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# Experimental Investigation of Water Cooled Minichannel Heat Sink for Computer Processing Unit Cooling

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## ABSTRACT

the present experimental research use a minichannel heat sink manufactured from copper metal with a rectangular cross section area channels and hydraulic diameter 1.6667 mm. The de-ionized water is used as a coolant liquid to cooled the 2.8 GHz computer processing unit chips in a real personal computer. This study discusses the effects of varying mass flow rates of the coolant water through minichannel, with changing the load operation conditions of the CPU chip, on CPU temperature of real personal computer, heat transfer rate, thermal resistance, Nusselt number, pressure drop. Also study the effect of junction temperature on failure rate and mean time to failure. A comparison between water cooling system with air cooling system. The results have shown that the CPU temperature is dependent on the coolant fluid (water or air) temperature, which is increases with the increase of coolant fluid temperature and vice-versa. The water cooling system have proved to be successful in

reducing the CPU temperature from 42˚C to 33˚C at 0.0044 kg/s. The values of heat transfer rate at load operation condition are 907.88 W/hr which is higher than at no-load operation conditions that reached to 670.51 W/hr at 0.0177 kg/s of mass flow rate for one hour of period time. The amount of pressure drop increases with increses a mass flow rate and with operation CPU at load conditionis which that is higer than at no load operation condition. The failure rate at load operation condition is higher than at no-load operation condition this due to CPU temperature which that at load operation conditions is higher than at no-load operation conditions, this lead to decreases the mean time to failure.

***Keywords:*** *Forced convection; Liquid cooling system; Minichannel heat sink; Personal Computer; computer processing unit chips*

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## I. INTRODUCTION AND PREVIOUS WORK

Today's requires of electronic equipment development need to be high CPU performance with process more data and faster [1]. To meet this requirement the CPU is assembled with more transistors [2], integrated circuits (IC) have become smaller and smaller this increase the transistors density of chips area and led to increase CPU heat fluxes [3]. The continuous miniaturization of electronic chip, the chips become down to micro/nano-scales from (10 µm - 30 nm) and reaching to the worst feature in nanotechnology area which the transistor gate length to 65 nm [2,4], besides to increasing the frequency of the system, the CPU and GPU higher operation for many gigahertz's of frequency [5]. All these reasons lead to increased heat generated and temperature inside the CPU chips, excessive temperature leds to increased power consumption through CPU chips, which decreases the chips efficiency and the thermal reliability of an electron [6 , 7], then a failure and a shortened life of CPU chip [8]. The chip temperature must be below the allowed limits which are less than 85˚C [9]. The perfect way to remove the heat dissipation and maintaining the chips in safe operation temperature is by using the suitable cooling system which is played an important part in ensuring reliable operation of electronic equipment [10], and removes the waste heat that produced by computer components to keep them within the limits of operation temperature [7]. Recently, attention was drawn to the use of minichannel heat sink because it's given a higher heat transfer and convective heat transfer coefficient with a mild pressure drop through minichannel.

Several researches have been studies minichannel heat sink such as M.B. Bowers and I. Mudawar [11] which is study two-phases flow inside microchannel and minichannel for cooling electronic chips explored for the application of flow boiling R-113 inside minichannel and microchannel heat sink with hydraulic diameter is

