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CASCADE STRAIGHT HEAT PIPE FOR COMPUTER COOLING SYSTEM WITH NANOFLUID

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ABSTRACT

Computer Central Processing Unit (CPU) technology is being developed rapidly for better work performance together with smaller size. This technology development produces significant heat flux increase on the processor. In this paper, a cascade straight heat pipe (CSHP) is created for a better CPU cooling system which is a fully passive system using nanofluids and hybrid nanofluid as the working fluid. Heat loads were given to the CSHP at 10 watts, 20 watts, 30 watts, and 40 watts, respectively. Based on the experiment's result, the CSHP with Al_2O_3-TiO_2-water working fluid showed the best performance, decreasing 41.872% of the simulator plate temperature at maximum load while also having the highest condenser output temperature. The CSHP with Al_2O_3-water working fluid decreased 35.243% of the simulator plate temperature. The CSHP with water working fluid decreased only 28.648% of the simulator plate temperature and had the lowest condenser output temperature. The CSHP with Al_2O_3-TiO_2-water showed the lowest thermal resistance and the highest coefficient of heat transfer.

Keywords: Heat pipe; Heat transfer; Nanofluid

1. INTRODUCTION

The progress of technological developments for the last few decades can be seen in several fields (electronics, power generation, etc.) (Ranga Babu et al., 2017). Smart technologies have rapidly developed, applying scientific knowledge for practical purposes with an evolutionary process, especially in computer hardware technology, as a solution to facilitate and improve the performance of human work (Brenner, 2007).

Central Processing Units (CPUs), the core of a computerized system, are experiencing rapid technology development (Paiva & Mantelli, 2015). The development of CPU technology leads to smart technology with the dimension decrease and has higher performance (Chen & Huang, 2017). However, this makes the CPU heat flux increase significantly (Elnaggar et al., 2011). The need for a high-performance cooling system with small dimensions without any additional power needs is a major issue faced by the computer industry (Elnaggar et al., 2011; Liu et al., 2015). Many solutions have been created to overcome CPU heat flux management problems, as in the conventional way by the application of forced convection heat transfer (Elnaggar et al.,

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2011). However, the conventional method is less efficient in removing heat, especially on smaller sized devices, because it requires higher power to support the fan performance.

Heat pipe is a heat transfer technology that uses a pipe (commonly made of copper, aluminum, etc.) containing liquid as a heat conductor from the end of the evaporator to the other end of the cooling section (heat removed) (Gupta et al., 2018). The heat pipe's inner wall is filled with capillary axis (wick) as transferring media to return the condensate. Condensate moves by the principle of capillarity (Putra & Septiadi, 2014). Various types of heat pipe have been investigated, such as Heat Pipe Heat Exchanger (HPHE) and Oscillating Heat Pipe (Muhammaddiyah et al., 2018; Winarta et al., 2019).

Research on using heat pipes as processor cooling systems began in 2003 to 2014 (Kim et al., 2003) with a study of Pentium IV CPU PC cooling system performance using aluminum heat sink with fan assistance has disadvantages (shapes, noise generated from the fan causing noise and ineffective heat transfer), so that heat pipe as cooling system which is smaller than heatsink does not need to use a fan for a support.

Cascade heat pipe (CHP) is a heat pipe design that has multilevel construction, combining two heat pipes into one system (Putra et al., 2015). The oscillating heat pipe (OHP) is an up-and-coming passive thermal transfer device that transports heat through the thermally excited oscillating motions of a working fluid.

Limited energy and material resources as well as undesirable man-made climate change make science seek for new and innovative strategies to save, transfer, and store heat energy (Buschmann, 2013). In recent years, conventional heat transfer fluids have been replaced by more advanced fluids for better heat transfer (Madhesh & Kalaiselvam, 2014). Various studies of heat pipe application as a cooling system have been conducted using nanofluid as a working fluid, including one by Putra et al. (2014).

A study investigated the synthesis of ZnO nanoparticle-based thermal fluids as the working medium for a conventional heat pipe with screen-mesh wick. The experiments were performed to measure the and heat pipe thermal resistances. The results showed distribution of temperature and thermal resistance to decrease as the concentration and the crystallite size of the nanoparticle increased (Saleh et al., 2013).

Putra et al. conducted a study employing a collar application as a wick on an LHP using nanofluid as the working fluid. With the collar wick, the temperature differences in the heat absorber with condenser sections were less than in the one that used the sintered copper powder wick. Working fluids of nanofluids resulted in lower temperature differences than using water-based working fluid; i.e., the thermal resistance of the LHP was lowered by using the collar wick and nanofluids (Putra et al., 2014).

