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The Effect of Wick Structure and Filling Ratio to the Vapour Chamber Performance in Electronic Cooling System Using an Experimental Method

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ABSTRACT

The need for higher performance of electronic device becomes very important presently. The heat dissipated from the device at high heat flux demand better cooling system for heat removal in order to maintain the performance and reliability of the electronic device. In order to solve this problem, the vapour chamber is introduced as a part of the heat remover device. The vapour chamber in this study has an area of 64 mm × 44 mm. The vapour chamber is a two-phase closed flat chamber made of copper. Water is enclosed as the working fluid, and five types of wick structure are used in the 5 mm thickness vapour chamber. The experimental results show that the rectangular wick structure

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gives the lowest thermal resistance. The wick structure with the working fluid and the boiling phenomenon is practically effective for a 45% fill ratio.

Keywords: *Vapour chamber, Electronic cooling, Heat flux, Wick structure, Fill ratio*

Introduction

Nowadays, the application of advance, smaller, faster and high performance electronic device has become very important and has a high demand. The mean chip surface heat density is approaching 100 W/cm^2 while local heat fluxes at hot spots are much higher. Assuming heat is dissipated only from the heat sink, the total thermal resistance for a typical microprocessor package includes the conduction resistance through the chip, thermal interface resistance between the chip and the lid, conduction resistance through the lid, thermal interface resistance between the lid and heat sink base and the resistance of the heat sink. Related to those matters, dissipation of heat at a very high heat flux becomes a major concern. It is important to maintain a suggested operation chip temperature, typically around 85°C to meet the performance and reliability requirements (Tsai et al., 2008).

Least temperature gradient between the heat source and radiating components is required for effective cooling. A vapor chamber is one of the most excellent devices for effective heat transfer with the lowest thermal resistance (Mochizuki et al., 2007). Basically, the vapor chamber is a two phase heat transfer device. The vapour chamber is a sealed vacuum chamber composed of three main sections, namely, vaporization, condensation, and transportation. The heat from the heater heats up the water within the vaporization causing it to vaporize. This vapour then moves through the vacuum until it hits the condensation. Here the vapour condenses and forms back into a liquid (releasing the heat in the process); this liquid is then absorbed by the transportation (by capillary action), where it is then transported back to the vaporization and the process is repeated. As the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end (Mochizuki et al., 2007). Thus, it is a device of very high thermal conductance. Its equivalent thermal conductivity can be several hundred times than that of a solid copper device of the same dimensions (Mochizuki et al., 2007).

Mochizuki et al. (2008) notified that the computer processor's die surface requires a large space for cooling due to large heat generation and dissipation. Thus, the most effective way to transfer heat from the heat source to dissipation area is to use vapour chamber at the base. It helps to reduce thermal spreading at the base. Therefore, the cooling capacity can be increased.

There are numerous studies in the literature regarding vapour chamber. Hsieh et al. (2008) conducted a study on thermal performance of flat vapour chamber heat spread. The experiment was performed to examine the heat transfer thermal resistance of heat sources positioned in the middle of an evaporator and the thermal performance of a water filling percentage. On the other hand, Ming et al. (2009) analyzed using experimental and simulation methods on a grooved vapour chamber.

In this research, a novel grooved vapour chamber was designed. The grooved structure of the vapour chamber can improve its axial and radial heat transfer and can also form the capillary loop between condensation and evaporation surfaces. The numerical simulation results show that the thickness distribution of liquid film in the grooves is not uniform due to the pressure of vapour and liquid beside liquid-vapour interface.

Zhang et al. conducted a study on thermal management of high power dissipation electronic packages from air cooling to liquid cooling. This paper reports targeted power dissipation of 140W for electronic packages by the characterization of air cooled vapour chamber heat sink (VCHS) and liquid cooled heat sinks (LCHS). Vadakkan et al. studied on silicon/water vapour chamber as heat spreaders for microelectronic packages. A numerical study was performed to compare the thermal and mechanical performances of silicon/water vapour chambers with copper heat spreaders. In addition to thermal modeling, finite element analysis was also performed to study the impact of the proposed vapour chamber design on die stresses.

Chen et al. (2009) presented a numerical simulation on a heat sink embedded with a vapour chamber and also calculation on effective thermal conductivity of a vapour chamber. This study presents a numerical investigation of a whole set of thermal module, including a plate-fin heat sink embedded with a vapor chamber and a heat source. Wei and Sikka conducted a study on modeling of vapour chamber as heat spreading devices. It is identified that the model can predict the temperature profile fairly well as compared with the results of a detailed numerical model. A vapour chamber performance is affected by the thermal conductivity of the wick structure.

