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Thermal resistance analysis of central processing unit cooling system based on cascade straight heat pipe

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Abstract. The development of electronic device is moving toward Smart Technologies, But, the idea of Smart Technologies brings a new problem to heat flux management because the device produces more heat to be banished, especially CPU. So to solve those problems, heat pipe was chosen to be an alternative solution. Heat pipe was hoped to be a passive cooling system technology, but further research shows that goal can't be achieved, due to the high condenser temperature, and the cooling system still needs fan support to banish the heat quickly from the device. So, this paper will discuss a research about new cascade system for heat pipe with variations of heat load and amount of condenser. The results were compared to non-cascade heat pipe to know its thermal performance, especially in thermal resistance. The results show that application of cascade straight heat pipe is effective to solve high condenser temperature problem. In thermal resistance, non-cascade heat pipe still better, but the differences only around 0.3-0.37 °C/W. For the comparison between single and double condenser, double condenser shows better thermal performance. In the end, this cascade heat pipe technology is effective to be applied for central processing unit cooling system technology.

1. Introduction

The development of electronic device's technologies has been developed toward the trend of Smart Technologies, which is the technologies become smaller in dimension, but have to be followed by some improvements in performance [1]. One of the technologies that affected by this trend is a computer, specifically its Central Processing Unit (CPU).

Smart technologies are a nice idea, but it brings a new problem to the heat flux management of electronic devices and CPU specifically. Smart technologies increasing the heat that needs to be banished from the CPU system to maintain its performance and lifetime. So, to solve this problem, the CPU system needs a cooling system with a high performance, slow dimension, and may works passively without any electrical energy supply [2,3].

If we see from all cooling system's properties that have been mentioned before, the heat pipe can be chosen to be an alternative solution for cooling system problems, because heat pipe applies the concept of natural convection phenomenon as its working method. So, the heat pipe can work passively and also have a better performance compared to the previous method that exists before.

The heat pipe is a heat exchanger device which generally made of a copper pipe combined with wick and coolant to move the heat from evaporator side toward condenser side. The performance of a heat pipe is affected by some parameter, such as heat load, heat pipe's material, wick's porosity, and permeability, coolant's amount and type, and the geometry of heat pipe itself [4].



The working method of a heat pipe starts from evaporator receiving some heats from the heat source. And then, the heat will evaporate coolant of the heat pipe. Based on the theory of convection, the vapor will flow naturally to the condenser part of the heat pipe. In the condenser, the heat saved in coolant's vapor will be banished to the surround and then the coolant will be back to the liquid phase. The last phase, the coolant will be flowing back to the evaporator helped by the wick. And the cycle will continue. The simple illustration of heat pipe mechanism can be seen in Fig. 1.

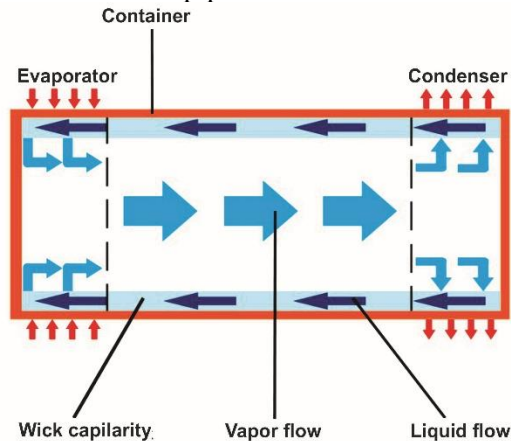


Figure 1. Schematic of a heat pipe [5].

Further, Putra, et al. [6] has been conducted an experimental study on sintered powder wick loop heat pipe. Putra, et al. [4] done a research on thermal resistance of a sintered powder wick heat pipe with the variation of concentration and loading fluid of nanofluids. Septiadi, et al. [7] has done a characterization of screen mesh wick heat pipe which loaded with nanofluid as a passive cooling system. But, all those research find out that heatpipe still produce a high outlet temperature from condenser which needs to be banished fastly from the system to maintain its performance and lifetime. Hence, a fan still used to banish the heat from condenser faster. So, the main purpose of heat pipe application has not been achieved yet.

