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Investigation on the Performance Test on Liquid Cooling System for CPU of Desktop Computer Cost Effective Enhancement

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ABSTRACT

The growth of rapid computing in the modern era over the past few years give personal computer microprocessor high computing ability with billions of transistors planted on it. This increasing transistor also increases total heat dissipation of CPU with higher voltage and frequency. Conventional aluminum extrudes heat sink used in desktop computers has several limitations to remove high heat flux generated in the microprocessor. The main focus of this paper was to investigate use of a liquid cooling system by modifying the conventional heat sink for improved heat dissipation in computers. The traditional heat sink was shifted with Copper-Aluminum joint composite system for material modification and liquid cooling system introduced instead of conventional air-cooling system method. Both experimental and numerical investigation are carried out for no load and full load condition. ANSYS-FLUENT finite volume software was used for the numerical simulation. CPU performance, processor temperature, thermal power, thermal resistance and different properties effect with varying material; method is demonstrated in this paper. Comparisons of the system with feasibility also checked out. This study can help to develop guideline for design and modification a conventional extruded aluminum heat sink with better heat transfer performance for microprocessor.

Keywords: Heat transfer, Heat sink, Liquid cooling, Composite material, Ansys-Fluent

1. Introduction

As modern computing progress very rapidly from the past decades, it needs more improved processing unit to transfer data to keep pace with. Due to this reason, the accessories and others components rapidly reduction with size performance. These compact and thinner gadgets are very high speedier along with produce more heat dissipation rate. Computer processor is also reduced from huge box to tiny little unit with small dimension. Those need others accessories to be kept cool within the temperature limit. Cooling of those components like CPUs, GPUs and others electronics has been taken seriously now a days to increase life and efficiency of those. At present, the waste heat released by the central processing unit (CPU) of a desktop and server computer is 80 to 130 W and of a notebook computer is 25 to 50 W [1]. In the latter case, the heating area of the chipset has become as small as 1‑4 cm2. This problem is further complicated by both the limited available space and the restriction to maintain the chip surface temperature below 100 ℃. Commonly used conventional aluminum extruded CPU heat sink block used for low price, weight and performance reasons. But this type of sinks is limited to dissipation rate of heat cooling performance and also caused acoustic noise. But water cooler of CPU system development is free from this problem with better efficiency. [2]. Heat sinks with high performance heat removal rate are used by rapid computer users and PC builders. Still, high revolution speed fans of the conventional extruded heat sinks attract attention with its acoustic noise [3]. Therefore, this study propose is to modification of a conventional heat sink, along with liquid cooling method capable of reducing acoustic noise. So that it can meet the cooling performance requirements perfectly by experimental and simulation that validate the work.

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 significantly in the electronic engineering, medical engineering and other fields. Researchers have widely studied the heat transfers and pressure drop in the mini and micro-channel. A theoretical model for calculating the cooling performance developed for integrated thermoelectric micro cooler by Gao and Rowe [4]. Heat dissipates of a computer with different process run and high computing performance analysis done by Amollo T.A [5]. A brief description of the cooling system for computer analysis is done by Kioan Cheon [6]. Water/air dual cooling method for CPU cooling arrangement invention carried out by Neng-Chao Chang [7]. A three-dimensional analytical method of Fourier expansion solution for determination of the spreading thermal resistance using a cubic heat spreader for electronic cooling applications developed by Feng and Xu [8]. Thermal performance of various geometry pin fin heat sink studied theoretically and experimentally by Kobus and Oshio [9]. Steady-state convective heat transfers from an in-line four electronic chips with water in a vertical rectangular channel reviewed by Bhowmil [10]. Li et al. ascertained the thermal performance confined impingement cooling to heat sink [11]. The study of microchannel heat sinks with single-phase heat transfer for electronic packages reported by Zhang et al. [12]. Experimental and numerical studied of in-line square pin-fin heat sinks on