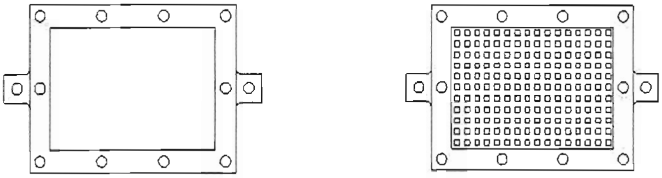
Wei provided a study on the measurement of vapour chamber performance. The thermal behavior of a vapour chamber with water as working fluid and sintered metal particles for wick structure has been experimentally determined. Results show that the film coefficient increases with heat flux in approximately linear trend. Xiao and Faghri conducted a study on a three-dimensional thermal-fluid analysis of flat heat pipes. A detailed, three-dimensional model has been developed to analyze the thermal hydrodynamic behaviors of flat heat pipes for the heat conduction in the wall, fluid flow in the vapor chambers and porous wicks. The results show that higher evaporative heat input improves the thermal and hydrodynamic performance of the heat pipe while shortening the size of heat pipe degrades the thermal performance of the heat pipe.

The main objective of the work is to study the best vapour chamber and their performance with different wick structures. The experiment also observed the temperature distribution of the vapour chamber spreaders to enhance heat spreading and reduce conduction resistance.

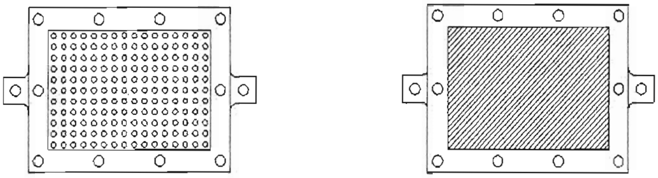
Methodology

The vapour chamber mainly consists of three parts of a bottom plate (evaporator section), a top plate (condenser section) and a spacer sandwiched between them. The bottom and top plate is made of copper. The types of structure for vapour chamber are empty, circular, rectangular, linear, and trapezium structures as shown in Figure 1. This research uses vapour chambers of approximately 64 mm × 44 mm in a span and 5 mm base thickness.

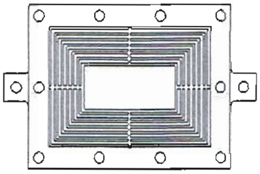
An electronic package was mimicked in the experiment as a heater (heat source), where constant heat flux of 7626.7 W/m^2 was controlled by a direct current (DC) from a digital power supply. The heat was applied from a small square of 30 mm × 30 mm, which was simulated as a heat source and placed at the center of the bottom plate. RS® heat sink compound, which has a good thermal conductivity, was pasted on the heater which was embedded into wood platform, which also served as a good thermal insulator. Figure 2 shows the cross section of the experimental setup used in the present study.



(a) Empty (b) Rectangular



(c) Circular (d) Linear



(e) Trapezium

Figure 1: Types of Wick Structure of Vapour Chamber

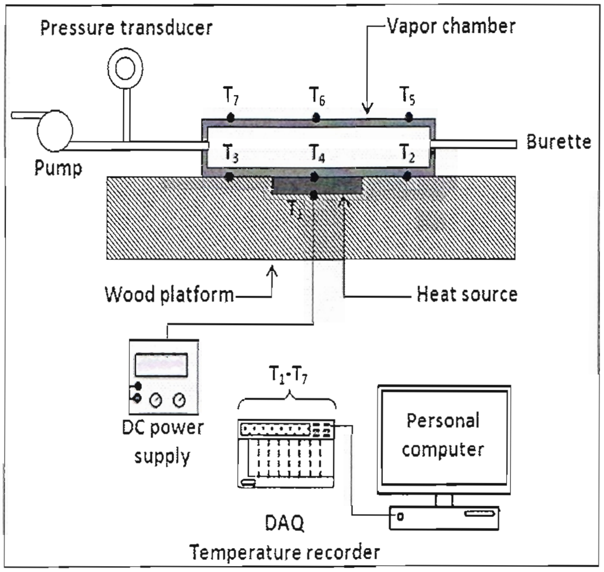


Figure 2: Cross Section of the Experimental Vapour Chamber Set-Up

The heat source temperature was measured by the thermocouple soldered underneath the heat source. Six thermocouples were soldered to the vapour chamber at six different locations. Three thermocouples were positioned at the top and bottom of vapour chamber respectively, and were arranged in series. The reading of temperatures from thermocouples were displayed and recorded into the computer by means of the data logger (ADVANTECH DAQ System) in order to evaluate the performance of the vapour chamber.

