapor chamber with radial groove wick. The results showed that the smallest thermal resistance is 0.72 K/W and 0.69 K/W when the mass charging amounts are 1.02 g and 2.69 g respectively, and the temperature difference is 3.1 °C when the input power is 80 W. Zhang et al. [13] made a multi-scale porous copper foams work as the wick structure, and found that it can decrease the resistance and enhance the capillary pressure. Take et al. [14] fabricated the kind of roll bond aluminum vapor chamber and used it as the heat spreader for notebook computers. The experiment results showed that the vapor chamber has smallest temperature difference at the mass charging volume of 25% when R-134a and R-123 is used as the working fluid respectively. Go [15] adopted the aluminum container with etched-metal

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**Nomenclature**

| | |
|---|---|
| $L_k$ | length of $k$th level microchannel (m) |
| $W_k$ | width of $k$th microchannel (m) |
| $l$ | length ratio |
| $w$ | width ratio |
| $A_{lv}$ | contact area between liquid and vapor ($m^2$) |
| $Asl$ | contact area between solid and liquid ($m^2$) |
| $A_{sv}$ | contact area between solid and vapor ($m^2$) |
| $A_w$ | cross section area of wick ($m^2$) |
| $H$ | height of microchannel (m) |
| $D_1$ | width of the up edge of the trapezoidal (m) |
| $D_2$ | width of the bottom edge of the trapezoidal (m) |
| $F_c$ | capillary force (N) |
| $P_c$ | capillary pressure (Pa) |
| $r$ | radius of meniscus in the microchannel (m) |
| $\Delta P$ | pressure drop of the wick (kPa) |
| $R_{vc}$ | thermal resistance of vapor chamber (°C $W^{-1}$) |
| $R_w$ | radius of wick (m) |
| $T$ | temperature (°C) |
| $Q$ | heat flux (W) |
| $L$ | distance flowing through by the working fluid (m) |
| $K$ | permeability ($m^2$) |
| $V$ | velocity (m $s^{-1}$) |
| $m$ | mass flow rate (kg $s^{-1}$) |
| $y$ | Cartesian coordinate (m) |

**Greek letters**

| | |
|---|---|
| $\sigma$ | surface tension (N $m^{-1}$) |
| $\varphi$ | contact angle (rad) |
| $\beta$ | angle between bottom edge and contact line (rad) |
| $\alpha$ | angle between the side face and the bottom face of trapezoid (rad) |
| $\mu$ | dynamic viscosity (Pa s) |
| $\rho$ | density of working fluid (kg $m^{-1}$ $s^{-1}$) |
| $\Delta$ | difference |

**Subscripts**

| | |
|---|---|
| $k$ | branching level, index from 0 to $\infty$ |
| $sv$ | solid–vapor |
| $sl$ | solid–liquid |
| $lv$ | liquid–vapor |
| $ij$ | indices |
| $c$ | capillary |
| $vc$ | vapor chamber |
| max | maximum |
| $av$ | average |
| $w$ | wick |

to obtain the micro wick structure, and found that the lost thermal resistance of the vapor chamber is about 0.24 K/W at the heat load of 140 W. Lu et al. [16] tried a vapor chamber by using the high thermal conductivity and permeability graphite foam to work as the wick. They found that the vapor chamber with traditional structure can function properly at a heat flux of 80 W/cm$^2$. Tasi et al. [17] designed a prototype vapor chamber heat spreader with dimensions of $90 \times 90 \times 3.5$. The experiments showed that the temperature uniformity is affected by the inclination angles, and the smallest temperature difference is 1.96 °C when the inclination angles is 90° and the input power is 50 W. Zhang et al. [18] established a visualization experiment to investigate the performance of the vapor chamber with diameter of 70 mm, and found that the vapor chamber has a larger thermal resistance although it has good temperature uniformity. We noticed that current studies on the performance of vapor chambers mostly focus on the improvement of its cooling performances, namely, the thermal resistance and temperature uniformity, two important parameters that indicate the working performance of vapor chamber. Whereas, we also noticed that the vapor chambers mentioned by current literatures mostly carried on the conventional wick structure or inherited the basic prototypes and just made some changes locally.

In the corresponding studies on the micro structure, the kind of fractal tree-like networks, which can be seen as a bionic structure, were considered as the optimized structure of reducing the flow resistance by many researchers [19–27]. However, the fractal tree-like networks of these studies were mainly used in heat sinks (an external power is needed) and few studies could be reviewed when it was used in a vapor chamber. In nature, plants, especially those live in high temperature environment, strongly need cooling. The strategy of plant cooling is the evaporation, namely, the water evaporates into air to taking away heat when the leaf suffers the heat attack. It is not hard to find that both the vapor chamber and the plants work with the same principle, in another word, they respond to the heat attack with the same strategy. Furthermore, as the result of evolution for millions of years, the leaf structure might be regarded as an optimized structure for heat and mass transfer, which inspires us to try to design a novel wick [28]. The capillary pressure, permeability, and hydraulic resistance were calculated and compared with that of the fractal tree-like network. Actually, from the viewpoint of botanist, the leaf vein system (or vascular system) is generally leaked tubes [29,30] through which the water can permeate into the mesophyll tissue, namely the destination of water transportation. Based on that, we proposed a composite wick, which shows better performance [31] in heat and mass transfer through theoretical analysis.

As mentioned in the context, so far, there are very few studies concerning the leaf vein-like network when it is used as a wick in a vapor chamber, let alone the experimental studies. Although our earlier work [28,31] has tried to evaluate the performance from theoretical and numerical analysis, experimental studies are still waiting for deep exploring.

In present work, in order to evaluate the thermal performance of the leaf vein-like network structure when it is used as the wick of a vapor chamber composed of the evaporator, the condenser and brass pipe, an experiment is conducted to study the temperature uniformity, the thermal resistance and the permeability. The temperature uniformity is evaluated by the difference between the high and low temperature. The smaller the temperature difference is, the better the temperature uniformity will be. The thermal resistance is defined as the temperature difference between the centroidal temperature at the heating area and the reference temperature, divided by the total heat from the heat source. At the same time, the permeability is a key factor to determine the performance of the vapor chamber for that the higher the permeability is, the smaller the flow resistance will be.

## 2. The vapor chamber based on the plant leaf

Fig. 1 shows the leaf-vein-like fractal network which is used to simulate the leaf vein network. The length ratio and width ratio are defined by