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Liquid cooling in the mini-rectangular fin heat sink with and without thermoelectric for CPU ☆

Paisarn Naphon *, Songkran Wiriyasart

Thermo-Fluids and Heat Transfer Enhancement Laboratory (TFHT), Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University, 63 Rangsit-Nakhornnayok Rd., Ongkharak, Nakhorn-Nayok, 26120, Thailand

A R T I C L E I N F O

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A B S T R A C T

In the present study, the liquid cooling in the mini-rectangular fin heat sink with and without thermoelectric for CPU is studied. Six mini-rectangular fin heat sinks with two different material types and three different channel widths are fabricated from the copper or aluminum with the length, the width and the base thickness of 37, 37, 5 mm, respectively. The de-ionized water is used as coolant. Effects of channel width, coolant flow rate, material type of heat sink and run condition of PC on the CPU temperature are considered. The liquid cooling in mini-rectangular fin heat sink with thermoelectric is compared with the other cooling techniques. The thermoelectric has a significant effect on the CPU cooling of PC. However, energy consumption is also increased. The results of this study are expected to lead to guidelines that will allow the design of the cooling system with improved heat transfer performance of the electronic equipments.

1. Introduction

Due to the air cooling limitation and the small physical size of the electronic devices, the development of the miniaturized technology, mini and micro-components has been rapidly increased especially in the electronic engineering, medical engineering and other fields. The heat transfer and pressure drop in the mini and micro-channel has been widely studied by researchers. Gao and Rowe [1] developed a theoretical model for calculating the cooling performance of an integrated thermoelectric micro cooler. Guglielmini et al. [2] experimentally studied the pool boiling heat transfer from finned copper surfaces immersed in a saturated dielectric fluid. Twelve test sections with different geometrical configurations were tested. Zhao and Lu [3] presented an analytical and numerical study effect of porosity on the thermal performance a micro channel heat sink. Honda and Wei [4,7] reviewed the researches concerning the boiling heat transfer enhancement for the micro-channel heat sink immersed in dielectric liquids. Luo et al. [5] applied the theory of finite time thermodynamics to analyze and optimize the performance of a thermoelectric refrigerator. Xuan [6] investigated the effect of the thermal and contact resistances of ceramic plate in thermoelectric micro coolers. Chein and Chuang [8,15,26] studied the micro channel heat sink performance with and without thermoelectric using nanofluids as coolants. Feng and Xu [9] developed a three-dimensional analytical solution using the method of Fourier expansion for determination of the spreading thermal resistance of a cubic heat spreader for electronic cooling applications. Kobus and Oshio [10] theoretically and experimentally studied on the thermal performance of a pin-fin heat sink with various geometrical. Bhowmil [11] studied on the steady-state convective heat transfer of water from an in-line four electronic chips in a vertical rectangular channel. Li et al. [12] determined the thermal performance of heat sinks with confined impingement cooling. The effects of the impinging Reynolds number, the width and the height of the fins, the distance between the nozzle and the tip of the fins on the thermal resistance were investigated. Zhang et al. [13] reported the study of a single-phase heat transfer of micro channel heat sink for electronic packages. Dogruoz et al. [14] experimentally and numerically studied on the hydraulic resistance and heat transfer of in-line square pin-fin heat sinks. Yu [16] studied on the thermal performance of a plate-pin fin heat sink and a plate fin heat sink. Peles et al. [17] investigated on the heat transfer and pressure drop over a bank of micro pin fins. Kosar and Peles. [18,19] experimentally studied on the single-phase heat transfer, boiling heat transfer and pressure drop of R-123 over a bank of shrouded micro pin fins. Yakut et al. [20] considered effects of the heights, widths of the hexagonal fins on thermal resistance and pressure drop characteristics. Chiang

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* Corresponding author.
E-mail address: paisarnn@swu.ac.th (P. Naphon).

