Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 78, Issue 2 (2021) 98-113

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

A Review on Development of Liquid Cooling System for Central Processing Unit (CPU)

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ARTICLE INFO

Article history:
Received 23 June 2020
Received in revised form 5 October 2020
Accepted 10 October 2020
Available online 9 December 2020

Keywords:
Liquid cooling; Central Processing Unit; Nanofluid

ABSTRACT

Electronic devices are becoming more efficient while getting a smaller size and compact design thus increase heat generation significantly. High heat generation from high technology electronic devices are needed to be cool down or control its temperature to prevent overheating problems. Due to the high cooling performance of liquid cooling, the electronic cooling system is shifting from an air-cooling system to a liquid cooling system. In the past few decades, numerous methods proposed by researchers for the central process unit (CPU) cooling using the liquid system either active cooling or passive cooling system. Other than physical configuration such as heat sink design, different configurations of working fluids are widely been studied by most of the researchers. Different working fluids have different heat transfer performance. Furthermore, a recent study has come out more interesting finding using nanofluid which can enhance heat transfer performance of liquid cooling. Nanofluid is a working fluid that has nanoparticles disperse in the base fluid which can increase the thermal properties of the based fluid. In this paper, comprehensive literature on the type of working fluid used in the respective system and methods of liquid cooling system for CPU including its cooling performance. Furthermore, this review paper discussed the different configuration of the liquid block and also the working fluid that had been used in the CPU cooling system.

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1. Introduction

Recent developments in electronic devices have heightened the need for a higher efficiency cooling system to counter the heat dissipated from the electronic device during operation. Nowadays, to remove heat from a chip with a surface area of a few square centimetres is a big challenge that is needed to study. Electronic devices are becoming more efficient while getting a smaller size and compact design. High heat dissipated from high technology electronic devices are needed to be cool down or control its temperature. Without a proper method of cooling, abundant heat produces could damage the devices and disturb the whole system. Furthermore, high heat

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https://doi.org/10.37934/arfmts.78.2.98113

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production will increase the power needed by cooling devices such as a fan for the cooling process. Table 1 shows the heat thermal design power (TDP) from the recent production of the Central Processing Unit (CPU). This data was taken from the intel website [1]. TDP is the maximum amount of power used by the CPU in watts. Therefore, CPU heat generation can be approximately estimating the same as the TDP value. An electronic component such as CPU should operate under 85^oC to work properly and provide good reliability. Usually, most computers have thermal sensors in the safety system to prevent overheating. As the temperature approaching the temperature limit, the computer will slow down the core and lower the voltage. The proper cooling method could decrease the max temperature and enhance CPU performance. The most efficient cooling method has high heat transfer, less consume spaces and low noise during operation.

Heat generation of CPU follows Moore's Law where the number of transistors increases doubling-up every 18 months so does heat generation increase. Approximately, the total heat dissipation resulting from a high-end CPU is 110–140 W and could achieve 100^oC which can damage the CPU. Since it was reported in 1970, transistor count on integrated circuit chips is only 1000 units. Surprisingly, in 2018, the transistor count on integrated circuit chips are 50 billion units [2]. Therefore, this abundant heat generation from the transistor units needs a highly efficient cooling system such as a liquid cooling system.

The conventional air-cooling system is slowly approaching the cooling limit. Although, air cooling system still capable for high heat transfer application but it involves many drawbacks. For this issue, more fans need to overcome high heat generation which leads to high power need and occupies more space. Contrary, liquid cooling has better heat conductivity and heat capacity which can increase cooling efficiency. Recently, the CPU cooling system shifted from an air-cooling system to a liquid cooling system due to its capability in heat transfer enhancement for desktop systems and workstations.

There are many kinds of research on liquid cooling CPU using various methods of cooling. Some of the studies use air cooling as a comparison for their proposed methods and working fluid. Many methods are suggested to increase heat transfer such as liquid jet impingement, thermosyphon, heat sink and direct liquid cooling using liquid block. Moreover, different configurations of heat sink also had been studied by many researchers. Other than liquid cooling methods, many types of working fluid had been studied for liquid cooling CPU. In recent years, there has been an increasing interest in nanofluid as heat transfer working fluid. Nanofluid is a working fluid which has nanoparticles disperse in the base fluid. Nanofluid can significantly enhance heat transfer performance due to the thermal properties enhancement[3, 4] by the nanoparticle suspension in the base fluid. Various parameters of nanofluid had been used for heat transfer enhancement in liquid cooling CPU.

Due to many types of liquid cooling methods and working fluids had been proposed by many researchers, this paper will provide a comprehensive review specifically about the liquid cooling system in CPU. Furthermore, a recent study about water cooling in CPU will be discussed. This paper will provide information about the several methods of liquid cooling system for CPU in recent applications. To date, only a limited number of reviews on methods and working fluids have been identified. It is hoped that this research will contribute to a deeper understanding of the liquid cooling system for CPU and offers some important insights for steps to increase the efficiency of the liquid system.