But later, Putra et al. [8] develop a cascade system for heat pipe by combining two loop heat pipes for CPU cooling system. Then, it was reported that the use of a cascade system for heat pipe was succeeded to reduce the outlet temperature at the condenser and reduce its thermal resistance up to 17.6%.

So, this research tries to develop a new heat pipe's cascade system by combining two straight heat pipes as a CPU cooling system technology. This research conducted to gain more information about the thermal performance of a cascade straight heat pipe by analyse its thermal resistance. So, a better evaluation of its thermal performance can be achieved.

2. Methodology

Cascade straight heat pipe was designed by combining two straight heat pipe, and it is divided into two level, they are level I heat pipe consist of first evaporator and condenser and level II heat pipe consist of second evaporator and condenser, and both of them are connected at first condenser and the second evaporator. The heat pipe is made of copper, water was used as its coolant, and it used sintered powder wick. Fig. 2 shows the design of cascade straight heat pipe.

The data was taken with two types of cascade straight heat pipe, they are cascade straight heat pipe with a single condenser and double condenser. CPU Core i5 2.90 GHz was used as the heat source for this experiment. The data was taken under two condition of the CPU, they are an idle condition with 10W heat load and maximum condition with the 48W heat load. The data of distributed temperature was taken by connecting 4, 5, and 8 type-K thermocouples to not cascade heat pipe, cascade straight heat pipe single condenser, and double condenser, respectively. For the nation cascade heat pipe, a thermocouple was connected to processor's surface, condenser, heatsink, and environment. Meanwhile,

for the cascade heat pipe, a thermocouple was connected to processor's surface, first and second evaporator part, first and second condenser part, and environment. Schematic diagram of the experiment can be seen in Fig. 3.

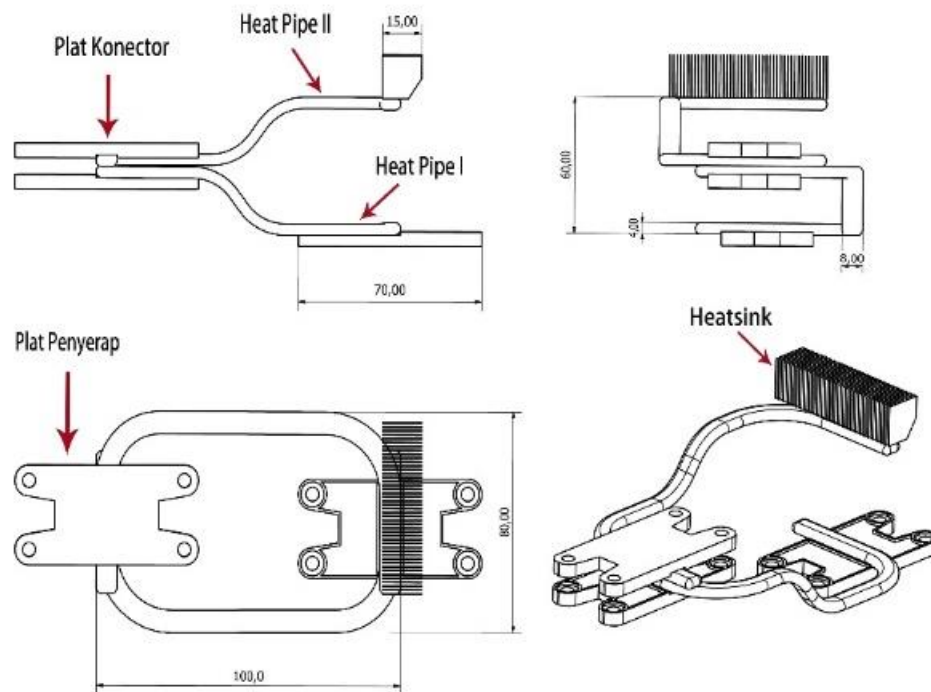


Figure 2. Design of cascade straight heat pipe.