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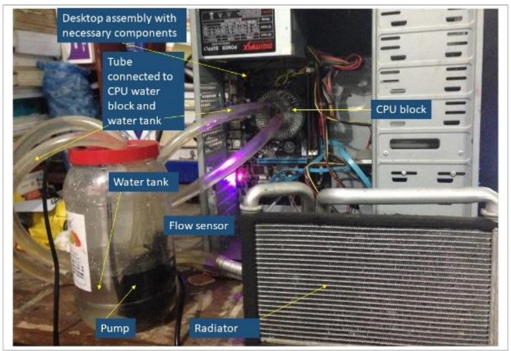
the hydraulic resistance and heat transfer by Dogruoz et al. [13]. An electronic devices heat sink with various square modules resistance and heat transfer by Dogruoz et al. [13]. An electronic devices heat sink with different square modules array was investigated on air cooling system to find characteristics done by Mohamed [14]. Heat transfer and fluid flow characteristics of finned surfaces investigated by Didarul [15]. The thermoelectric cooler calculation for steady-state operational point user-friendly graphical method proposed by Lineykin and Yaakov [16]. Simulation using COMSOL Multiphysics to determine the fluid dynamics on the active liquid heat sink for CPU cooling system done by Song-Hao Wang et al. [17]. The relationship between CPU and system temperature, thermal power, CPU tasking level investigation done by Anna Haywood et al. [18]. An innovative active heat sink using liquid for CPU cooling system developed by Song-Hao Wang et al. [19]. Heat pipe cooling technology for desktop CPU construction and performance analysis by Kwang-Soo Kim et al. [20]. Application of nanofluids to heat pipe liquid block and thermoelectric cooling of electronic equipment carried by Nandy Putra et al. [21]. Miniature loop heat pipe with the flat evaporator for CPU cooling developed by Randeep Singh et al. [22]. Heat dissipation issue of microprocessor cooling current traditional process by air cooling system can reach to a point where they failed to cool more of that point [2]. Copper Aluminum nano junction normal temperature process and methods applied to LED heat transfer performance experimented by Ming-Wen Wang et al. [23] Air can carry away more heat dissipate from the CPU with more heat sink area and more airflow. The heat sink size doesn't matter, cause the contact point of CPU slug can get more heat and encounter with spread resistance. Copper-based heat sinks can disperse heat over the surface but up to an end more than aluminium material. Presently there are many limitations on the liquid cooling system that's why the mainstream industries of desktop and notebook computer makers can't adopt to use and introduction liquid cooling technology. Still, in case of air-cooling system vs liquid cooling system, water is much more efficient as a dissipating medium for cooling CPU. But the researcher tries to advancement the limitation and works hard to make the liquid cooling system integrated simplify with improving cooling efficiency.

2. Methodology

2.1 Experimental apparatus setup

In this experiment procedure, different components are used as 1. One aluminium heat sink block and one Cu-Al joint heat sink block 2. Two Temperature Sensors connected with inlet and outlet 3. One Liquid flow measurement sensor 4. Aluminum Radiator 5. A DC 1020 small fish tank USB pump 6. Reservoir 8. Water (as coolant) 9. Soft tube and fittings. The USB pump powered by CPU port connection after starting the desktop and then coolant liquid (water) flow from reservoir through soft tubings and mountings to the heat sink contact with the processor. In this experiment, Intel Core i3-2120 3.30 GHz processor used and its minimum thermal design power is 33.8 Watts at the idle situation and 65 Watts at full load condition [24]. The heat flux conducted to the heat sink block, and then coolant take away the heat by convection process. The convected heat is dispersed into the environment by the radiator. The temperature sensors were attached to the inlet and outlet position of the heat sink and the flow sensor attached in the finished position of the pump outlet pipe. Temperature and water mass flow rate were measured at idle load and full load conditions.

The basic block diagram of the proposed system is as shown in Fig.1(a). diagram. From the diagram, the water pump driven from the CPU when the USB port connection powers on it. Then the coolant liquid flow from the reservoir through the soft tubing and mountings to the area where the heat flux produced in the central processing unit (CPU) and graphics processing unit (GPU) area. Then the heat flux carried away from there by the latent temperature of the fluid flow by forced circulation of coolant liquid. Then the liquid passed through the radiator and cooled down there in the block which contact with the area to be cooled there the heat flux flow through conduction. From Fourier's law of heat conduction, simplified one-dimension form in the x-direction, we can calculate with the help of the higher and lower region temperature at which rate the heat transferred by conduction. With the flow of coolant, the heat flux moved to the radiator area.