Vacuum pump was used to suck out the air inside in the vapour chamber till it was completely under the vacuum condition where it was confirmed through a vacuum pressure transducer. The working fluid was charged by using a burette where the amounts of charged working fluid were 25%, 35% and 45 % of the total inside volume of the vapour chamber respectively.

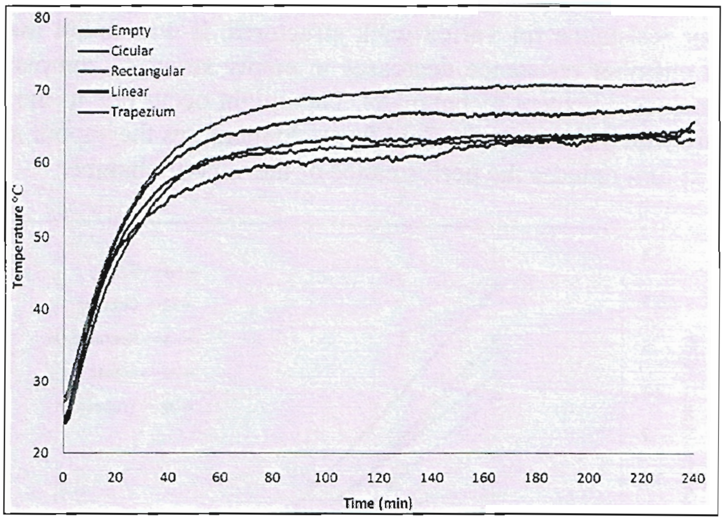
Water was selected as the working fluid due to its high surface tension which could generate a large capillary force that can allow operation in any orientation. In addition, it also has high latent heat of vaporization which will spread more heat with less fluid flow. This liquid test was carefully prepared and kept clean to avoid contamination. The room temperature was maintained at 24°C so that the loss of heat from the test section was almost constant throughout the experiment.

Results and Discussion

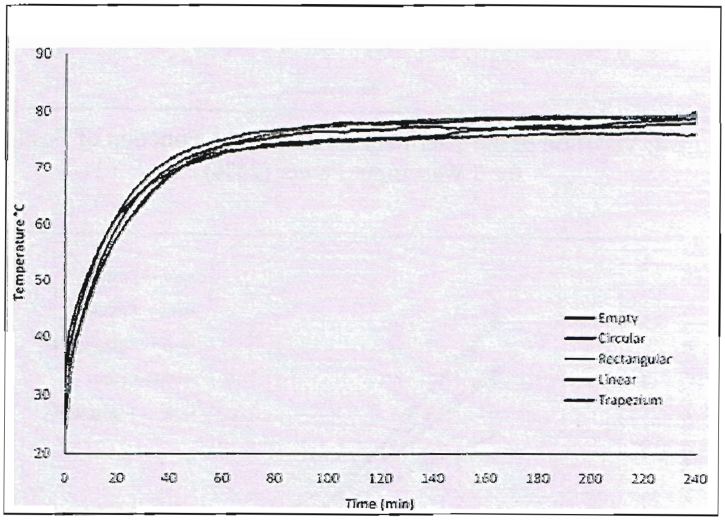
The effects of wick structures on giving the lowest thermal resistance were investigated. Figure 3 shows the examples of variation of the maximum evaporator and condenser as a function of time. The temperatures was measured with the heat flux of 8782W/m^2 and it reaches the steady state at $t = 140$ min.

Figure 4-6 shows the thermal resistance for each wick structure with different filing ratio as a function of location. From the experiment, the wick structure of rectangular led to the smallest overall thermal resistance which are 1.22, 0.49 and 0.05°C/W at 7 W, and the maximum evaporator temperature were 65°C, 64°C and 70°C respectively.

With respect to the fill ratio of the working fluid in a vapour chamber, a preferable quantity is found to be 45%. It is attributed that, for a smaller fill ratio, the condensed liquid is insufficient to sustain the evaporation region and evaporator temperature soars to a situation known as the dry outcondition.



(a)



(b)

Figure 3: Variation of the Maximum (a) Evaporator Temperature (b) Condenser Temperature; as a Function of Time for 7 Watt Input Power

When the heat was transferred from a smaller area to a larger one, the highest temperature occured at the center and gradually decreased towards the periphery. This phenomenon known as the spreading resistance, hinders the heat from being transferred to the environment.

However, discrepancies were observed on heat dissipation on vapour chamber resistance for varied wick structures. It was found that the vapour chamber resistance decreases in empty structure compared to the remainders (except rectangular). This might occur due to the wick structure which obstructs the fluid flow and increases the vapour space, which in turn reduces the performance of the vapour chamber.