2.54 mm and 0.51 mm respectively, they obtain higher heat fluxes for cooling the electronic application with low flow rate and low pressure drop. Bruno Agostini and Barbara Watel [12] are study friction factor and heat transfer of flow R134a as a coolant liquid inside a rectangular minichannel heat sink, they getting the higher heat flux from 210 – 49700 W/m$^2$ for mass flow rate 65 - 2900 kg/m$^2$. Ning Lei [13] was study the thermal properties of multilayer minichannel heat sink in single and two-phase flow. This study shown that the multilayer minichannel should get higher advantages more than single-layer minichannel. Paisarn Naphon [14] experimentally studies the de-ionized water cooling for CPU by the minichannel heat sink with and without thermoelectric, the thermoelectric allows to improve efficiency of heat transfer in the electronic equipment**.** Kazuhisa yuki [15] experimental study the minichannel heat sink for single phase flow with different fin thickness, channel width and number of fins, the result of experiment is the minichannel improves heat transfer, which the heat flux is reaching to 300 W / cm$^2$. Ali jam et al. [16] study the cooling by using two type of nanofluids such as $AL_2O_3$–$H_2O$ and to $TIO_2$–$H_2O$ with different laminar flow rate through minichannel heat sink they found the nano-fluid improved the thermal conductivity to 11.98% by using $AL_2O_3$–$H_2O$ and 9.97% by using $TIO_2$–$H_2O$. Jami Frances Tullius [17] show by his study that increasing the surface roughness of minichannel heat sink leads to increased thermal performance about 3.6%, the addition of surface roughness could provide a more important contribution in removing heat compared to smooth surface. Mousa and Mostafa [18]. study the air as a coolant working fluid of minichannel heat sink in electronic devices with air flow rates 0.002 - 0.005 m$^3$/s by using a heater at the ability of power 80 - 100 W, they explained that increases heat transfer with increasing air mass flow rate and channel base temperature. Keyur Thakkar et al. [19] studying thermal and hydraulic single phase flow through minichannel for cooling electronic equipments. They found that in laminar single phase flow with reduce hydrodynamic diameter gives higher heat transfer, lower in thermal resistance and higher Nussle number. M. Gayatri [20] experimental study of liquid cooling system in a single phase flow by using minichannel heat sink for cooling electronic equipment. This experimental shown the liquid cooling system that using water as a coolant has best performance compared with diluted ethylene glycol at various flow rates. Vijayaraghavan Vembuli [3] study three different minichannel heat sinks were design with a variation of width 2 mm, 3 mm and 4 mm, which kept the height of the channel at 4 mm. This study show that 2 mm is the most effective formation from all three minichannel heat sink which has the maximum temperature drop from 17 - 20 ˚C at 25 ml/min of mass flow rate and 82 Pa pressure drop also the base temperature decreases with increasing the flow rate of distilled water during a period of time.

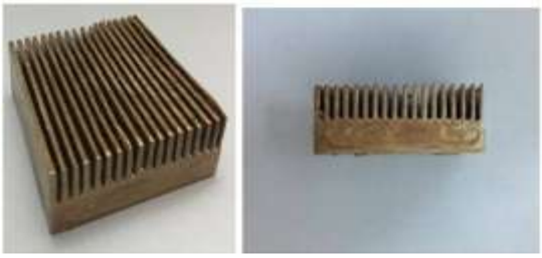
The objective of our work is to improve the electronics equipment performance such as competure processing unit by using water cooling system with minichannel heat sink at load and no-load operation condition of CPU chips model Intel ® Celeron ® Process running at 2.8 GHz for a personal computer. The CPU chips provides a various load power were the instability and irregular CPU temperature which depending on CPU jobs or hotspots region inside the CPU chips. The heat transfer and pressure drop in the minichannel have been reported, the failure rate and mean time to failure for CPU chip have been investigate.

## II. EXPERIMENTAL SETUP

### 2.1 Minichannel Heat Sink:

The minichannel heat sink as shown in Fig. 1 was manufactured from copper 360 alloy, with dimensions 35 mm × 35 mm with 10 mm thickness. A minichannel includes the uniform arrays of 18 fins and 17 channels, a fins design of rectangular cross section with hydraulic diameter 1.667 mm. A fins thickness, channel width and channel height and all other dimensions are illustrated in Fig. 2 and given in Table 1. The bottom base of minichannel heat sink is installed on the upper face of CPU chips to absorb and transfer the heat that dissipation from CPU chips to the water flow through the channels of minichannel. The minichannel heat sink consists of one inlet and one outlet. The interface materials (silicon paste type AOS Silicone XT white paste) was used to install minichannel heat sink at the CPU chips of the motherboard for personal computer.