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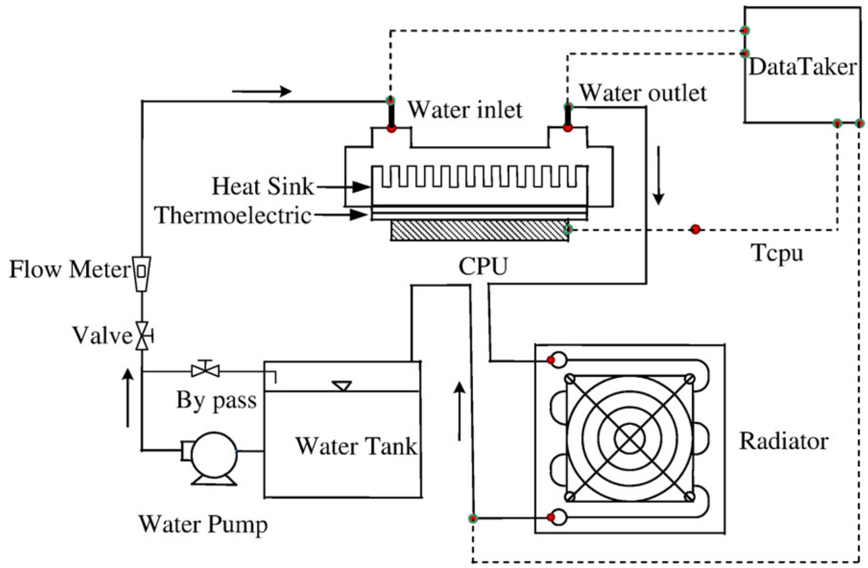

Fig. 1. Schematic diagram of experimental apparatus.

and Chang [21] developed an effective procedure of response surface methodology for designing parameters of a pin-fin type heat sink. Mohamed [22] investigated on air-cooling characteristics of an electronic devices heat sink with various square modules array. Launay [23] experimentally studied the boiling heat transfer from hybrid micro-nano structure. Didarul [24] investigated on the heat transfer and fluid flow characteristics of finned surfaces. Yang et al. [25] experimentally studied on the heat transfer coefficient of pin fin heat sinks with different cross sections. Twelve pin fin heat sinks with inline and staggered arrangements were tested. Lineykin and Yaakov [27] proposed a user-friendly graphical method for calculating the steady-state operational point of a thermoelectric cooler. Jeng and Tzeng [28] experimentally studied the pressure drop and heat transfer of a square pin-fin array in a rectangular channel. Lie et al. [29] investigated the flow boiling heat transfer of FC-72 on a heated micro-pin-finned silicon chip. Qi et al. [30] studied on the single-phase pressure drop and heat transfer of turbulent liquid nitrogen in the micro-channel.

To the best of author' knowledge, the papers presented the study on the heat transfer and pressure drop in the mini and micro-channel have been reported. However, only few works reported on the heat transfer characteristics of the mini-rectangular fin heat sink with and without thermoelectric. The objective of this paper is to study on the heat transfer characteristics of the mini-rectangular fin heat sink with and without thermoelectric of CPU of PC. Effects of relevant parameter on the cooling CPU are considered.

2. Experimental apparatus and method

A schematic diagram of the experimental apparatus is shown in Fig. 1. The test loop consists of a set of PC, cooling de-ionized water loop and data acquisition system. The test section and the connections of the piping system are designed such that parts can be changed or repaired easily. The close-loop of de-ionized water consists of a 10^{-3} m^3 storage tank, water pump, flow meter, and radiator. The cooling de-ionized water is chilled by the atmospheric air. After the temperatures of the water are cooled to achieve the desired level, the cooling water is pumped out of the storage tank, and is passed through a flow meter, CPU and returned to the storage tank. The flow rates of the cooling water are controlled by adjusting the valve and measured by the flow meter with the accuracy of ±0.2% of full scale. The test sections fabricated from the blocks of copper or aluminum with the details are listed in Table 1. The measured temperatures of cooling water at various positions are shown in Fig. 1.

De-ionized water was used as coolant. The de-ionized water was pumped into the mini-rectangular fin heat sink which installed on the hot side of thermoelectric and the CPU of PC, respectively. The inlet temperature of coolant water before entering the cooling section was kept nearly constant of 28–30 °C. The mini-rectangular fin heat sink unit was shown in Fig. 2. Experiments were conducted with various cooling water flow rates, channel width of heat sink, material type of heat sink and run condition of PC. The supplied load into the CPU was adjusted to achieve the desired level by setting run condition of PC.