Ahlatli et al. (2016) conducted an experimental study of the thermal performance of carbon nanotube nanofluids in solar microchannel collectors. They investigated the effects of pumping power, heat transfer, and pressure drop on the heat and flow characteristics of nanofluid. The results showed that as the weight of nanofluids increased, the measured heat transfer, pump power, and pressure drop increased.

Septiadi et al. (2018) conducted a study synthesizing two nanoparticles to create hybrid nanofluids. The study determined how nanoparticle composition affects the thermal conductivity value with the lowest agglomeration value. This research was conducted by dispersing Al_2O_3-TiO_2 nanoparticles in water.

2. METHODS

The CSHP research was done by first designing the CSHP model, then injecting the working fluid of Al_2O_3-water and Al_2O_3-TiO_2-water, and last running the experiment to find the simulator plate surface temperature and the condenser (output) temperature.

2.1. CSHP Preparation and Design

The CSHP used two L-shaped conventional heat pipes; the first-level heat pipe with copper material was equipped with a 40 mm × 40 mm copper thermal contact plate, while the second-level heat pipe was equipped with fins.

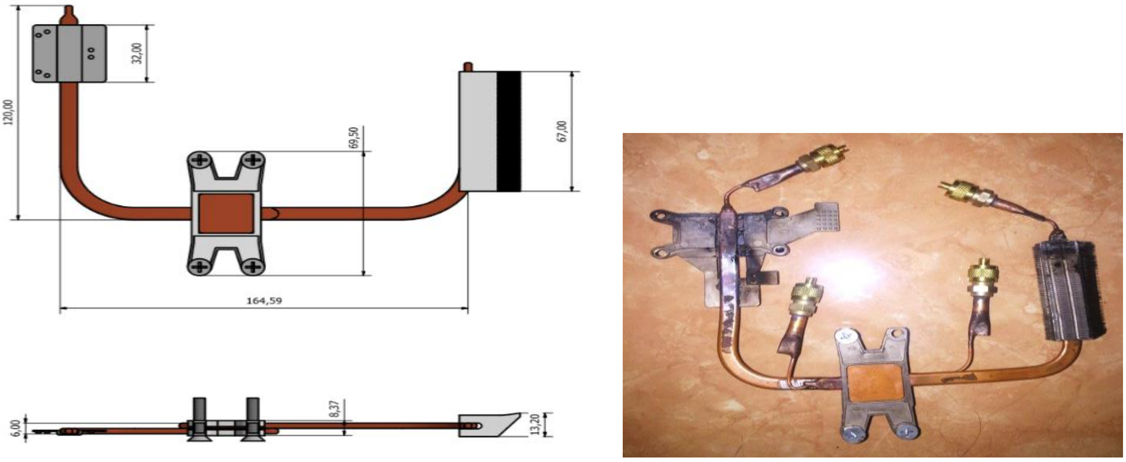


Figure 1 Design of CSHP

2.2. Working Fluid Injection

The working fluids used for the CSHP were water, Al_2O_3-water, and Al_2O_3-TiO_2-water nanofluid. Water was the base fluid of the heat pipe used, so it did not have to be injected. The nanofluid used has a low volume fraction of 0.7%. For the hybrid nanofluid, the comparison of nanoparticles between Al_2O_3 and TiO_2 is 75% Al_2O_3: 25% TiO_2.

The working fluid injection began by creating two holes on the CSHP surface, which then were fitted with valves. The first valve functioned as a vacuum valve (and also was used for the discharge of the working fluid), and the second valve functioned as a filling valve (for injection). Vacuuming was carried out using a vacuum pump, while the working fluid was injected using a vapor chamber.

Figure 2 Working fluid injection

2.3. Thermal Performance Test

Variations of heat load were given to the CSHP from 10 watts to 40 watts. The characterization of the simulator plate was done before carrying out the test, so that the simulator plate functioned to simulate the heat load given by a miniCPU core i5 3.30 GHz processor. K-type thermocouples (as many as 7) were installed at the top of the simulator plate surface; on the first-level evaporator, first-level condenser, second-level evaporator, and second-level condenser; in the heat sink; and for ambient temperature. The temperature data read by the thermocouple sensors were collected and monitored on a computer through the cDAQ data acquisition system with the NI-9213 (National Instrument) module.