**Fig. 1** The minichannel heat sink.



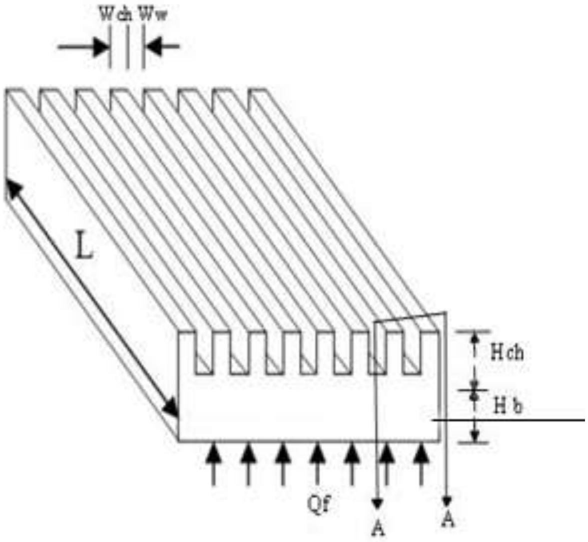


Fig. 2 Schematic of the minichannel heat sink geometry.

**Table 1** Dimensions of minichannel heat sinks.

| Description | Symbol | Value |
|---|---|---|
| Channel Width | $W_{ch}$ | 1 mm |
| Height of channel | $H_{ch}$ | 5 mm |
| Length of channel | $L_{ch}$ | 35 mm |
| Width of finned section on heat sink | A | 35 mm |
| Un-finned length of heat sink (manifold) | B | 3 mm |
| Thickness of fins | $W_w$ | 1 mm |
| Thickness of heat sink base plat | $H_b$ | 5 mm |
| Hydraulic diameter | $D_h$ | 1.6667 mm |
| Number of channel | N | 17 channels |
| Number of fins | $N_{fin}$ | 18 fins |

**2.2 Test loop System:**

A schematic diagram of experimental device is shown in Fig. 3 the close loop of de-ionized water is consisting from a set of personal computer, minichannel heat sink component, water pump and water storage tank, all these parts are connected by flexible tube. The water is cooled by vapour compression refrigeration system to keep the temperature of the coolant water inside the storage tank between 20˚C - 22˚C and water pump used to recirculation the coolant from the storage tank to the flow meter sensor and then pass through the minichannel heat sink. The hot water outlet from minichannel to storage tank. A personal computer turned on to record a data every one minute for a period time of one and two hours at load operation conditions by applying a softwore program at experimental computer or at no-load operation conditions without applying any softwore programs to measured the different pressure between the inlet and outlet of coolant water, inlet and outlet temperature of coolant water to and from minichannel, CPU temperature, and mass flow rate for coolant water.

Water inlet and outlet temperatures to and form the minichannel heat sink was measured by two positive temperature coefficient sensor PTC with Arduino device, the mass flow rate measured by Hall effect water flow meter sensor model YF - S201 with Arduino, the differential pressure between inlet and outlet of minichannel measured by the pressure transducer digital manometer modul Lurton PM -9107 with data acquisition software, and a program software (inst-speed fan, 4.5.1) was used to measured CPU temperatures. This experiment conducted with various flow rate of coolant water cooling with load and no-load operation conditions of CPU chips of personal computer.

An experimental work representing of an experimental flow chart linked to the experimental procedureare illustrated in Fig. 4.

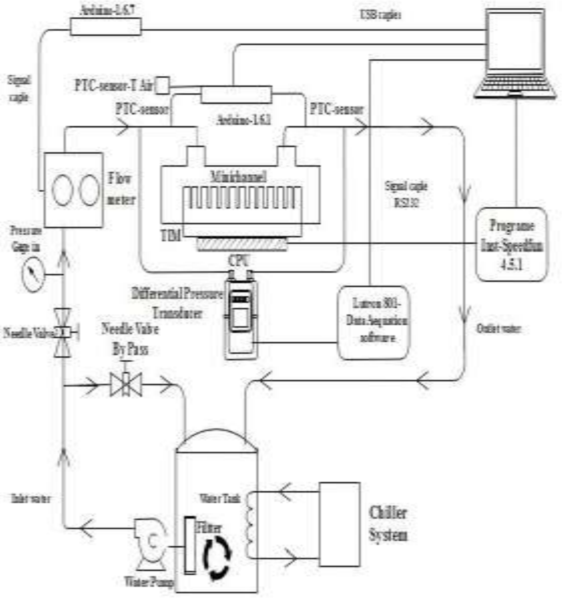


**Fig. 3** The overall schematic of experimental setup of minichannel heat sink with water cooling system and refrigeration system for a central processing unit (CPU).