Table 1
Dimensions of the mini-rectangular fin heat sinks

Channel	Fin height (mm)	Fin size (mm)	Channel width (mm)	Size of heat sink (mm)
Aluminum	4	1.00*1.00	0.50	37*37*5
Aluminum	4	1.00*1.00	1.00	37*37*5
Aluminum	4	1.00*1.00	1.50	37*37*5
Copper	4	1.00*1.00	0.50	37*37*5
Copper	4	1.00*1.00	1.00	37*37*5
Copper	4	1.00*1.00	1.50	37*37*5

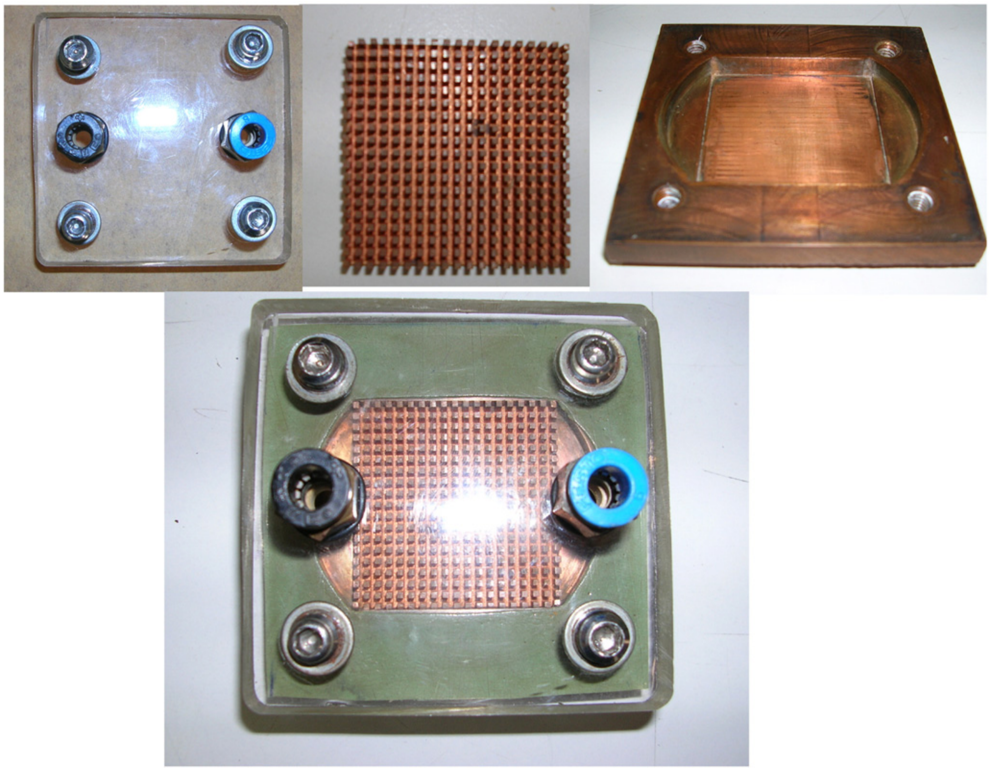

Fig. 2. Photograph of the mini-rectangular fin heat sink components.

The consumption electrical power of the PC was measured by the watt–hour meter. The temperatures at each position were recorded in the period time of 200 min. Data collection was carried out using a data acquisition system (DataTaker, DT800). The uncertainty and accuracy of the measurement are given in Table 2.

3. Results and discussion

Each condition of the experiment was performed at the room temperature of 26–27 °C in the period time of 200 min for the steady state condition. The cooling water in the radiator was cooled by the atmospheric air at this temperature. Therefore, the inlet temperature of coolant water before entering the cooling section was kept nearly constant of 28–30 °C. In the present study, the cold side of thermoelectric is attached on the CPU of computer while the hot side of thermoelectric is attached with heat sink. The heat is removed from the cold side to the hot side when the electric current passes through the module and then removed to the heat sink. In Fig. 3, the variation of CPU temperature with time for no load and full load conditions are shown. The hot and cold side temperatures of thermoelectric depend on the input electric current. To avoid the condensation of water vapor, the input voltage of the thermoelectric was set constant of 6 volts. It can be seen from both figures that the CPU temperature is nearly constant with time. For the two heat sinks, the temperature obtained from the heat sink fabricated from the copper lower than that from the aluminum. This is because the copper gives the thermal conductivity higher than the aluminum.