Table 1
Heat dissipated from CPU [1]

Processors	Thermal design power (TDP)
Intel® CORE™ i7-8550U Processor (8M Cache, 4.00 GHz)	25W
Intel® CORE™ i7-8750H Processor (9M Cache, 4.10 GHz)	45W
Intel® CORE™ i7-9700K Processor (12M Cache, 4.90 GHz)	95W
Intel® Core™ i7-8086K Processor (12M Cache, 5.00GHz)	95W

2. Working Fluid

The development of working fluid had been actively studied to increase the thermal performance of the cooling system in electronic devices. Air- and water-cooling system are favorably used today for CPU cooling. However, the heat dissipation capacity of conventional air-cooled heatsinks is limited because of non-uniform temperature distribution in the base of heatsinks [5]. The most common working fluid used for liquid cooling is deionized water. It is cheap and better heat capacity than the air-cooling system. Moreover, ethylene glycol is one of the base fluids can be used. Ethylene glycol has a structure similar to water but has a lower freezing point and higher boiling point. Azmi *et al.,* [6] had done a review about heat transfer augmentation of ethylene glycol. During the late 90s, the application of nanoparticle provides effective ways to increase heat transfer characteristic of fluid [7]. Further development of working fluid has come out with the nanoparticle in the based fluid which is called nanofluid. Further development of enhancing heat transfer working fluid is important to decrease the high portion of energy for cooling and could increase the efficiency of heat removal [8]. Different nanoparticles have been developed and had been applied for many applications in heat transfer.

2.1 Recent Application of Nanofluid on Electronics Cooling

Replacing conventional working fluid with nanofluid is one of the beneficial developments. Nanofluid with high thermal conductivity will increase the cooling efficiency of cooling devices. The nanoparticle that exists in the fluid will decrease the thermal resistance for heat transfer. Table 2 shows the application of nanofluid or hybrid nanofluid in recent electronic devices. The thermal performance is compared with based fluid. From the literature review, nanofluids parameters that have effects on cooling device thermal performance are the type of nanofluids, volume concentration, flow rate, and temperature.

Table 3 shows the list of nanofluids that had been used in the liquid cooling systems for CPU with heat transfer coefficient analysis. Type of nanofluid had been used is CuO [10, 12, 15, 22], Al_2O_3 [10, 14, 21, 23, 24], TiO_2 [9, 25], SiO_2 [16] , ZnO [10], graphene [13, 26], CNT [18] and MWCNT [19]. It is difficult to compare the best nanofluids as there are various concentrations and heat generation is used. There are also other studies on the maldistribution of nanofluid at heat sink with different designs [26, 27]. Different type of nanofluids has a different rate of heat transfer enhancement. One of the properties for heat transfer enhancement by nanofluids is thermal conductivity. Table 4 shows several thermal conductivities of nanoparticles. Supposedly, the higher thermal conductivity of nanofluid has better thermal enhancement. Sun and Li [14] study confirm that higher thermal conductivity of Cu nanofluid has better thermal performance compared to Al_2O_3. But some study has contrary results [12, 23]. Based on the literature review on the study of thermal conductivity of nanofluid, the thermophysical properties of nanofluid are strongly depended on the concentration of the concentration on nanoparticle in base fluid and temperature. Therefore, it's hard to consider thermal conductivity specifically for heat transfer enhancement in liquid cooling.

Table 2
A summary of the application of nanofluid or hybrid nanofluid in the liquid cooling system for CPU