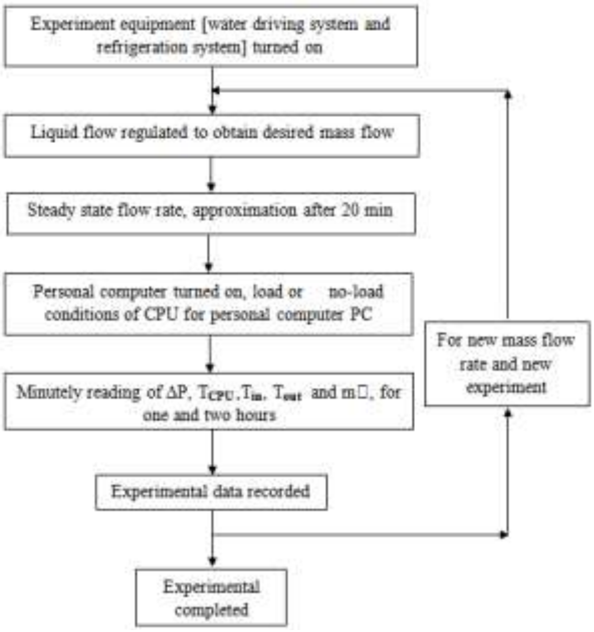


**Fig. 4** The experimental flow chart.

**2.3 Experimental Data Reduction:**

The heat transfer $Q_f$ to coolant water which is flow through minichannel heat sink is calculated by the following equation [3, 22, 24];

$Q_f = m^{\cdot} \; C_p \; (T_{out} - T_{in})$
(1)

The mean fluid temperature $T_{mf}$ was used to evaluate the Thermophysical properties of water which is calculated by the following equation [21];

$T_{mf} = \frac{(T_{out} + T_{in})}{2}$
(2)

The convective heat transfer coefficient is depending on the heat absorbed by the fluid which is calculated by the following equation [2, 3, 22];

$h = \frac{Q_f}{A_{eff} \times \Delta T_{LMTD}}$
(3)

where the effective surface area of minichannel heat sink $A_{eff}$ was calculated by the following equation [3, 21, 23];

$A_{eff} = N \, L_{ch} \, (W_{ch} + 2 \; \eta_{fin} \, H_{ch})$
(4)

The fin efficiency $\eta_{fin}$ was taken equal to 100% because the minichannel heat sink made from copper material which has a high thermal conductivity [21].

The logarithm mean temperature difference $\Delta T_{LMTD}$ is very common way use to calculate the thermal performances of heat exchanger and can be estimated by the following equation [21, 22, 24];

$\Delta T_{LMTD} = \frac{(T_b - T_{in}) - (T_b - T_{out})}{ln(\frac{T_b - T_{in}}{T_b - T_{out}})}$
(5)

The $T_b$ is the base temperature and can be calculated by the following equation;

$T_b = T_{cpu} - Q_f \sum(\frac{H_b}{K_{hs} \, A_b})$
(6)

The temperature of central processing unit $T_{cpu}$ measuring by a program softward (inst-speedfan 4.5.1), and this softward apply at experimental personal computer.

The convective thermal resistance $R_{Th}$ can calculate by the following equation [21, 24];

$R_{Th} = \frac{\Delta T_{LMTD}}{Q_f}$
(7)

A Nusselt number can be calculate from the following equation [3, 12, 24];

$Nu = \frac{h D_h}{k_f}$
(8)

Where $D_h$ is the hydraulic diameter for rectangular minichannel and can be calculate by following equation [3, 21, 25];

$D_h = \frac{4 \, W_{ch} \, H_{ch}}{2 \, (W_{ch} + H_{ch})}$
(9)

The Reynolds number was evaluated from following equation;

$Re = \frac{U_m \; D_h}{v}$
(10)

The mean velocity of fluid $U_m$ through minichannel heat sink which is equal to inlet velocity $U_{in}$ [12, 23, 26], and can be evaluated by following equation;

$U_m = \frac{m^{\cdot}}{f \; A_c \; N}$
(11)

Where $A_c$ is the fins spacing area and can be calculating from following equation;

$A_c = H_{Ch} \, W_{Ch}$
(12)

Which is equal in this study to $5 \times 10^{-6}$ $m^2$ for one fin.