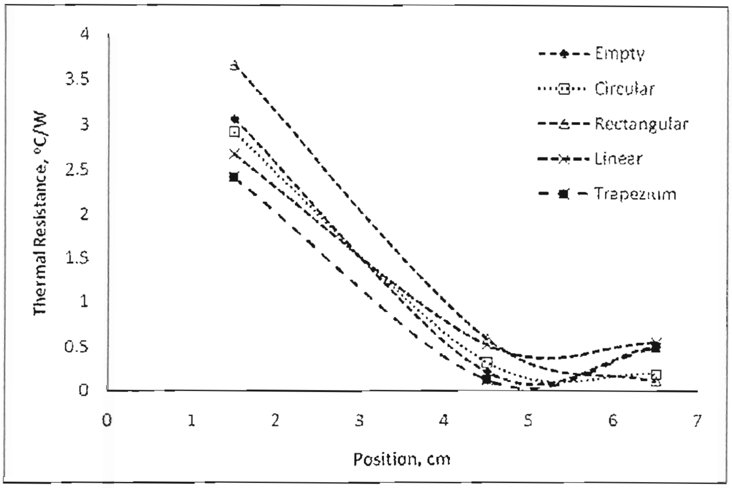


Figure 4: Variation of the Thermal Resistance as a Function of Position for 7 Watt Input Power (25%)

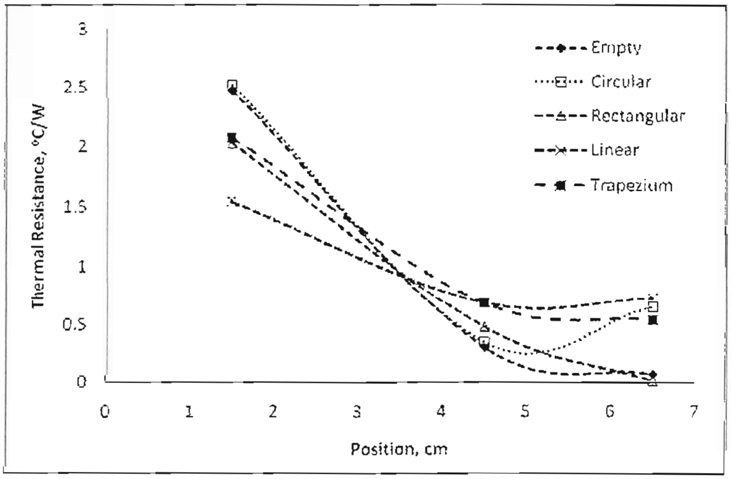


Figure 5: Variation of the Thermal Resistance as a Function of Position for 7 Watt Input Power (35%)

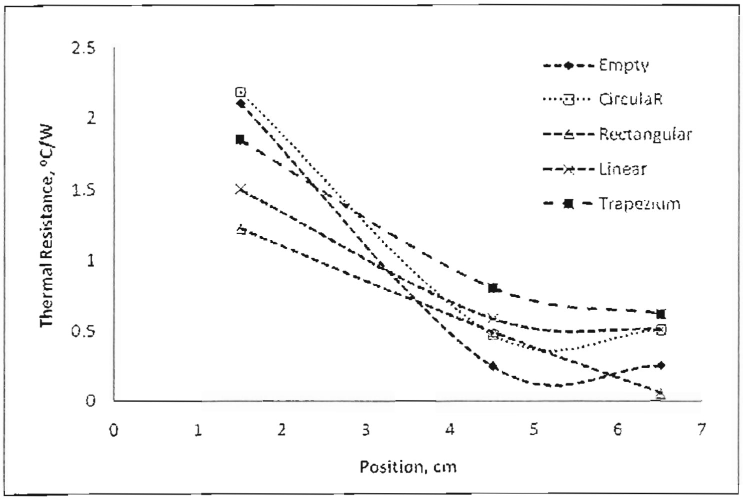


Figure 6: Variation of the Thermal Resistance as a Function of Position for 7 Watt Input Power (45%)

Conclusion

Five different designs of vapour chamber which are empty structure, circular structure, rectangular structure, linear structure and trapezium structure have been studied for their effect on giving the lowest thermal resistance. From the experiment, it clearly shows that the geometrical shape of wick structured played a significant contribution to the thermal resistance of the vapour chamber. The design that has the lowest thermal resistance is the rectangular structure followed by linear structure, trapezium structure, circular cubic structure and the last is the empty structure. The wick structure with the working fluid and the boiling phenomenon is practically effective for a 45% fill ratio.

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