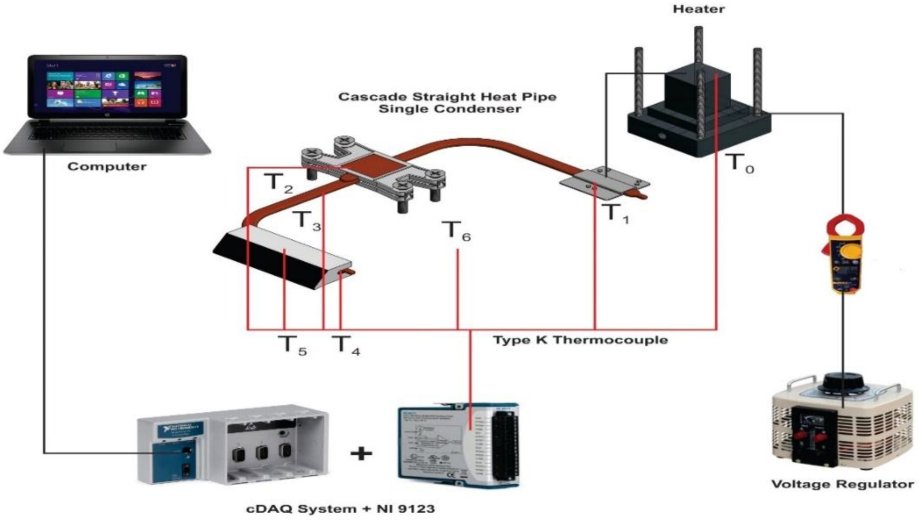


Figure 3 CSHP thermal performance test

3. RESULTS AND DISCUSSION

3.1. Temperature Distribution on Simulator Plate and Condenser

The CSHP cooling performance by each working fluid used can be determined by comparing the simulator plate temperature distribution at the various heat loads given. Figure 4 shows the simulator plate temperature distribution of each working fluid used at the maximum load of 40 watts. From Figure 4a, we can see that the highest simulator plate steady temperature was in the use of water, the second highest was with Al_2O_3-water, and the lowest was with Al_2O_3-TiO_2-water working fluid.

The decrease of simulator plate temperature calculation (before and after using the CSHP) was performed by using Equation 1.

$$\text{Tps decrease} = \frac{Tps\ on\ characterization - Tps\ by\ heat\ pipe}{Tps\ on\ characterization} \times 100\% \tag{1}$$

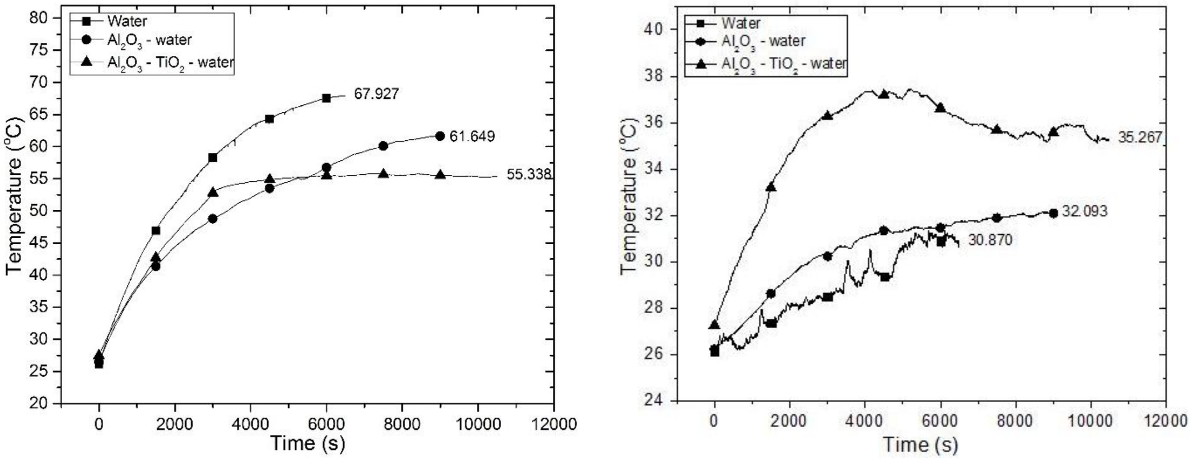
Table 1 Temperature decrease of simulator plate on each working fluid at the maximum load

Working fluid	Tps by heat pipe (°C)	Tps on characterization (°C)	ΔTps (°C)	Tps decrease (%)
Water	67.927	95.2	25.837	28.648
Al_2O_3-water	61.649	95.2	33.551	35.243
Al_2O_3-TiO_2-water	55.338	95.2	39.862	41.872

The greatest decrease of simulator plate temperature was in the use of Al_2O_3-TiO_2-water working fluid, the second greatest was Al_2O_3-water, and the lowest was water. This finding shows that the most effective CSHP in cooling the simulator plate (processor) is the one that uses Al_2O_3-TiO_2-water working fluid, then Al_2O_3-water, and the least effective is water.