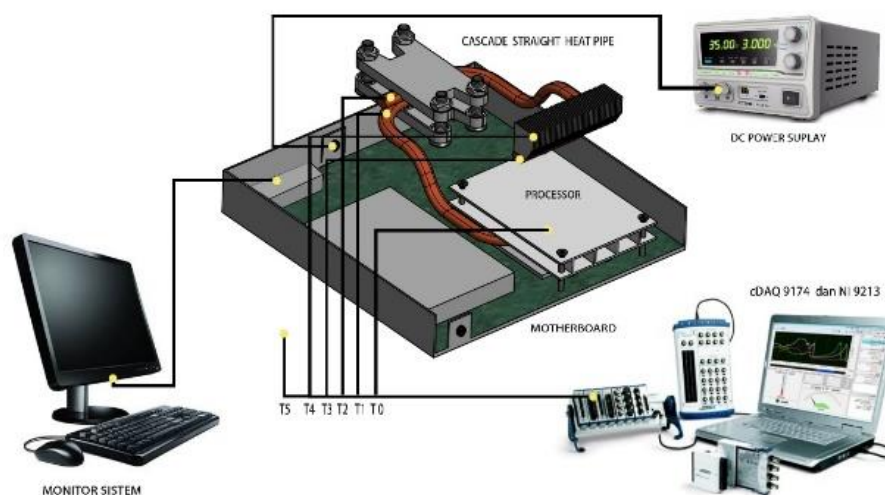


Figure 3. Schematic diagram of the experiment.

Thermal resistance calculation in this research was done for each of heat load (10W and 48W). The calculation was done in three steps. The first one was thermal resistance for the whole level I heat pipe system, followed by calculation for whole level II heat pipe system, and the last one was the calculation of the whole system of cascade straight heat pipe. The equation for each calculation is presented in equation (1), (2), (3), (4), and (5).

$$R_{hps} = \frac{T_e - T_c}{Q} \quad (1)$$

$$R_{hpl} = \frac{T_{el} - T_{cl}}{Q} \quad (2)$$

$$R_{hpII} = \frac{T_{eII} - T_{cII}}{Q} \quad (3)$$

$$R_{hp,csc} = \frac{T_{el} - T_{cII}}{Q} \quad (4)$$

$$R_{hp,cdc} = \frac{T_{el} - (T_{cII} - T_{cIII} / 2)}{Q} \quad (5)$$

3. Results and discussion

In order to analyze the thermal resistance of cascade straight heat pipe. The temperature data from four, five, and eight measure points for non cascade heat pipe and both cascade straight heat pipe single and double condenser respectively has been taken. All data can be seen in Table 1, 2, and 3, respectively. Looking at table 1, 2, and 3, we can say that the purpose of cascade straight heat pipe system to reduce the outlet temperature at the condenser are succeed. The outlet temperature difference is quite good, it is up to 19.6% for cascade straight heat pipe single condenser and 21.42% for the double condenser. It can happen because by using a cascade system, the heat is taken from processor going through two-step of the cooling process, in level I and II heat pipe.

Table 1. Temperature data for non-cascade heat pipe

Heat load (Watt)	T _{ev-nc}	T _{c-nc}	T _{hs-nc}	T _{env-nc}
Idle 10 Watt	69.10	59.99	53.32	26.13
Max 48 Watt	69.68	63.06	60.85	25.64

Table 2. Temperature data for cascade straight heat pipe single condenser

Heat load (Watt)	T _{ev1-cs}	T _{c1-cs}	T _{ev2-cs}	T _{c2-cs}	T _{hs-cs}	T _{env-cs}
Idle 10 Watt	66.36	53.03	45.32	40.39	38.38	25.91
Max 48 Watt	68.19	46.25	45.48	43.66	39.73	26.23

Table 3. Temperature data for cascade straight heat pipe double condenser

Heat load (Watt)	T _{ev1-cd}	T _{c1-cd}	T _{ev2-cd}	T _{c2-cd}	T _{ev3-cd}	T _{c3-cd}	T _{hs-cd}	T _{env-cd}
Idle 10 Watt	65.21	54.00	49.57	45.64	42.3	38.57	36.20	24.30
Max 48 Watt	65.44	54.35	49.74	48.20	45.8	39.49	36.69	24.39

By using equation number (1), (2), and (3). Thermal resistance calculation for non-cascade heat pipe, level I, and level II cascade straight heat pipe was done. Based on Chen et al. [9], the highest temperature was produced by temperature at the evaporator and then followed by temperature at the condenser. That is the reason why the temperature used for calculating thermal resistance of cascade is temperature at the first evaporator and the temperature at the last condenser. The comparison result for non-cascade heat pipes, level I's, and level II's cascade straight heat pipe is showed in Fig. 4.