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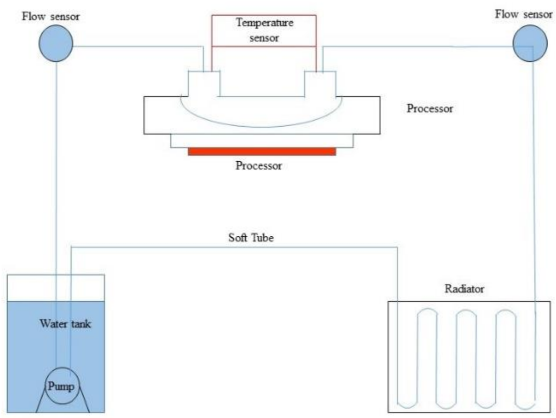

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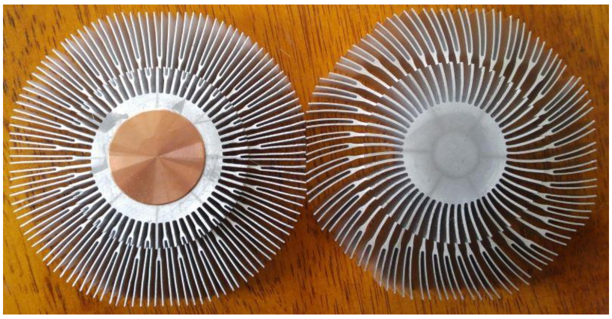
Fig.1 (a) Experimental and (b) Schematic diagram of the proposed system

A radiator has multiple fins inside of it with the increasing surface area inside the radiator. There the heat flux carried away by the convection process and the cooled liquid coolant again stored in the reservoir. Those the loop system of coolant works to remove the excess heat flux produce in the high-performance CPU and GPU. The Cu-Al joint heat sink block constructed such way that Cu plate surface contact with CPU slug and Al extruded block connected with liquid cooling system unit. The experimental data are taken when the processor is running at no load condition and full load condition. During no-load condition, the processor running idly without any task. But when the processor running at top load condition, its insured by running several high configuration program names: Windows Media Player Google Chrome-5 tabs, Format Factory-4 tabs and Solidwork.



(a)

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Fig.2 (a) Cu-Al joint slug heat sink and only Al extruded heat sink used for experiment (b) Conventional air cooling system and liquid cooling system block

2.2 Experimental data calculation

The temperature sensors using inside inlet and outlet give coolant temperature, and flow sensor provides a mass flow rate of the coolant—the CPU base temperature taken from the system using software which is connected with the heat sink. The temperatures are collected at near no-load idle conditions and full load condition. For the first test CPU running at idly with no software running background. Thermal power calculated using recorded temperature and measured mass flow rate with the following equation (1) [10],

$$\dot{Q} = \dot{m}\, C_p\, \Delta T \quad (1)$$

Where, C_p of coolant (water) is 4.18 $Jg^{-1}K^{-1}$, mass flow rate, $\dot{m}$ is 31.667 gs^{-1} and ΔT is temperature difference outlet and inlet fluid temperature,

$$\Delta T = T_{fluid,out} - T_{fluid,in} \quad (2)$$

The coolant received the heat calculated as following equation (3), (4) [25]:

$$q_f = \rho \dot{m} C_p \left(T_{fluid,out} - T_{fluid,in}\right) \quad (3)$$

Using the log mean temperature difference method, the thermal performance of the heat sink calculated as heat transfer performance directly related to inlet ($T_{fluid,in}$), outlet ($T_{fluid,out}$) and base temperature (T_{Base}) of sink.

$$\Delta T_{LMTD} = \frac{(T_{Base} - T_{fluid,in}) - (T_{Base} - T_{fluid,out})}{\ln\frac{(T_{Base} - T_{fluid,in})}{(T_{Base} - T_{fluid,out})}} \quad (4)$$

The convective thermal resistance has effects on resisting heat removal performance on coolant, so convective thermal resistance for coolant flow calculated using following equation (5) [26]

$$R_{th} = \frac{1}{\bar{h} A_{eff}} = \frac{\Delta T_{LMTD}}{q_f} \quad (5)$$

Using equation (5) with experimental values, heat transfer coefficient calculation carried out. The equation simplified as followed:

$$\bar{h} = \frac{q_f}{A_{eff} \Delta T_{LMTD}} \quad (6)$$

3. Numerical modeling and validation

Using ANSYS 2020R1 Academic, 2D simulation for liquid cooling system carried out with experimental data validation and mesh dependency test. For this process, some assumption taken respect to data calculation described follow:

- Assumed that all inlet, outlet joint junction with Cu-Al joint slug interface are perfect.
- There is no thermal radiation from heat source, only conduction from processor surface which heat carried out with coolant flow.
- The heat distribution is uniform all over the surface of the heat sinks.