The CSHP cooling performance can also be seen by comparing the second-level condenser output temperature distribution. Figure 4 is a comparison of the condenser output temperature distribution of each working fluid at the maximum heat load of 40 watts. The highest steady condenser temperature was in the use of hybrid nanofluid Al_2O_3-TiO_2-water, the second highest was Al_2O_3-water, and the lowest was water.

The higher the temperature drop in the heat source (i.e., temperature produced on the simulator plate is lower), the higher the condenser output temperature.



(a) (b)

Figure 4 (a) simulator plate; and (b) condenser temperature distribution by CSHP in each working fluid used at 40-watt heat load

3.2. Total Thermal Resistance and Heat Transfer Coefficient of CSHP

The total thermal resistance of CSHP was obtained by calculating the temperature difference between the first-level evaporator and the second-level condenser then dividing by the heat load received as shown in Equation 2.

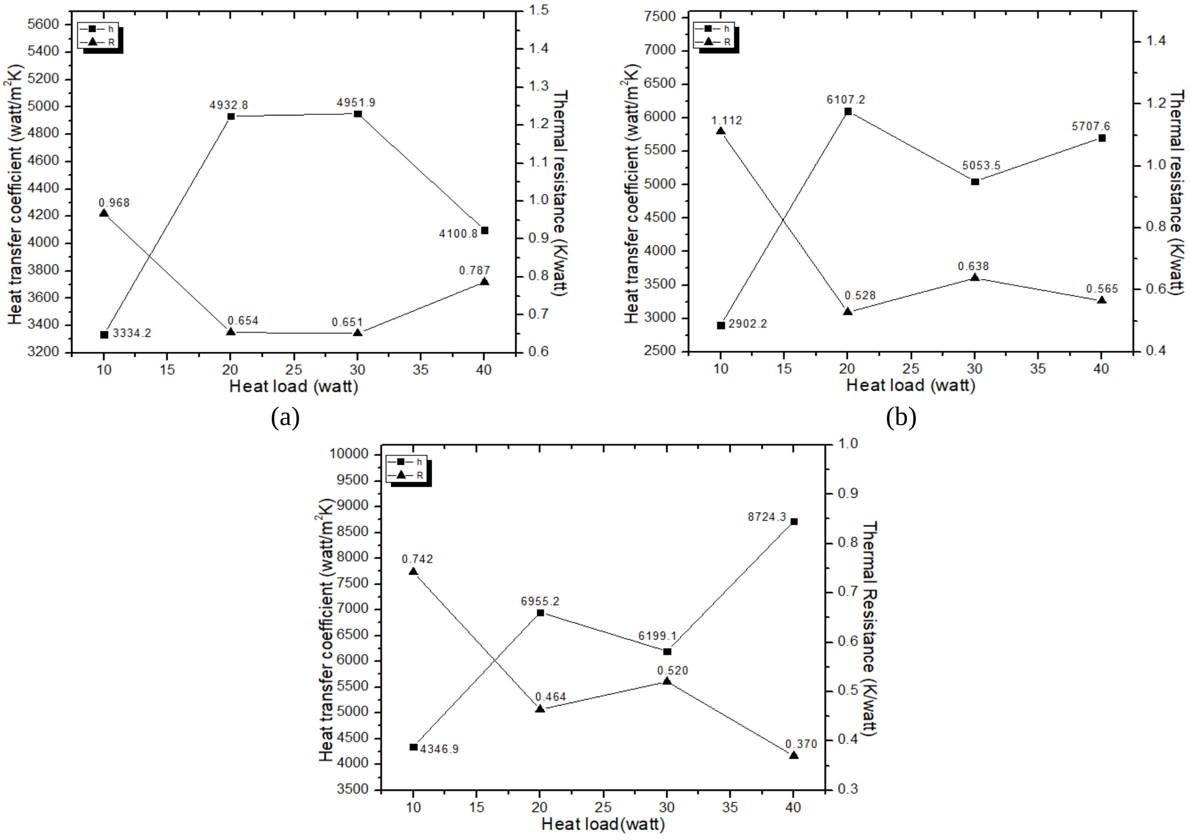
$$R_T = \frac{Te1 - Tc2}{Q} \tag{2}$$

*Te*1 is the first-level evaporator temperature, *Tc*2 is the second-level condenser temperature, and *Q* is the heat load given. The thermal resistance decreases when the heat load increases, according to the statement by Mujaya and Putra (Mujaya et al., 2015; Putra et al., 2015).