As we can see in Fig. 4. (a) the trends of the data are the same, the more heat load was supplied to the heat pipe, the thermal resistance of the heat pipe was decreased. This has been mentioned before in

Chen et al. [9] research, they also found that thermal resistance of heat pipe was decrease as the heat load supply increasing. But it will only happen until heat pipe reach its maximum heat load, after that the thermal resistance was increased as the heat load supply increased. It could be happened due to the effect of dry out. We also can see in the figure that thermal resistance value for level II heat pipe when Q_{in} 10W is so small compared to thermal resistance of non-cascade heat pipe and level I cascade straight heat pipe, it happened because when heat load received by heat pipes in the first evaporator is 10W, actually the heat load received by level II smaller than 10W. Hence, level II heat pipe haven't received the heat maximally. So, all the coolant inside level II heat pipe hasn't fully evaporated yet. It makes level II heat pipe wasn't work in its real performance.

The differences between thermal resistances of level I heat pipe and non cascade heat pipe at 10W and 48W heat load are between 0.3-0.4 °C/W. Meanwhile, the differences between thermal resistance of level II heat pipe and non cascade heat pipe at 10W and 48W heat load are between 0.11-0.17 °C/W. And when thermal resistance for level I and level II heat pipe compared to each other, the difference are bigger, specially at 48W heat load, the differences are between 0.43-1.26 °C/W. Author's considered that thermal resistance data for level II heat pipe are too small, it can be happened because Q used in level II heat pipe thermal resistance's calculation was considered the same with level I heat pipe. Meanwhile, actually heat load received by level II heat pipe of course smaller than the first received by level I heat pipe.

To see the effectiveness of the whole cascade heat pipe system. A calculation was done by following equation (4) and (5). The result of the calculation was compared with thermal resistance calculation for the non-cascade straight heat pipe. And the comparison is showed in Fig. 4 (b).

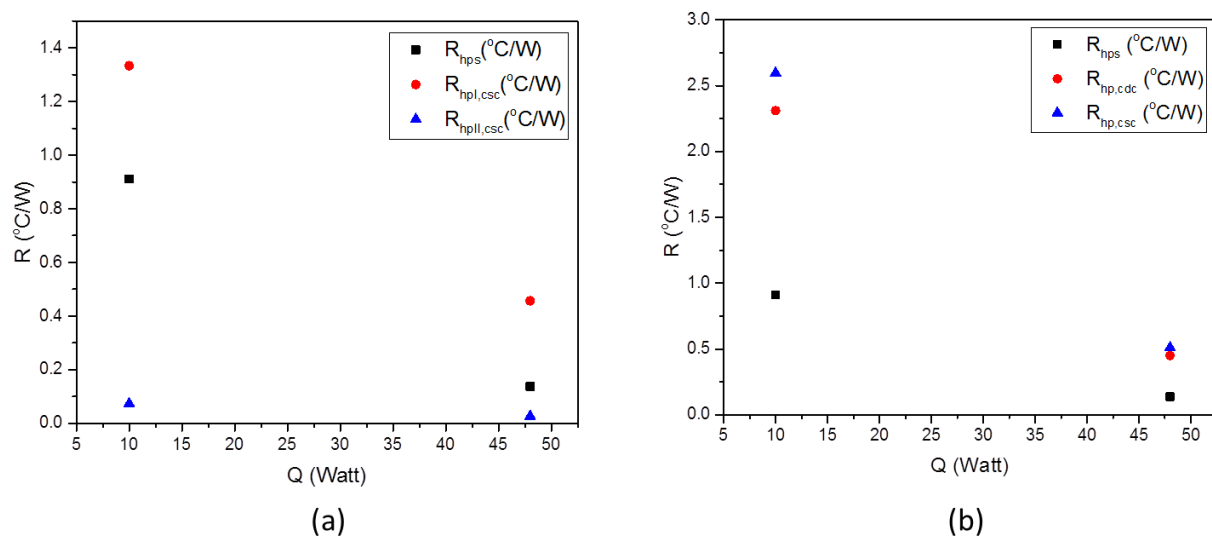


Figure 4. (a) Thermal resistance comparison of non-cascade heat pipe, first level, and second level cascade straight heat pipe, (b) Thermal resistance comparison of the non-cascade straight heat pipe, cascade straight heat pipe single condenser, and cascade straight heat pipe double condenser.