First-order upwind scheme for energy and momentum, standard pressure and least-squares cell-based gradient use for spatial discretization. COUPLED pressure velocity coupling algorithm for absolute velocity formation in 2D planed space for steady time pressure-based solver use. Default Aluminum and Copper material properties are selected from the ANSYS material database for solid surface and water (l) use in the fluid section. The governing equations are considered converged when residuals are small for 10^{-6} for mass momentum equations and 10^{-8} for energy equation—the area-weighted average value taken for different field variable from surface integrals results.

Mesh dependency test performed for specific suitable mesh size for analysis for an independent solution as closely as possible. The validation of the simulation carried out for Cu-Al joint slug and only for an Aluminum heat sink for the different velocity of the coolant.

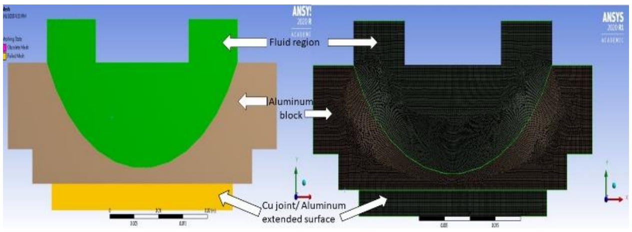
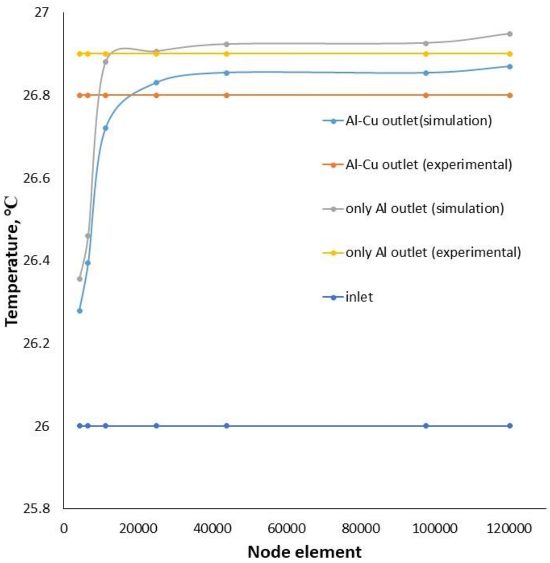


Fig.3 Planer geometry of the simulation before and after meshing



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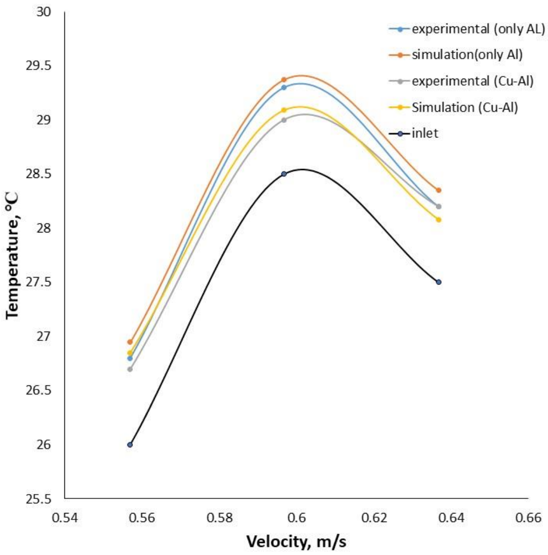

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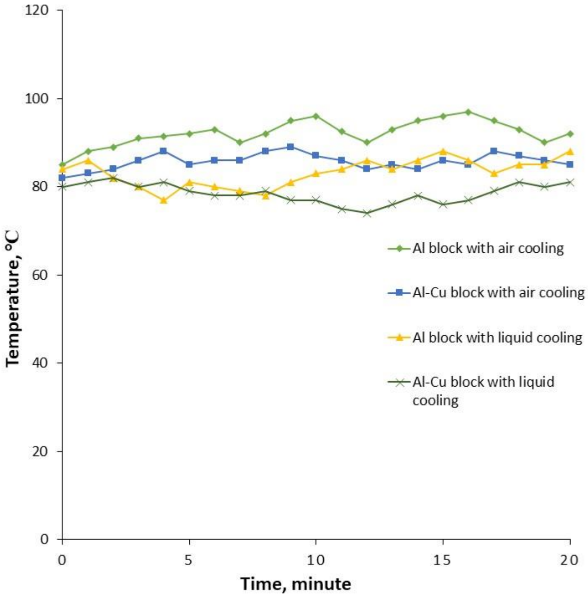
Fig.4 (a) Mesh dependency test and (b) Verification of simulation work with experimental data

The simulation works validate using experimental data for different velocity. Mesh dependency test carried out with the element size of 9e-5 m. Fig.3 showed the geometry and mesh of the simulation and Fig.4 showed the mesh dependency (a) and verification with experimental (b) for the simulation work.