The failure rate $\lambda$ is the number of elements failure per unit time and can be calculate by following equation [27];

$\lambda \; (t) = (C_1 \; \pi_T + C_2 \; \pi_E) \; \pi_Q \; \pi_L$
(13)

which $C_1$, $C_2$, $\pi_E$, $\pi_Q$ and $\pi_L$ are constants as given in Table 2, which is depending on the description of CPU chips and is given in Table 3.

The value of temperature factor $\pi_T$ can be calculated from following equation [27];

$\pi_T = 0.1 \, exp\left(\frac{-Ea}{8.617 \times 10^{-6}}\left(\frac{1}{T_j} - \frac{1}{298}\right)\right)$
(14)

Where the maximum chips temperature $T_{CPU,max}$ is used as estimate for junction temperature $T_j$ [28].

The mean time to failure (*MTTF*) can be calculated by following equation [28];

$MTTF = \frac{1}{\lambda}$ $(10^6/failures \;\; hour)$
(15)

**Table 2** Description of the empirical constant of CPU chip

| Symbol | Description | Factor | Value |
|---|---|---|---|
| $C_1$ | Empirical constant (gate/logic arrays) | No. Bits | 0.56 |
| $C_2$ | Empirical constant (package failure rate for microprocessor) | No. Pins | 0.12433 |
| $\pi_E$ | An environmental factor | Type GB | 0.50 |
| $\pi_Q$ | A quality factor | Class B | 10 |
| $\pi_L$ | Learning factor | More than 2 years | 1 |
| $\pi_T$ | Temperature factor | $T_j$ = $T_{cpu,max}$ | Eq. 14 |
| $Ea$ | The effective activation energy in (ev ) | For copper wire | 0.6 eV |

**Table 3** The description of CPU chips.

| The CPU chips description | Pentium Processor 2.8 GHZ |
|---|---|
| Kind of CPU | Intel® Celeron ®Process |
| The processer base frequency | running at 2.8 GHz |
| FSB speed | 400 MHZ |
| No. of cores | 1 |
| Number of Bits | 32 |
| Type | MOC devices, GB |
| VID voltage range | (1.315-1.525) Volt |
| No. copper pins [$N_p$] | 224 |

## III. RESULTS AND DISCUSSION

This experiment study the water cooling computer processing unit by using copper minichannel heat sink, which performed at the room temperature of 31˚C - 34˚C, firstly operation the chiller unit and water recirculation pump then regulation the mass flow rate at desired value lately operation the personal computer to turn the 2.8 GHz CPU chips with changing the CPU operation conditions at no-load and load conditions for a period of time. A multi-softwore program work load as load operation conditions that applying on CPU chips of experiment personal computer.

### 3.1 The CPU Temperature ($T_{CPU}$):

The CPU temperature is illustrated in Fig. 5 and 6 were the irregular fluctuations are observed in CPU temperature with time at no-load and at load operation conditions for three different mass flow rates of coolant water which is 0.004 kg/s, 0.0066 kg/s and 0.011 kg/s were the inlet temperature of coolant water to the minichannel heat sink is approximately constant. This irregularity in CPU temperature is due to CPU working with non-uniformity heat dissipation which is that dependent on the jobs of CPU chips, that cause the hotspots region inside the CPU chips during operation and increase in CPU junction temperature [29]. Also the maldistribution of flow rate in parallel channel causes nonuniformity in CPU temperature due to inlet and outlet manifold design where the flow rate in centre channel is higher than at bottom channel in minichannel heat sink, this lead to different in CPU temperature between centre cannel and bottom channel which is causative the non-uniformity temperature pattern. The non-uniformity temperature is increases with increase the heat generated at load operation conditions as show in Fig. 6 [30, 31].

