Central processing unit based on cascade straight heat pipe

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Abstract. Smart technologies are the scientific knowledge application that develops into computer technology. Central Processing Unit (CPU) is a computer hardware that carries out the computer program instructions. The CPU technology development is very fast with the impression of smaller dimensions yet maintain its performance and efficiency, this results in a heat flux or overheating that should be reduced and even removed from the CPU system to maintain the CPU performance and life because the overheating could potentially damage and slow down the computer work. To solve the CPU heat flux problem, we use heat pipes as the cooling system, because of its ability to transfer heat and contribute to the high outlet temperature in the condenser. The cascade heat pipe design is made by combining two heat pipes into one. The design is expected to be able to reduce the processor temperature by 2.74°C at the idle condition, 1.48°C at maximum conditions, and condenser section by 14.94°C at the idle condition, and 21.12°C at maximum condition. Cascade heat pipe with double condenser reduce processor temperature by 3.89°C at the idle condition, 4.24°C at the maximum condition, condenser section by 17.12°C at the idle condition and 24.16°C at maximum condition lower than the non-cascade cooling system.

1. Introduction

Central Processing Unit (CPU) is an important hardware of a computer which controls the instruction of a computer program. Nowadays, CPU technology has been developed towards Smart Technologies which has a better performance with smaller dimension [1]. The development of Smart Technologies affected the heat flux and overheating which are produced by CPU. Most electronic devices produced more than 100 W/cm² heat flux which needs to be removed from the CPU system to maintain its performance and life [2].

Some research has been done to solve the heat flux management problem, such as application of heat pipe using biomaterial wick as cooling system [3], application of heat pipe as cooling system integrated with sintered powder and screen mesh wick [4], potential of both nanofluids and hybrid nanofluids as heat pipe’s coolant such as Al₂O₃-water, Al₂O₃-ethylene glycol, TiO₂-water, TiO₂-ethylene glycol, and ZnO-ethylene glycol [5] have been done to improve the performance of heat pipe to solve the CPU’s heat flux management problem.

The heat pipe is a device used in transferring the heat from one place to another which is hollow, closed, evacuated pipe containing a working fluid (coolant). The heat pipe is divided into three sections: evaporator, adiabatic and condenser section [6]. The heat pipe is generally made by aluminum, cooper or nickel coated cooper. In the inner wall of the heat pipe contains capillary pipes (wick) which have a function as a track of the coolant from condenser back to the evaporator. After
the coolant evaporates in the evaporator, the vapor flows into the condenser and it condenses at this section, so the coolant flows back into the evaporator through the wick [7].

![Diagram of heat pipe](image.png)

**Figure 1.** Heat pipe’s work principal

However, a good heat transfer performance of a heat pipe affects the outlet temperature level at the condenser [8]. So, Putra et al. [9] have done a research to solve the high outlet temperature at the condenser by designing a cascade heat pipe by combining two loop heat pipes. It is reported that the application of cascade system was succeeded on reducing the temperature at the condenser and reduce thermal resistance up to 17.6%.

Cascade heat pipe consists of two evaporators (level I evaporator at the first heat pipe and level II evaporator at the second heat pipe) and two condensers (level I condenser at the first heat pipe which is connected to level II evaporator and level II condenser at the second heat pipe). The principle of cascade loop heat pipes are not so different with single heat pipe, where in single heat pipes, there is only one cooling process, but in cascade heat pipe, there are two cooling processes in level I condenser and level II condenser, so the outlet temperature at the last condenser will be smaller than the one in single heat pipe.

2. **Methodology**

This research was done by the experimental method through several steps. The first step was designing the cascade straight heat pipe model with a single and double condenser, then the next step was the experiment to find the temperature of the processor and condenser.