4. Result and Discussion

All the experiments were run at room temperature of 27-31℃ for 20 minutes for both full load and no-load conditions using air cooling and liquid cooling methods with five minutes' interval before starting again to cool down the processor (heat source). The CPU's temperature profile for full load (a) and no-load (b) condition for different sink with method type is shown in Fig.5. The coolant used for the experiment is locally available water and the air-cooling use conventional air-cooling fan at the upper side of the heat sink.



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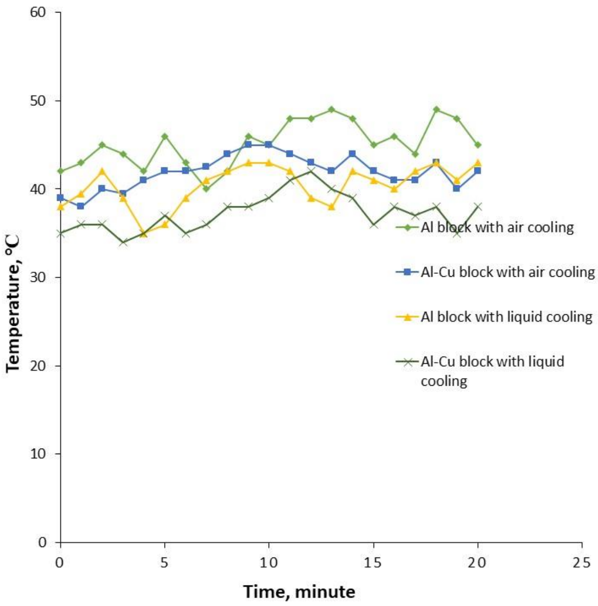

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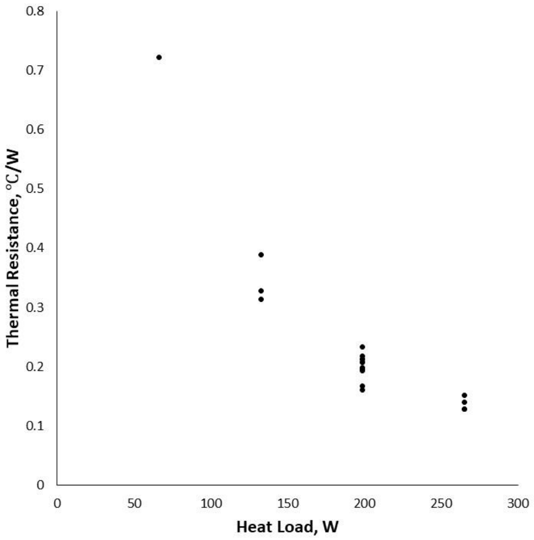
Fig.5 CPU temperature profile (a) Full load (b) No load condition for different block and method

As modern processors can produce 130 watts or more depending upon that, the block and coolant inlet, outlet temperature may be different along with the processor.

The main objective of the cooling system is to minimize the base temperature of the heat sink and heat source temperature from rising and hold at a constant level. Cu-Al joint heat sink show consistency for both air and water-cooling system method growing below then Al heat sink at full load condition. For no-load condition, the CPU usage almost 1 to 10% but the result was randomly varied 7 to 10 ℃.

Fig.6 showed a variation of convective thermal resistance concerning heat load for different processor works. With the increase of the processor work, heat load also increases, resulting in gradually decreasing the thermal resistance for both Al and Cu-Al heat sink with liquid cooling. When the processor workload about 75 to 90% the thermal resistance dropped from 0.7 ℃/W to 0.15 ℃/W for both sinks.