The effect of changing the operation conditions on CPU temperature every 15 minute of period time was shown in Fig. 7. The CPU temperature is increases at load operation conditions and decreasing at no-load operation conditions because the hotspot regions inside the CPU chip increase with load operation conditions [29].

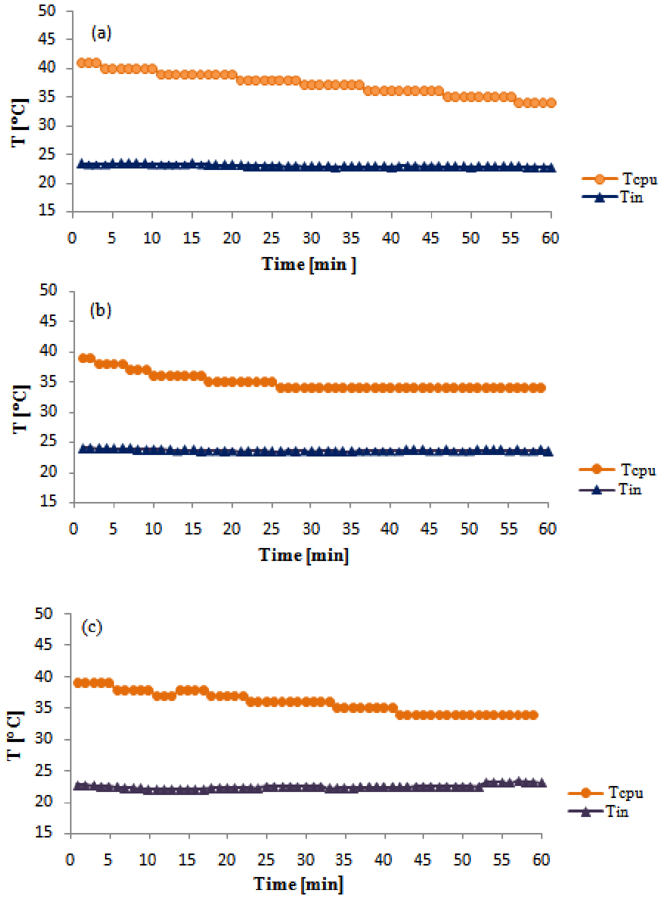


**Fig. 5** Variation of CPU temperature with time for no-load operation condition at different mass flow rate of 2.8 GHz CPU chip; (a) $\dot{m}$ = 0.0044 kg/s; (b) $\dot{m}$ = 0.0066 kg/s; (c) $\dot{m}$ = 0.011 kg /s.

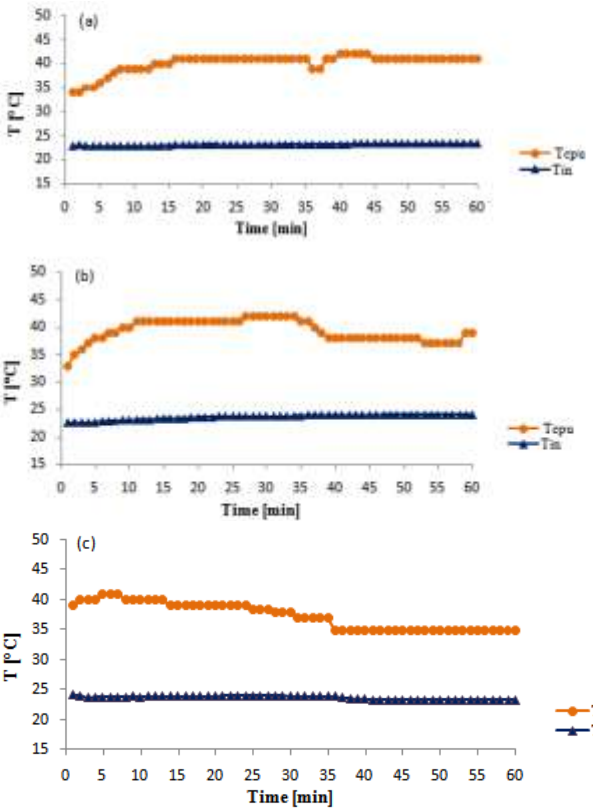


**Fig. 6** Variation of CPU temperature with time for load operation condition at different mass flow rate of 2.8 GHz CPU chip; (a) $\dot{m}$ = 0.0044 kg/s; (b) $\dot{m}$ = 0.0066 kg/s; (c) $\dot{m}$ = 0.011 kg/s.