2.1. **Heat pipe design**

In this step, the design of cascade straight heat pipe with single and double condenser was made by a flat cooper pipe with 8 mm width, 4 mm thick and 100 mm length for the first heat pipe and the second heat pipe was a flat cooper pipe with the same width to the first heat pipe. The design size was made by considering the heat pipe work limits and the CPU and the processor’s surrounding area. The first heat pipe was functioned as the evaporator which absorbed heat from the processor. One of the ends of the first heat pipe was equipped by a thermal contact plate made by Cooper with the dimension of 40 mm x 40 mm, the second heat pipe was equipped by fins.
2.2 Experimental setup

In the step of the performance experiment of CPU cooling system based on cascade straight heat pipe was done on the Central Processing Unit (CPU) Core i5 2,90 GHz which is a new manufacturer and widely used, it also gave an idle load which was the CPU load condition without operation, and the maximum condition was when the CPU was being operated. The performance of the cascade straight
heat pipe cooling system was observed by putting 5 K-type thermocouples on the single condenser heat pipe and 8 K-type thermocouples on the double condenser heat pipe. Thermocouples were put on the surface of the processor, evaporator of the first and second heat pipe, and condenser of the first and second heat pipe.

3. Result and discussion

3.1 The temperature distribution of non-cascade CPU cooling system

Figure 4 (a) shows the temperature comparison of non-cascade at the 10 Watt idle condition. From the shown image, there is a dramatic rise of temperature from 0 seconds to 800 seconds, after that the temperature is steady, in a steady state, the processor temperature (Evaporator) reaches 69.10 °C and the outlet temperature of the condenser reaches 59.99 °C, and the temperature of the heat sink reaches 53.32 °C.

Non-cascade temperature distribution with a processor loading of 48 Watts or at maximum conditions can be specified in Figure 4 (b), the figure shows that the temperature rise drastically starts from 0 seconds to 800 seconds, after that the temperature is steady. In a steady state, the processor temperature (Evaporator) reaches 69.68 °C and the outlet temperature at the condenser reaches 63.06 °C, and the temperature at the heat sink reaches 60.85 °C.

![Figure 4](image)

**Figure 4.** (a) Temperature distribution of non-cascade cooling system at the idle condition, (b) Temperature distribution of non-cascade cooling system at maximum condition

3.2 The temperature distribution of cascade straight heat pipe with a single condenser

Figure 5 (a) shows the temperature distribution of a cascade straight heat pipe with a single condenser at the 10 Watt idle conditions. From the shown image, it can be seen that the temperature rise drastically from 0 seconds to 800 seconds, after that the temperature is in the steady state, the processor temperature (Evaporator) reaches 66.36 °C and the outlet temperature at the condenser reaches 53.03 °C, and the temperature at the heat sink reaches 38.38 °C.

The temperature distribution of a cascade straight heat pipe with a single condenser at a maximum condition of 48 Watts can be seen in Figure 5. (b). The figure shows the temperature rise drastically starts from 0 seconds to 800 seconds, after that the temperature is steady. In the steady state, the
processor temperature (Evaporator) reaches 68.19 °C and the outlet temperature of the condenser reaches 43.66 °C, and the temperature at the heat sink reaches 39.73 °C.

Figure 5. (a) Temperature distribution of cascade straight heat pipe with a single condenser at the idle condition, (b) Temperature distribution of cascade straight heat pipe with a single condenser at maximum condition

3.3 The temperature distribution of cascade straight heat pipe with a double condenser

Figure 6. (a) Temperature distribution of cascade straight heat pipe with a double condenser at the idle condition, (b) Temperature distribution of cascade straight heat pipe with a double condenser at maximum condition

Figure 6 (a) shows the temperature distribution of the cascade straight heat pipe with a double condenser at the idle condition of 10 Watts. The figure shows a dramatic rise in temperature from 0 seconds to 800 seconds, after that the temperature is steady. In the steady state, the processor temperature (Evaporator I) reached 65.21 °C and the outlet temperature of condenser 3 reached 38.57 °C, and the temperature of the heat sink reached 36.20 °C.
The temperature distribution of the cascade straight heat pipe with a double condenser at a maximum condition of 48 Watts is seen in Figure 6 (b). The figure shows that the temperature rise drastically starts from 0 seconds to 800 seconds, after which the temperature is steady. In the steady state, the processor temperature (Evaporator I) reaches 65.44 °C and the outlet temperature in condenser 3 reaches 39.49 °C, and the temperature at the heat sink reaches 36.69 °C.