The CSHP heat transfer coefficient was also calculated using Equation 3 to determine the cooling performance of CSHP.

$$h = \frac{q}{\Delta T} = \frac{Q}{A \times \Delta T} \tag{3}$$

h is the coefficient of heat transfer, *q* is the heat flux calculated by dividing *Q* (heat load) by *A* (cross-sectional area or evaporator area), and ΔT is the temperature difference between the evaporator on the first-level heat pipe and the condenser on the second-level heat pipe. Graphs of CSHP heat transfer coefficients were made for each working fluid used and combined with CSHP total thermal resistance results, which then shows that the trend of the heat transfer coefficient is inversely proportional to the total thermal resistance trend; Figure 5 shows these graphs. The thermal performance of CSHP can also be known from the coefficient of heat transfer value.



(a)

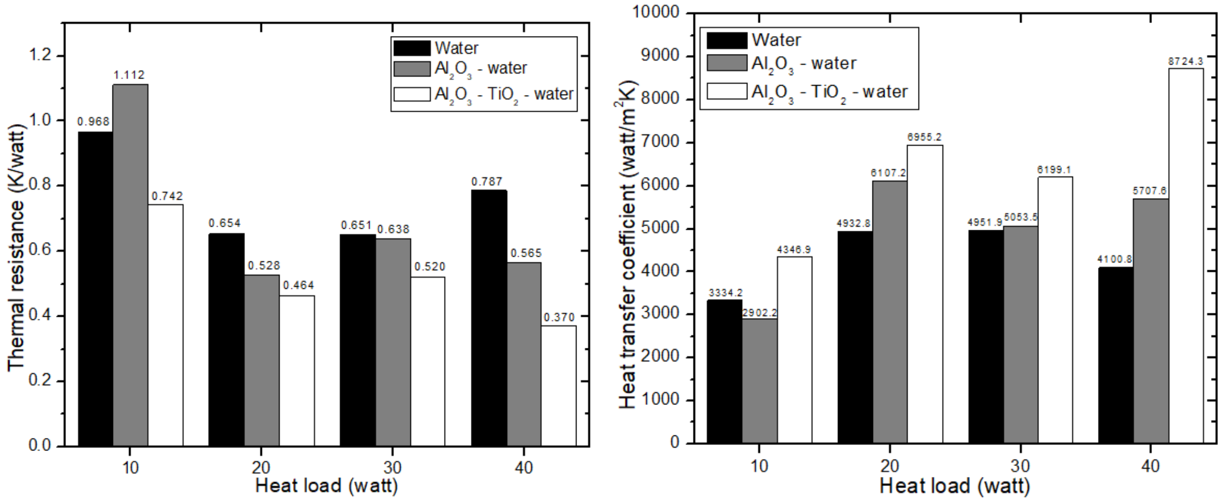
(b)

(c)

Figure 5 Comparison of CSHP total thermal resistance and coefficient of heat transfer for: (a) water; (b) Al_2O_3-water; and (c) Al_2O_3-TiO_2-water working fluid

CSHP thermal resistance and coefficient of heat transfer data were then used to make comparisons using bar graphs, as seen in Figure 6. As Figure 6a shows, the lowest thermal resistance at each given heat load was in the use of Al_2O_3-TiO_2-water working fluid. This finding indicates that the best CSHP cooling performance was given by Al_2O_3-TiO_2-water, since the lower the thermal resistance on the heat pipe, the better the heat pipe thermal performance, as stated by Putra et al. (2015).

In Figure 6b we see that the highest coefficient of heat transfer for each given heat load was in Al_2O_3-TiO_2-water working fluid, indicating that the best performance of the CSHP was in Al_2O_3-TiO_2-water use, since a higher value of heat transfer coefficient means better heat pipe thermal performance.



(a) (b)

Figure 6 Comparison of: (a) thermal resistance; and (b) coefficient of heat transfer on each working fluid use

4. CONCLUSION

The cascade straight heat pipe or CSHP-based CPU cooling system with the best cooling performance in this study was the system using Al_2O_3-TiO_2-water working fluid, which reduced 41.872% of the simulator plate temperature and had the lowest condenser output temperature. The second-best performance was in the use of Al_2O_3-water working fluid, which decreased 35.243% of the simulator plate temperature, while the poorest cooling system was in the use of water, which decreased 28.648% of the simulator plate temperature. The lowest thermal resistance given by CSHP at each heat loading was in the use of Al_2O_3-TiO_2-water working fluid, and the coefficient of heat transfer given by Al_2O_3-TiO_2-water use was the highest. These findings show that Al_2O_3-TiO_2-water hybrid nanofluid working fluid gives the best cooling performance of the CSHP for CPU cooling system.

5. ACKNOWLEDGEMENT

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