We can see in Fig. 5 that thermal resistance for non-cascade heat pipe was smaller than thermal resistance for the cascade system heat pipe. It was normal because there are more resistances element in the cascade system heat pipe compared to the non-cascade heat pipe. In non-cascade heat pipe, the heat received by heat pipe only get through three-steps of heat transfer. The first one in evaporator from the heat source by conduction, move the the coolant by convection and then move to the condenser surface by conduction. Meanwhile in cascade straight heat pipe, the heat received by heat pipe need to get through twice-steps of heat transfer compared to non-cascade heat pipe. The thermal

resistance network comparison for non-cascade and cascade heat pipe can be seen in Fig. 5 (a) and 5 (b), respectively.

From Fig. 4 we also can see that when heat pipe receives 10 W of heat load, thermal resistance for cascade heat pipe and non-cascade heat pipe have a quite big difference, the difference are ± 1.7 °C/W for cascade heat pipe with single condenser and ± 1.4 °C/W for cascade heat pipe with double condenser. It happened because when cascade heat pipe receives only 10W of heat load, it hasn't fully worked yet, especially for the level II heat pipe because the coolant used in the heat pipe hasn't fully evaporated yet. So, at that time heat transfer that happened in level II heat pipe wasn't in its true performance, and it also affected the performance of whole cascade heat pipe systems.

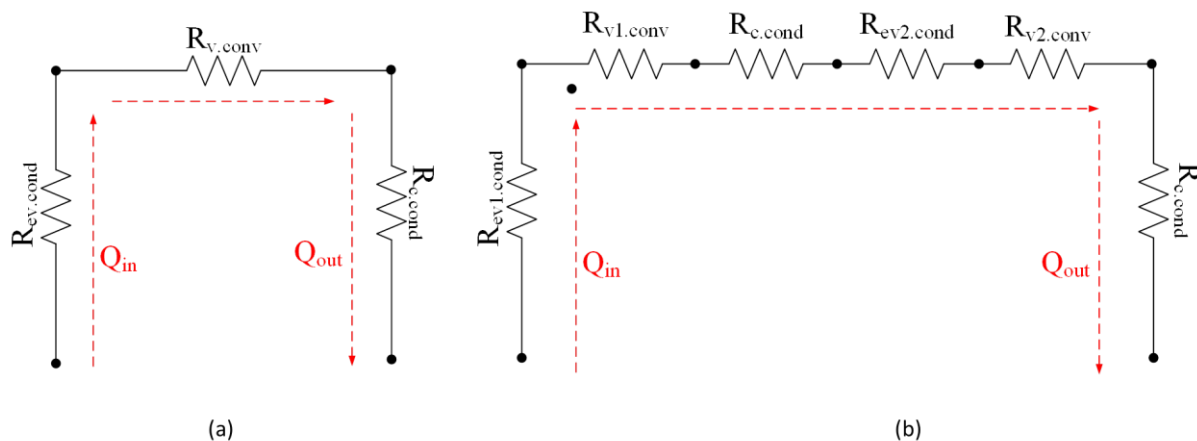


Figure 5. (a) Thermal resistance network for non-cascade heat pipe, (b) thermal resistance network for cascade straight heat pipe.

The thermal resistance of cascade straight heat pipe double condenser in 10W heat load was quite better than the cascade straight heat pipe single condenser, the difference is ± 0.287 °C/W. Meanwhile, in 48W heat load, cascade straight heat pipe with double condenser only slightly better than the one with single condenser, the difference is only ± 0.062 °C/W. It can be happened because of the effect in using two heat pipes as its level II heat pipes, so the heat has to get through more cooling process than the one with a single condenser.

4. Conclusion

From the research, it was found:the cascade straight heat pipes are effective to reduce the outlet temperature at condenser part until range between 19-25 °C. Even the differences are not so big, but we can say that based on the experimental result, cascade straight heat pipe double condenser has better cooling performance than the one with one condenser only.

Acknowledgments

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