Effects of cooling flow rate on the CPU temperatures for different load conditions of the copper heat sink with the channel width of 0.5 mm are shown in Fig. 4. For the four different coolant flow rates, a larger CPU temperature drop is found for a larger coolant flow rate. A larger coolant flow rate results in lower capacity resistance and consequently lower heat sink thermal resistance.

Fig. 5 shows effect of channel width of heat sink on the CPU temperature of PC for no load condition and full load condition. Due to higher heat transfer surface area, the heat transfer rate from CPU to the heat sink increases. Therefore, the CPU temperatures obtained from the heat sink with lower channel width are lower than those from higher especially for full load condition. It can be seen from figure that the CPU temperatures for the full load condition are higher than those from the no load condition for the whole range of the period time as shown in Fig. 6. This is because the full load condition generates the heat higher than the no load condition. The CPU temperatures obtained from the liquid cooling for mini-rectangular fin heat sink with thermoelectric are compared those from the other cooling techniques as shown in Fig. 7. It can be seen from both figures that the liquid cooling with thermoelectric gives the CPU temperature lower than other systems especially for no load condition. The thermoelectric has significant effect on heat transfer from the CPU as shown in Fig. 8. The basic TEC operating principle can be found in the thermoelectric text book [31].

The CPU temperature and the energy consumption obtained from the water cooling without thermoelectric technique, water cooling with thermoelectric technique, air cooling with heat pipe technique, are compared with those from the conventional air cooling technique

Table 2
Accuracy and uncertainty of measurements

Instruments	Accuracy	Uncertainty
Voltage supplied by power source, (volt)	0.2%	±0.5
Current supplied by power source, (ampere)	0.2%	±0.5
Flow meter	0.2%	±0.5
Thermocouple type T, Data logger, (°C)	0.1%	±0.1

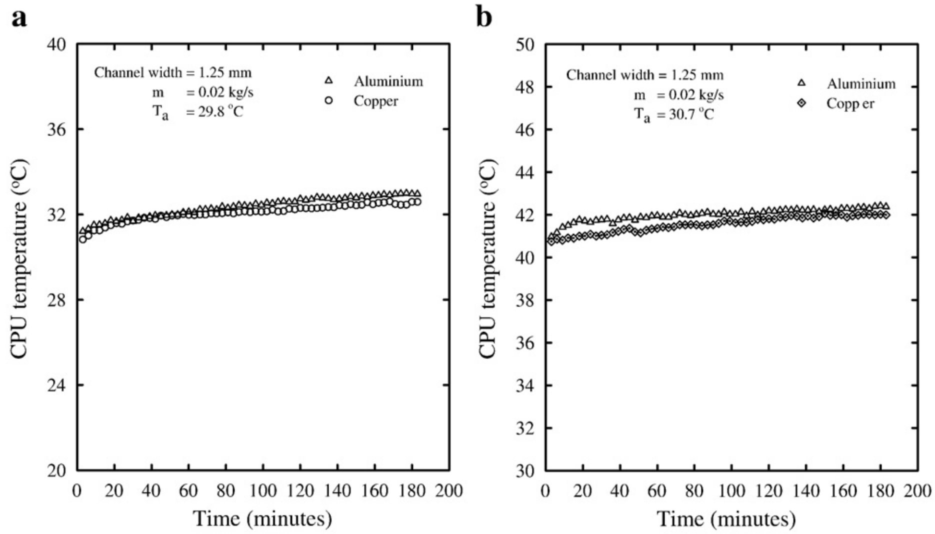

Fig. 3. Effects of heat sink material type on CPU temperature for (a) no load conditions and (b) full load conditions.