Authors	Nanofluids	Findings
Zhao *et al.,* [9]	TiO2-water	Nanofluids with 0.3% concentration can improve the cooling performance by 58% at most compared with deionized water under the identical conditions
Hassan *et al.,* [10]	Al2O3-water, CuO-water, SiO2-water, ZnO-water	The SiO2 nanofluid has the highest Nusselt number value, followed by Al2O3, ZnO, and CuO. The highest heat transfer enhancement showed by SiO_2 with 14% enhancement.
Gunnasegran *et al.,* [11]	Fe_2NiO_4 - water	An average decrease of 5.75°C (14%) was achieved in core temperatures of desktop PC CPU using Fe2NiO4-H2O
Sarafraz *et al.,* [12]	Liquid gallium CuO-water	Results demonstrated that both coolants present a higher thermal performance in comparison with water. Gallium showed superior thermal performance compared to nanofluid.
Bahiraei *et al.,* [13]	Graphene/Ag-water	Nanofluid has better cooling than pure water, reduction of surface temperature due to adding the nanoparticles is more obvious at lower Reynolds numbers. Applying the nanofluid increases the uniform distribution of temperature.
Sun *et al.,* [14]	Cu-water Al_2O_3-water	The convective heat transfer coefficient of nanofluids with a mass fraction of 0.1–0.4% was significantly higher than deionized water, and the convective heat transfer coefficient of Cu-water nanofluids was about 1.1–2 times the heat transfer coefficient of the DI water.
Al-Rasheed *et al.,* [15]	CuO-water	The results show 7.7% heat transfer improvement in thermal conductance is observed in the case of nanofluids in comparison to water.
Gunnasegaran [16]	SiO_2-water	The optimized nanoparticle mass concentration and heat inputs are 0.48% and 59.97 W, respectively, the minimum Rth being 2.66 (C/W)
Turgut *et al.,* [17]	Al_2O_3-water	With 1% volume concentration, nanofluid decreases the maximum temperature of the system, almost 2.7°C compared to water
Nazari *et al.,* [18]	Al_2O_3-water CNT-water	An increase of 6% is also reported by using a 0.5% volume fraction of Alumina nanofluid. The best heat transfer enhancement (about 13%) is related to CNT nanofluids with the volume fraction of 0.25% for the flow rate of 21 mL/s.
Jajja *et al.,* [19]	MWCNT-water	The lowest value of heat sinks base temperature recorded was 49.7°C at a heater power of 255W by using a heat sink of 0.2mm fin spacing and MWCNT nanofluid as a coolant.
Yousefi *et al.,* [20]	Al_2O_3-water	Introduction of 0.5 wt% Al 2O3 nanoparticles to the water coolant of heat pipe has led to a decrease in thermal resistance. It is shown that at 10 W, the presence of nanofluid has reduced the thermal resistance by 15%, while at 25 W, the thermal resistance has dropped by 22%.
Putra *et al.,* [21]	Al_2O_3-water	Application of Al2O3 nanofluid as working fluid would enhance the thermal performance of the vapor chamber by 9% compare with based fluid.

Table 3
Applications of nanofluid or hybrid nanofluid with heat transfer coefficient

Cooling device	Nanofluid	Vol. concentration (%)	Heat transfer coefficient (maximum enhancement)	Ref
Microchannel Heat Sink	Carboxymethyl Cellulose/CuO-water	0-3	386.01W/m^{2}K	[15]
Heat Sink	Gallium CuO-water	0.1–0.3	Gallium = 600W/m^{2}K CuO = 400W/m^{2}K	[12]
Heat Sink	Cu-water Al_2O_3-water	0.1–0.4	Cu-water = 11100W/m^{2}K Al2O3-water = 8400W/m^{2}K	[14]
Heat Sink	Al_2O_3-water CNT-water	0.1- 0.25	Al2O3-water = 340W/m^{2}K CNT - water = 365W/m^{2}K	[18]
Heat Sink	SiO_2-water, TiO_2-water, Al_2O_3-water	SiO_2: 0.5, 1.0, 1.5 TiO_2: 0.1, 0.25, 0.5 Al_2O_3: 0.5, 0.75, 1.0	SiO_2-water = 1000W/m^{2}K TiO_2-water = 920W/m^{2}K Al_2O_3-water = 1250W/m^{2}K	[25]
Heat Sink	CuO-water	0.1 and 0.2	1900 W/m^{2}K	[28]

Table 4
Thermal conductivity of nanoparticles

Nanoparticles	Thermal Conductivity(W/mK)	Ref
Water	0.6	[23]
Al_2O_3	36	
SiO_2	1.2	
ZnO	13	
CuO	440	[12]
Gallium	29.4	
Cu	401	[14]

Other than the thermal conductivity of nanofluids, Brownian motion also being reported provides thermal enhancement using nanofluid. Selvakumar and Suresh [28], and Qi *et al.,* [29] strongly agree that the effects of thermal conductivity and Brownian motion may play a major role in the heat transfer enhancement when the nanoparticle mass fraction is less than the critical value. Other than that, other reported that Brownian motion could only happen for heat transfer applications of flowing fluids [24, 25, 30-32]. At the stationary conditions, Brownian motion could be neglected [33].

Thermal enhancement strongly depends on the concentration of nanofluids. From the literature reviews, it is confirmed that a higher concentration of nanofluid has better heat transfer performance. Unfortunately, most of the studies just use a small percentage of nanofluid approximately <5% concentration in the liquid system [10, 11, 22]. One of the considerations of the selected concentration is the stability of nanofluid. Although higher concentration has better heat transfer enhancement, the higher concentration will decrease the stability of nanofluid. This is supported by Mehrali *et al.,* [34] where the stability of prepared graphene nanoplatelets drops as the concentration of nanofluid increases. Furthermore, a higher concentration of nanofluid needs a more complicated and longer period of preparation which is inconvenient. Other than that, the channel size of the heat sink or liquid block also one of the factors of choosing nanofluid's concentration. Most of the channel heat sink are in micro or milli size. The higher concentration of nanofluid could cause pressure drop [12] or disturb the cooling system due to clogging at the channel of the heat sink. Conclusion that can be made from the literature reviews are the concentration used in the respective study are at the limit of heat sink's size. This is because the maximum concentration did not state in each study. Only the optimization study had shown the optimum concentration used in the liquid cooling system [16].