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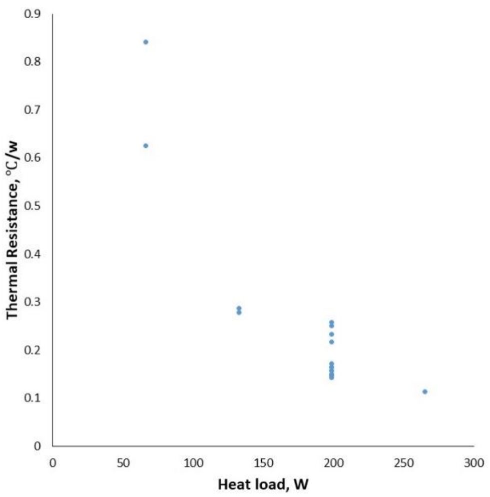

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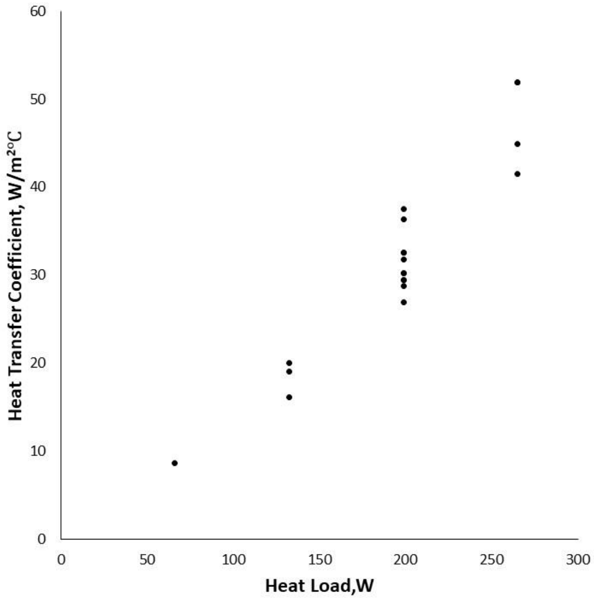
Fig.6 Thermal resistance vs Heat load for different processor works for (a)Al block (b)Cu-Al block at full load condition with liquid cooling system

The thermal performance of the heat sinks depends on the conductive heat transfer coefficient. The heat transfer coefficient calculated based on a log means temperature difference of the fluid flow through the sink. The high value of heat load gradually increases the heat transfer coefficient for both heat sinks shown in Fig.7. The operating temperature limit of the cooling system limits the heat transfer coefficient.



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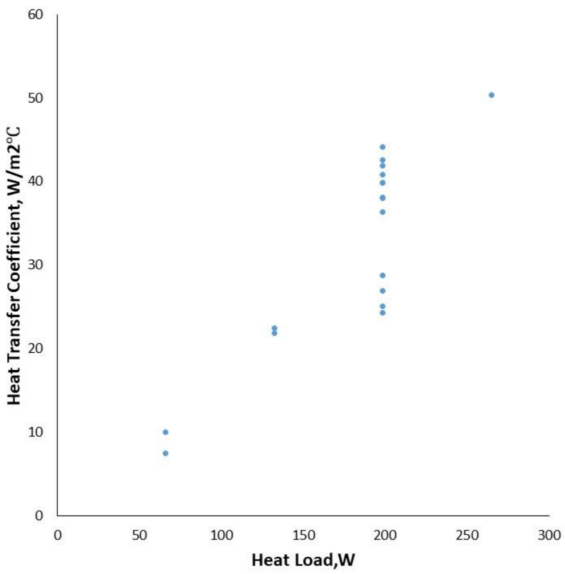

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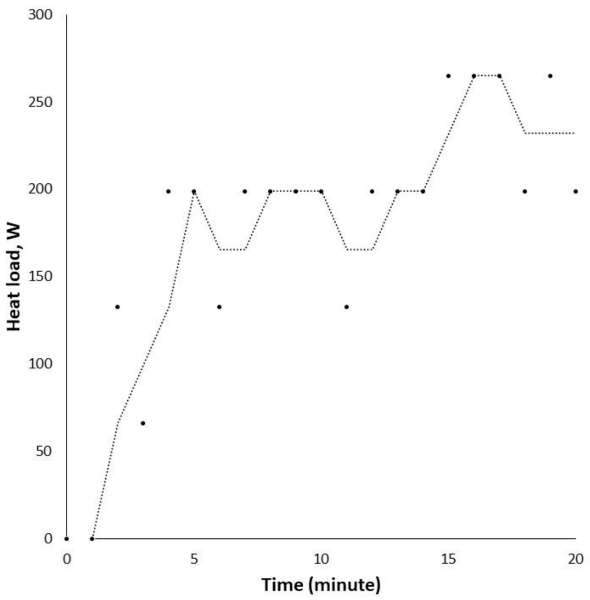
Fig.7 Heat transfer coefficient vs Heat load for different processor works for (a)Al block (b)Cu-Al block at full load condition with liquid cooling system

Fig.8 showed liquid cooling thermal power extraction heat load for the liquid cooling system block. As the computer components work faster and process a lot of information at full load, workload implies more current to use, and the processor workload increases rapidly.