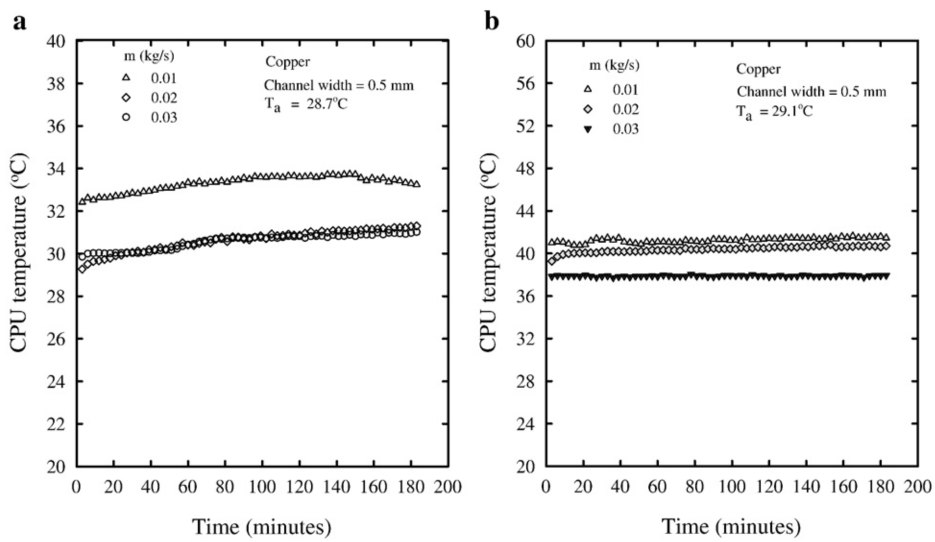

Fig. 4. Effects of coolant flow rate on CPU temperature for (a) no load conditions and (b) full load conditions.

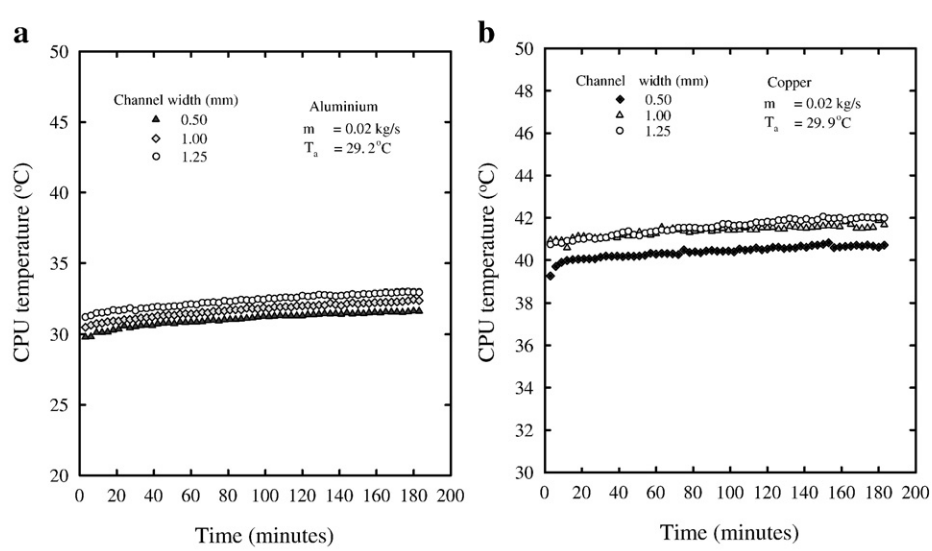

Fig. 5. Effects of channel width on CPU temperature for (a) no load conditions and (b) full load conditions.

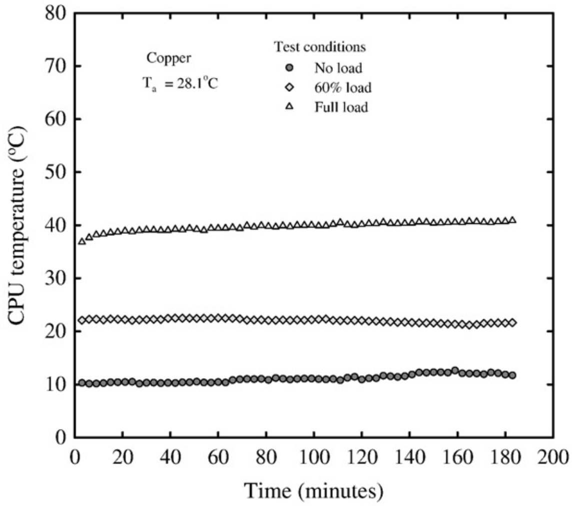

Fig. 6. Variations of CPU temperature with time for different load conditions.