3. Methods of Liquid Cooling System for CPU

Liquid cooling has been widely used and has been commercialized. Water block with cold plate will have physical contact with the CPU and heat will be transferred between CPU and working fluid [35]. The liquid cooling system used less space and noise-free operation because fewer fans are used. A heat sink is a heat transfer device that transfers heat generated by electronic devices to the fluid medium. Usually working fluid used is air and liquid. Heat sink designs to maximize surface area contact between the heat source and the working fluid. Base on the recent studies, many researchers had come out with different configurations of the liquid block which can be shown in the Table 5. Different configurations of liquid blocks involve heat sink channel design, thermoelectric cooler (TEC), vapor chamber, heat pipe, thermosiphon, and jet impingement.

Table 5
Table of findings for different configurations of the liquid block

Authors	LB	TEC	HP	TS	JI	Findings
Lu *et al.,* [36]	/					I- and T-arrangement give the best heat transfer performance due to their impingement configuration compare to]-, L-, and T-arrangements
Naphon & Wiriyasart [37]		/				Thermoelectric has 68% thermal enhancement on the CPU cooling of PC. However, energy consumption is also increased.
Huang *et al.,* [38]		/				TEC performs better than the water-cooling system without TEC by 385%. The maximum effective operating heat load is 57 W
Naphon & Wongwise [39]					/	It is found that the CPU temperatures obtained from the jet liquid impingement cooling system are lower than those from the conventional liquid system about 1°C
Putra *et al.,* [40]				/		The dual taper thermosiphon loop has 12% and 33% thermal enhancement compare to water cooling and air cooling respectively
Khonsue [41]		/				The cooling system with thermoelectric gives the highest efficiency where 77% enhancement on no load and 22.21% enhancement on full load compared to the air-cooling system.
Yousefi *et al.,* [42]			/			The 90° inclination has the highest thermal resistance
Jajja *et al.,* [43]	/					The heat transfer coefficient for 0.2 mm fin spacing heat sink is considerably higher than the other geometries
Putra *et al.,* [44]			/			The used of coral as wick structured can improve the performance of heat transfer while decrease the CPU temperature for 38.6 % at the maximum heat load compared to a conventional copper heat sink.
Tan & Demirel [45]		/				The temperature difference of 5°C reveals that the thermoelectric cooler is more effective than the water-cooling system.
Muszynski & Andrzejczyk [46]					/	The hybrid microjet – microchannel module has higher heat removal compare to the traditional heat sink with forced air convection. The jet impingement heat transfer is dominant in 90% of total channel length
Bahiraei *et al.,* [13]	/					At a constant pumping power, the distributor liquid block has better heat transfer performance compare to serpentine, and parallel flow liquid block by 0.3%
Siddique *et al.,* [47]		/				The LTEEC has lower temperature CPU reading compare to commercial heat exchanger around 2oC
Wong *et al.,* [48]	/					The plate-fin heat sink has lower temperature reading compare to other designs followed by circular pin fin and strip pin fin for all velocity rate.
Bahiraei *et al.,* [26]	/					The fin height has a more significant effect on the temperature compared with the fin diameter.

Authors	LB	TEC	HP	TS	JI	Findings
Chauhan & Kandlikar [49]						The 2° dual taper angle has the best performance which can maintain the surface temperature at 45.5 °C with a heat transfer coefficient of 22.5 kW/m2 °C
Kumar & Singh [50]	/					Inlet/outlet arrangement with flow inlet angle θ = 105° has more uniform flow distribution in heat sink thus 2o lower temperature CPU compare to the conventional arrangement
Zhao *et al.,* [9]	/					Heat transfer performances of CPU with staggered arrangement grooves can be improved by 4.2% at best compared with that with aligned arrangement grooves.

LB = Liquid Block (Channel Design)
TEC = Thermoelectric Cooler
HP = Heat Pipe
TS = Thermosiphon
JI = Jet Impingement

3.1 Heat Sink Design

The performance of the liquid cooling system is affected by the design of the heat sink and the type of working fluid used. Uniform cooling distribution is the most important motivation for the further development of heat sink design in water block. The better uniform cooling distribution will prevent the hotspot problem. The hotspot is where heat is concentrated at one spot where heat is failed to be dissipated. The parallel channel is used for conventional liquid block.

A comprehensive study about the effect of fin spacing on mini channel heat sinks for microprocessor cooling had been done by Jajja *et al.,* [43]. Five different heat sinks with fin spacings of 0.2 mm, 0.5 mm, 1.0 mm, and 1.5 mm along with a flat plate heat sink and 0.5 LPM, 0.75 LPM and 1.0 LPM flow rate were investigated. They found that decreasing the fin spacing of the heat sinks increased the overall heat transfer coefficient while thermal resistance decreased. A significant finding, they found that 0.2 mm fin spacing at a flow rate of 1.0 L/min shows about 9% lower than the best-reported base temperature of 40 °C using a nanofluid with 3D Galaxy II from Gigabyte with the thermal design power of 125 W [25]. Other than that, for a flat plate heat sink, the maximum thermal resistance was 0.216 K/W that was reduced to as little as 0.03 K/W by using a heat sink of 0.2 mm fin spacing.