3.4 Processor operational temperature of CPU cooling system

From the graph analysis that has been done then the calculation of the CPU cooling system design used will be done based on the operating temperature at idle and maximum loading, the condenser operating temperature is shown in the form of a diagram in Figure 7. CPU cooling system based on cascade straight heat pipe is able to reduce the operational temperature of the processor below 80 °C which is 66.36 °C for design with a single condenser and 65.21 °C for design with the double condenser. Cascade heat pipe with single condenser can reduce processor temperature to 2.74 °C at idle conditions, and 1.48 °C at maximum conditions lower than the non-cascade cooling systems. Cascade straight heat pipe with the double condenser is able to reduce processor temperature to 3.89 °C in idle conditions, and 4.24 °C at maximum conditions lower than the non-cascade cooling systems.

![Figure 7. Comparison of non-cascade, single condenser and double condenser design processor operational temperature](image)

The lower result of the processor temperature decrease happened because the cascade straight heat pipe with single and double condenser model absorb the processor heat twice, but the non-cascade model only absorb the heat once. According to the design of cascade straight heat pipe, the first level heat pipe functioned as the evaporator which absorbs heat from the processor, and the second level heat pipe absorbs the outlet heat from the first heat pipe and release it from its condenser, it makes the cooling system with cascade straight heat pipe is better than the non-cascade cooling system for its ability to remove more heat from the processor.

3.5 Condenser operational temperature of CPU cooling system

From the graph analysis that has been done, the calculation of the efficiency of the use of CPU cooling system design based on the operating temperature at idle and maximum loading, the condenser operating temperature is shown in the diagram shown in Figure 8. CPU cooling system based on cascade straight heat pipe is able to reduce the condenser operational temperature below 40 °C which is 38.38 °C for the design with a single condenser and 36.20 °C for design with the double condenser.
The condenser of cascade straight heat pipe with the single condenser is able to reduce the outlet temperature in the condenser section to 14.94 °C at idle conditions, and 21.12 °C at maximum conditions lower than the non-cascade cooling systems. The condenser of cascade straight heat pipe with the double condenser is able to reduce the outlet temperature in the condenser section to 17.12 °C at idle conditions, and 24.16 °C at maximum condition lower than the non-cascade cooling systems. Percentage of condenser temperature decrease at idle loading using CPU cooling system based on cascade straight heat pipe of each design to the temperature non-cascade condenser are 28% for cascade straight heat pipe with a single condenser and 32% for the double condenser. And the maximum loading of each design is 35% for design with a single condenser and 40% for the double condenser.

The lower result of the condenser outlet temperature happened because of the continued absorption of the cascade straight heat pipe with single and double condenser model where the second level heat pipe absorbs the heat form the first level heat pipe affects the lower temperature of the second heat pipe, while the non-cascade model which only absorbs the heat once affects the higher condenser temperature. This makes the cooling system with cascade straight heat pipe is better than the non-cascade cooling system.

4. Conclusions
CPU cooling system based on cascade straight heat pipe with single condenser can reduce the processor temperature at idle condition of 10 Watt by 2.74 °C and at a maximum loading condition of 48 Watts can reduce processor temperature by 1.48 °C, and reduce the condenser temperature at idle conditions of 10 Watts to 14.94 °C and at a maximum loading condition of 48 Watt can reduce the condenser temperature to 21.12 °C lower than the non-cascade cooling system. CPU cooling system based on cascade straight heat pipe with double condenser can reduce the processor temperature at idle condition of 10 Watt by 3.89 °C and at a maximum loading condition of 48 Watt can reduce the processor temperature by 4.24 °C, and reduce the condenser temperature at idle condition of 10 Watt to 17.12 °C and at a maximum loading condition of 48 Watt can reduce the processor temperature to 24.16 °C lower than the non-cascade cooling system. The use of cascade straight heat pipes is better than the non-cascade because it can reduce more temperature of the processor and the temperature of
the heat sink. The use of the CPU cooling system on the processor using a cascade heat pipe must adjust to the size of the heat absorption area of the CPU, both in terms of processor size and CPU size. In the research action, the use of cascade heat pipes can be implemented by using a fan/cooling fan on the heat sink.

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