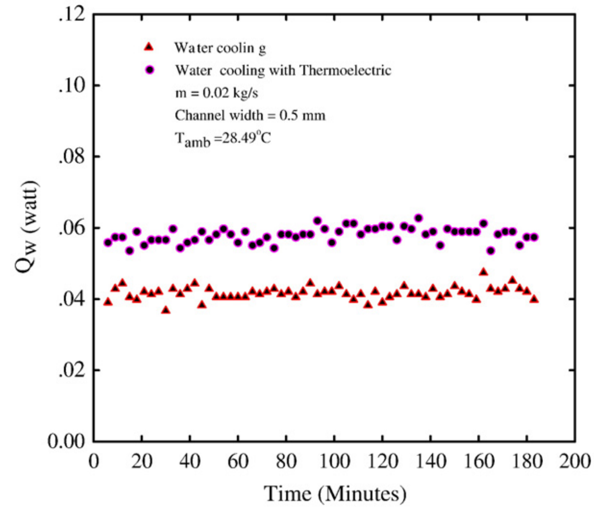

Fig. 8. Effects of cooling technique on cooling rate for full load conditions.

where the plus symbol is represented the higher value while the minus symbol is represented the lower value as compared with the value from the air cooling technique. It can be seen from Table 3 that thermoelectric has significant effect on the cooling of the CPU of PC, however, the energy consumption is also increased especially for full load condition. In addition, the water cooling with thermoelectric give the largest CPU temperature drop and the largest energy consumption. While the water cooling without thermoelectric gives a larger CPU temperature drop while the energy consumption slightly increases.

4. Conclusions

Due to the air cooling limitation of the electronic devices with high level of heat generation, the liquid cooling in the mini-rectangular fin channel heat sink with and without thermoelectric for CPU has been investigated with de-ionized water as working fluid. Effect of thermal conductivity and channel width of heat sink, coolant flow rate and run condition of PC on the CPU temperature are considered. The results obtained from this technique are compared with those from other cooling techniques. The results of this study are expected to lead to guidelines that will allow the design of the cooling system with improved heat transfer performance of the electronic devices.

Table 3
Comparison of the energy consumption between various cooling techniques with air cooling technique

Cooling techniques	CPU temperature		Energy consumption	
	No load	Full load	No load	Full load
Water cooling with thermoelectric	−68.4%	−1.8%	+78.4%	+75.5%
Water cooling	−13%	−10.4%	+2.7%	+8.2%
Air cooling with heat pipe	−3.2%	−7.8%	0%	0%

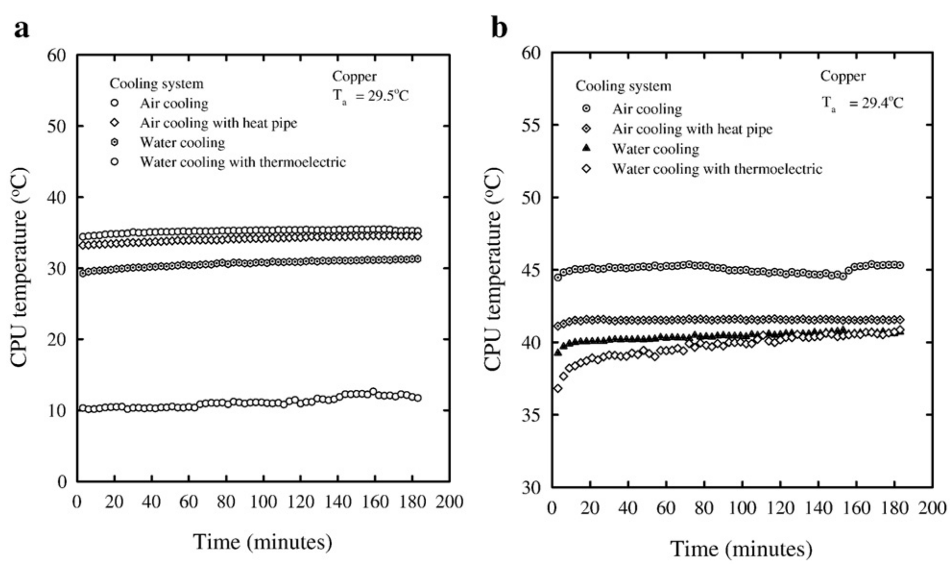

Fig. 7. Effects of cooling technique on CPU temperature for (a) no load conditions and (b) full load conditions.

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