Next, the configuration on the inlet and outlet arrangement had been studied. In conventional liquid block inlet and outlet arrangement, working fluid enters the liquid block vertically upward and getting out vertically downward from the outlet. Initially, Lu *et al.,* [36] had studied the effect of the inlet location on the performance of parallel-channel cold-plate. A total of five inlet configurations have bet set up which are I-, Z-,]-, L-, and T-arrangement. The conventional liquid block is similar to I-arrangement. The results show that the I- and T-arrangement give the best heat transfer performance due to their impingement configuration. Maldistribution from I-arrangement could be solved by increasing the number of channels on cold-plate. On the other hand, one of the researchers S. Kumar, P.K. Singh [50] come out with a novel inlet and outlet arrangement with different flow inlet angles. This is the further work of the Z-arrangement. The inlet angles used are θ = 90°, θ = 105°, and θ = 120°. Configuration of inlet and outlet arrangement is to ensure better flow distribution and heat transfer performance. In this design, working fluid enter the liquid block horizontally with different flow inlet angle. The results show that proposed inlet/outlet arrangement with flow inlet angle θ = 105° has more uniform flow distribution in heat sink. Conventional arrangement has highest value of maldistribution. Furthermore, temperature drop of 2 °C has been noticed with the proposed flow arrangement as compared to conventional flow arrangement for the same volumetric flow rate. The inlet and outlet arrangement do not significantly affect cooling performance. Therefore, inlet and outlet arrangements can be used for the arrangement of the cooling system in the desktop.

Therefore, one of the research by Zhao *et al.,* [9] had experimentally studied the thermo-hydraulic performance of nanofluids in a CPU heat sink with different designs that are rectangular grooves and cylindrical bulges. The effect of rectangular grooves depth (1mm, 2mm) and cylindrical bulges arrangement which is aligned and staggered. It is found that large depth rectangular grooves and staggered arrangement cylindrical bulges are enhanced heat transfer performance. Furthermore, the mass fraction with 0.3% and 0.4% are the best heat transfer for cooling for both heat sink design.

Similar design also had been studied by Wong *et al.,* [48] where three types of heat sink design plate pin in line, strip pin in line and circular pin-fin. Heat flux applied for all models is 900W/m^2. The inlet velocity varied from 0.05, 0.10, 0.15, 0.20 and 0.25 m/s. They found out the trip pin fin design model has a higher pressure drop than circular pin fin because of the obstruction of the design model for strip pin fin resulting in the airflow unable to flow through effectively. As the inlet velocity increase, the thermal enhancement also increases. The result shows that the plate-fin heat sink has the better thermal performance. Mehdi *et al.,* [26] had study cylindrical bulges mini-pin fin heat sink. Four designs have been used in this study. Fin height used are 0.2, 0.4, 0.6 and 0.8 mm, and fin diameter used are 0.6, 0.9 and 1.2 mm. As the fin height, fin diameter and mass concentration of nanofluid increase, the temperature of the bottom surface decreases. Unfortunately, pumping power increases. Another finding is the temperature distribution becomes more uniform with increasing the concentration, fin height and fin diameter, which can decrease the possibility of hot spot formation. Furthermore, the fin height has more significant effect on the temperature compared with the fin diameter.

Next, a new type of heat sink water block design had been proposed by Bahiraei and Heshmatian [13] which are serpentine, parallel and distributor heat sink. At constant Reynold number, the serpentine liquid block has better cooling but needs higher pumping power. But for constant pumping power, distributor liquid block shows better results cooling. The uniform flow in distribution liquid block has decreased the possibility of the formation of hot spots. Therefore, surface cooling is much more uniform. There are many other channel designs had been proposed by researchers, but only research that has been presented in this paper has been used for CPU cooling applications.

To study the thermal performance of the working fluid in the liquid cooling system, most of the researchers study the maximum temperature readings, thermal resistance, heat transfer coefficient, and Nusselt number. Turgut and Elbasan [17] focused their study on the maximum temperature reading of CPU. The maximum temperature of CPU is taken after a 100% workload is applied to the CPU in a duration of time. This analysis is the main and basic findings to analyze the heat transfer performance of the liquid cooling system for CPU.