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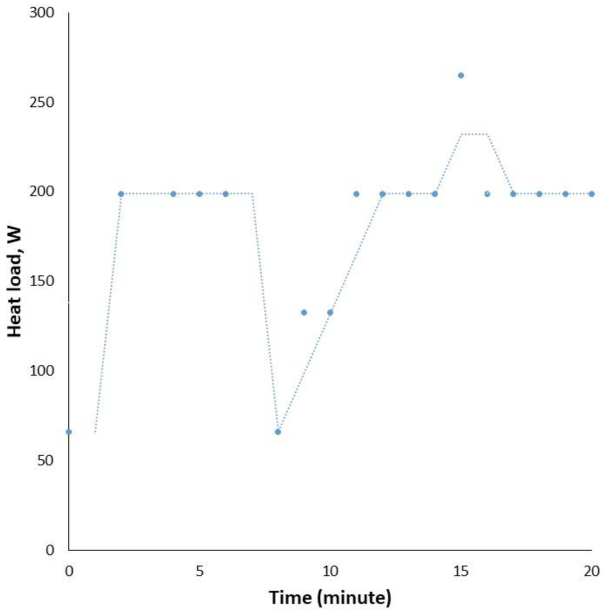

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Fig.8 Heat load vs Time for (a)Al block (b)Cu-Al block at full load condition with liquid cooling system

Table1: Comparison of different cooling technique

	No load		Full load	
Cooling Technique System	Low temperature of processor ,℃	High temperature of processor, ℃	Low temperature of processor ,℃	High temperature of processor ,℃
Only Al Extruded Air cooling	40	49	85	97
Al-Cu joint Air cooling	38	45	82	89
Only Al Extruded Water cooling	35	43	77	88
Al-Cu joint Water cooling	34	42	74	82

Heat load depending upon processor and another current system consumption works. The Al block only showed linear slop increasing heat load at fig.8(a), but the Cu-Al block showed almost constant heat load at fig.8(b) for full load conditions for 20 minutes. At table 1, the summary of the experiments can be offered with maximum and minimum temperature of the cooling system.

5. Conclusion

Because of various different limitations of air-cooling system along with improvement of high-level heat consumption for CPU, modified heat sink studies are experimented. As copper is better than aluminium for heat transfer and aluminium is better than copper for heat dissipation, Cu-Al joint heat sink performance much faster and better for both air and water-cooling systems. A high-speed fan can be used to improve the thermal performance of conventional Al extruded block, but liquid cooling solves the problem of acoustic noise of it. Heat dissipation increase with the increase of processor works of the computer run; resulting in high conductive absorbance with heat sinks and then convection the heat to air or water. But using the pumps and water in the cooling system, any leak can proceed to accidental disaster and damage to the expensive electrical components. Industrial mass production of 3-4 mm Cupper block can reduce two to three times copper waste joining with Aluminum extruded design sinks. Also introducing liquid cooling to conventional heat sinks give much efficiency to remove heat. By simulation, the feasibility of the cooling system capacity justified. Thus, it can be concluding that Cu-Al joint heat sink is better with feasibility but with proper consideration, with the liquid cooling system, it gives a much-improved performance.

7. Acknowledgement

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NOMENCLATURE

$\dot{Q}$: Thermal power, Watts
$\dot{m}$: Mass flow rate, gs^{-1}
C_p : Specific heat of water, $Jg^{-1}k^{-1}$
ΔT : Inlet and outlet fluid temperature difference, °C
$T_{fluid,in,out}$: Inlet and outlet fluid temperature, °C
q_f : Coolant heat received from processor, Watts
ρ : Density of water, kg/m^3
ΔT_{LMTD} : Log mean temperature difference, °C
R_{th} : Convective thermal resistance °C/Watts
A_{eff} : Effective area, m^2
h : Heat transfer co-efficient, W/m^2°C