The heat transfer coefficient is important to study the rate of nanofluid's heat transfer. The amount of heat transfer between the wall (surface of the heat sink) and the working fluid can be written as Eq. (1).

$$q = hA\Delta T_b \tag{1}$$

where q is the heat flux from the heat source, A is the effective cross-section in contact with the surface of the heat sink and ΔT_b is the bulk temperature which is the difference between the wall temperature and the fluid temperature. Some researchers [18, 25] used the LMTD method to estimate ΔT_b as stated in Eq. (2).

$$\Delta T_b = \ln \frac{T_{cpu} - T_{in}}{T_{cpu} - T_{out}} \tag{2}$$

where,
T_{CPU} = Surface temperature of CPU
T_{in} = Inlet temperature
T_{out} = Outlet temperature

On the other hand, Sarafraz *et al.,* [12] calculate ΔT_b with an arithmetic average of inlet and outlet temperatures readings. This is because the liquid cooling system involves the transient heat transfer coefficient.

3.2 Thermoelectric Coolers (TECs)

Thermoelectric consists of two categories which are thermoelectric generators (TEGs) and thermoelectric coolers (TECs) [51]. TEGs transform heat energy into electrical energy. Seebeck effect is a phenomenon that occurs where voltage is generated which a temperature difference between two different electrical conductors or semiconductors. Meanwhile, TECs dissipated heat by using electric through the Peltier effect. The Peltier effect is described as a phenomenon whereby heat is dissipated or absorbed when electric current flows across a junction between two materials. There are many commercialize thermoelectric Peltier available on the market. Usually, TEC is used for cooling electronic devices. Figure 1 shows the mechanism of the Pielter effect in TEC.

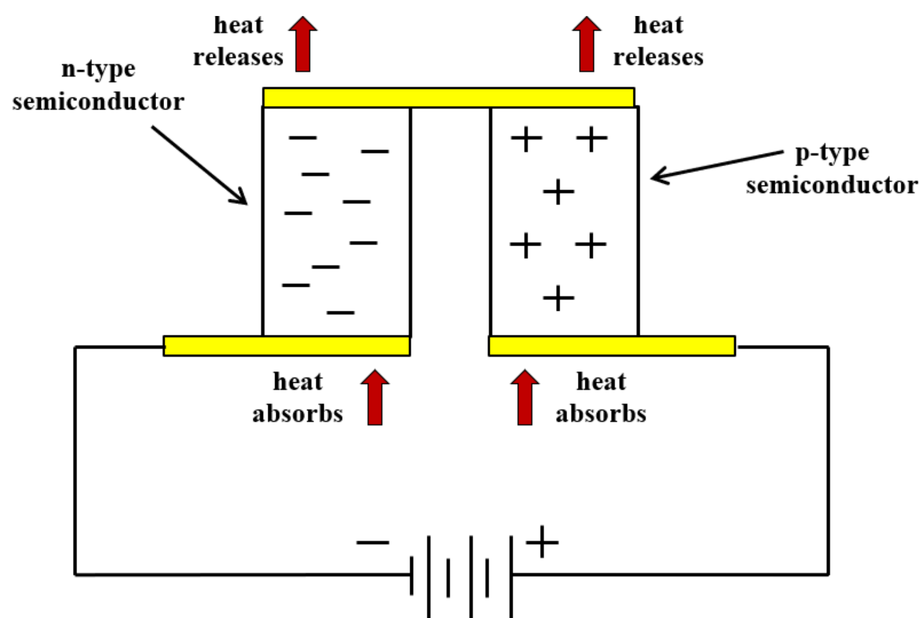

Fig. 1. Pielter effect

Among conventional TEC that are usually being used, there are three types of TEC modeling available which are single-stage thermoelectric coolers, multi-stage thermoelectric coolers, trapezoid, and annular thermoelectric coolers. TEC is widely being used for cooling CPU to increase the CPU cooling performance while decreasing the noise of the cooling system. The application of TEC could reduce the noise to less than 40dB with a power consumption of 130 W to cool the CPU in Kumar *et al.,* [45]. As the TEC is a very simple yet high cooling performance device, researchers are

interested to combine with different cooling applications. This will increase the cooling performance and more heat can be absorbed from the electronic device.

Tan and Demirel [45] had carried out the study with a heat sink, water cooling system and thermoelectric cooler comparatively to examine the temperature and performance of the CPU and motherboard. The Peltier or thermoelectric cooler (TEC) module was proposed for cooling the CPU to increase the CPU cooling power and decrease the noise of the cooling system. ATEC1-12706 Peltier module with 2⁄90 W power and 4⁄4⁄0.5 cm size was used under 12 V DC voltage to cool the CPU and Northbridge chipset. TEC has the lowest average CPU and motherboard temperature compare to the water-cooling system and air-cooling using a heat sink. The temperature difference of 5°C reveals that the thermoelectric cooler is more effective than the water-cooling system.

Siddique *et al.,* [47] carried out an experimental analysis with a liquid-based thermoelectric electronic cooling system, using two developed aluminium heat exchangers. An Ethylene-Glycol based fluid was used as the coolant in the cooling system. The results show that a large aluminium heat exchanger shows better performance compared to the small one. The commercially found cooling system performed the worst performance. The temperature variation was between 29-30°C, which is nearly 2°C less than the commercial cooling system and showed steady performance.

Huang *et al.,* [38] had studied the thermal performance of a thermoelectric water-cooling device for electronic equipment. The influences of heat load and the thermoelectric cooler's current on the cooling performance of the thermoelectric device are experimentally and theoretically determined. Besides, this study verifies that the thermal performance of the conventional water-cooling device can be effectively enhanced by integrating it with the thermoelectric cooler when the heat load is below 57W. Higher heat loads decrease the efficiency of the TEC as the Peltier effect cannot overcome a high heat load. Low temperature different from TEC cold side and hot side decreases the efficiency of TEC in the cooling system. The further cooling system needs to be studied to cool down heat load more than 57W.

Naphon and Wiriyasart [37] study on the liquid cooling in the mini-rectangular fin heat sink with and without thermoelectric for CPU. The de-ionized water is used as the coolant. The de-ionized water was pumped into the mini-rectangular fin heat sink which installed on the hot side of thermoelectric. Water cooling without thermoelectric gives a larger CPU temperature drop while the energy consumption slightly increases. Thermoelectric has a significant effect on the CPU cooling of the PC. However, energy consumption is also increased. Further study needs to be done to manage energy consumption by TEC.

Khonsue [41] had carried out an experimental investigation on liquid cooling in the microchannel fin heat sink with and without thermoelectric for CPU of the personal computer. The de-ionized water is used as the coolant. The experiments are performed at no load and full load conditions within 60 min after a steady state. The cooling system with thermoelectric gives the highest efficiency where 77% enhancement on no load and 22.21% enhancement on full load compared to the air-cooling system.

3.3 Heat Pipe

The Heat pipe work by transferring energy from one point to another using working fluid or coolant. The heat pipe is a device with highly effective thermal conductors due to their high heat transfer for condensation and boiling. The heat pipe is considered one of the best cooling devices due to its high thermal conductivity, reliability and cost-effectiveness [52]. There are many types of heat pipes which are pulsating heat pipe, rotating heat pipe, oscillating heat pipe, wick heat pipe and thermosyphon and many more [53]. Usually, the heat pipe is divided into three parts which are the

evaporator section, adiabatic (transport) section and condenser section. Heat dissipated at the external heat pipe parts will transfer to working fluid in evaporator parts. The heated working fluid will flow through the adiabatic section to the condenser. Vaporize working fluid will condense in condenser part where latent heat of vaporization is released to the heat sink. The capillary pressure/action is responsible to transport working fluid to the evaporator. Not enough capillary pressure to supply working fluid to evaporator could disrupt the heat pipe system. The wicked heat pipe is defined as a heat pipe with working fluid flow by using a capillary wick. The capillary-driven heat pipe, loop heat pipe (LHP) and capillary pumped loop heat pipe (CPLHP). Heat pipe for electronic cooling is usually in mini/micro size. Therefore, this type of heat pipe is very suitable to apply in a laptop and notebook which has limited space.

Putra *et al.,* [44] proposed the design of a heat pipe of CPU cooling using a coral biomaterial wick structure. Heat pipe was made from copper pipe and the wick structure was made from tabulating coral with a mean pore diameter of 52.95 µm. This design is compared with wick structure fabricated from sintered Cu-powder with a mean pore diameter of 58.57 µm. This wick structure will transport the working fluid naturally during heat transfer. The used of coral as wick structured can improve the performance of heat transfer while decrease the CPU temperature for 38.6 % at the maximum heat load compared to a conventional copper heat sink. This method also decreased the temperature of the simulator plate by as much as 44.25 °C compared to a heat pipe composed of a sintered Cu-powder wick.

Yousefi *et al.,* [42] had studied the effects of inclination angle and nanofluids on heat transfer performance of a CPU cooling heat pipe. It is shown that the inclination angle of the unit has a significant effect on the cooling process since it directly influences the operation of the evaporator. It is observed that as the CPU temperature increases, the threshold angle decreases from 60° to 30°. At 10 W, the presence of nanofluid has reduced the thermal resistance by 15%, while at 25 W, the thermal resistance has dropped by 22%. It is shown that nanofluid and the inclination of heat pipe help significantly the heat transfer performance of the heat pipe. Only a low concentration of nanofluid could be used to prevent clogging at the wicked part.

Thermosyphon is one of the heat pipes that been used in electronics cooling. The mechanisms of thermosyphon are similar to a typical heat pipe as mention above and do not require any mechanical devices such as pumps [54]. In this system, the condenser is placed above the evaporator. The liquid flows from the condenser to the evaporator by using gravity force which means this type of heat pipe is wickless. After that, the vapor will flow to the condenser upwards due to lower density and pressure force. Therefore, the lesser cost is needed to fabricate this type of heat pipe than wick heat pipe. There are also thermosyphon with wick, but the major force flow is gravity force.

Stable circulation of working fluid in thermosyphon is very important for better efficiency of cooling. Chauhan and Kandlikar [49] had proposed a dual taper thermosiphon to increase the stability of fluid flow in thermosyphon. The tapered section in the flow domain helps in pressure recovery. So, stable fluid could be established. The dual taper design has a smaller flow length and results in less expansion. This characteristic helps in establishing a more efficient vapor removal mechanism with stable fluid flow. The 2° dual taper angle performed the best among all taper angles tested and was able to dissipate a maximum of 280 W without reaching critical heat flux. The surface temperature was maintained at 45.5 °C with a heat transfer coefficient of 22.5 kW/m^2 °C. This type of heat pipe is suitable to apply in CPU cooling as long as the arrangement of the condenser is above evaporator so gravity will make sure the working fluid flows properly. Unfortunately, this type of cooling is not yet available in commercial due to the limit of the specific arrangement of the components.

3.4 Jet Impingement

Jet impingement cooling method is one of the promising developments in the heat transfer application. As its name, this method involves high velocity forced convection by ejecting coolant directly onto a heated surface through a convergent nozzle [55]. Due to its high heat transfer rate, this method could benefit from the electronic cooling application. To the current development, several parameters that had been studied by researchers that affect the cooling performance which is jet to target distance, flow region (Reynold's number), surrounding (confined, semi-confined), surface shape (rough or smooth, incline or flat, etc.) and fluid type. To support this, Singh [56] had comprehensively studied the heat transfer of jet impingement with novel surface roughness. Variable involve in the research are jet to jet spacing, jet to target distance and Reynold's number. The results show that concentric surface roughness has higher heat transfer and fin effectiveness compared to traditional cubic and cylindrical roughness. Furthermore, as the jet to jet spacing, jet to target distance and Reynold's number increase, the Nusselt's number also increases. Therefore, heat transfer is increased.

For electronic cooling such as CPU, the best configuration to apply this method is by combining heat sink and jet impingement. Naphon and Wongwise [39] had studied on jet liquid impingement heat transfer characteristics in the mini-rectangular fin heat sink for CPU cooling. A larger velocity in the heat sink results in a higher heat transfer coefficient. It is found that the CPU temperatures obtained from the jet liquid impingement cooling system are lower than those from the conventional liquid system. However, this technique requires higher energy consumption.

Next, Muszynski & Andrzejczyk [46] had studied the heat transfer performance of a microjet–microchannel cooling module. The tests were conducted under steady-state conditions for a single-phase liquid cooling system. The results achieved for the jet impingement experimental data were compared to standard cooling techniques. The hybrid microjet – microchannel module has higher heat removal compare to the traditional heat sink with forced air convection. The jet impingement heat transfer is dominant in 90% of total channel length

4. Conclusion

This paper presented an inclusive review of the development of the liquid cooling system for CPU. Various methods and working fluid had been reviewed for CPU cooling. Furthermore, the various aspects and parameters of each method were considered. The liquid cooling system is proven to enhance the heat transfer performance for CPU cooling. Furthermore, various working fluid had been studied including nanofluids. The presence of nanoparticles in the liquid cooling system will also improve the performance of heat transfer. Unfortunately, only a low concentration of nanofluids had been used due to the stability of the nanofluid and the limit of cooling systems such as the size of the heat sink. The only limited study had been done on hybrid nanofluid for CPU cooling. More synthesis of working fluid with higher heat transfer enhancement is needed in the future.

Application of liquid base working fluid in all liquid cooling methods (heat sink, thermoelectric cooler, heat pipe, jet impingement) enhances significantly the heat transfer performance of the CPU cooling system. There are many types of heat sink and the liquid block had been studied. Current research actively studies using heat sink design and different types of working fluid including nanofluid. More studies on higher heat transfer enhancement of heat sink design and different types of working fluid need to be proposed in the future. Next, the TEC method where the CPU is directly connected with the cold side of TEC and the hot side of TEC is directly connected with water block also one of the efficient ways for CPU cooling. But more study is needed to overcome high-power

consumption. Other than that, the heat pipe consists of a wicked heat pipe and thermosiphon. The study of natural convection using capillary wick needs to study more to increase the efficiency of cooling device Thermosiphon is limited to gravity orientation. Jet impingement with a high-velocity profile of working fluid can enhance the cooling performance of the cooling device. Jet impingement method has many parameters that can be studied such as distance jet-to-surface, distance nozzle-to-fins, nozzle diameter and many more. But more study is needed for high power consumption by jet impingement method.

Acknowledgement
The authors would like to thank Universiti Teknologi Malaysia and the Ministry of Education of Malaysia for supporting this research activity. This research was funded by a grant from International - Takasago Thermal Engineering Co. Ltd. (Takasago Grant R.K130000.7343.4B365).

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