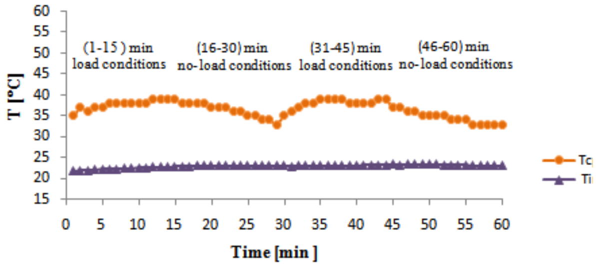


**Fig. 7** Variation of CPU temperature with time for changing the operation conditions of 2.8 GHz CPU chip at mass flow rate 0.0266 kg/s.

### 3.2 Heat Transfer to Coolant Water ($Q_f$):

The heat transfer to coolant water for three mass flow rates 0.0044 kg/s, 0.0066 kg/s and 0.011 kg/s at no-load and load operation conditions are shown in Fig. 8. The non-uniformity in heat transfer rate is due to maldistribution of mass flow rate through minichannel, this causative the non-uniformity in outlet temperature causes [30]. Also the heat transfer at load operation condition is greater than at no-load operation condition, this cause to increases the load applied on the hotspot positions in CPU chips [29].

The variation of heat transfer to coolant water with time for changing the operation conditions of CPU for two mass flow rates 0.0044 kg/s and 0.0155 kg/s are shown in Fig.9. The amount of non-uniformity in heat transfer to coolant water at no-load and load operation condition is increases with increase mass flow rate, hence the non-uniformity in heat transfer for 0.0155 kg/s of mass flow rate is greater than at 0.0044 kg/s of mass flow rate.

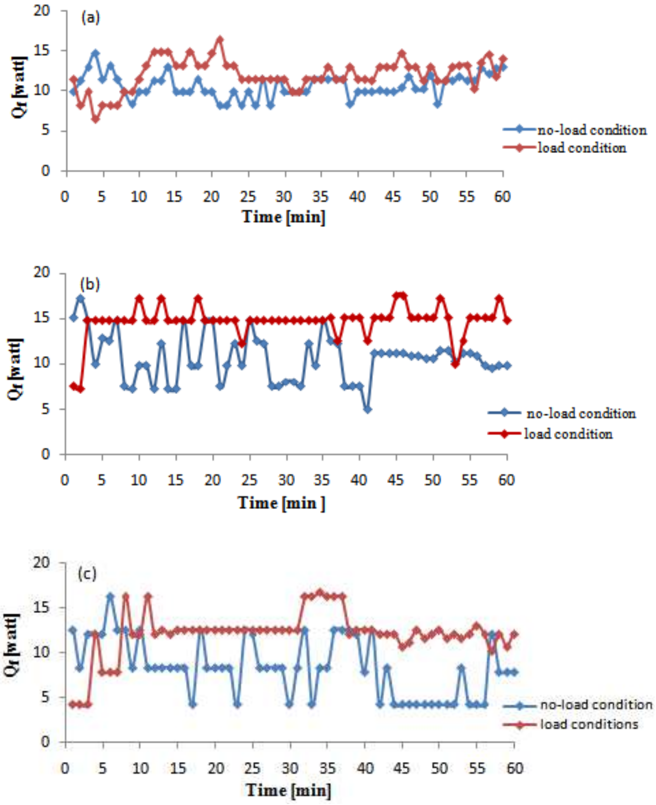


**Fig. 8** Variation of heat transfer to coolant water with time for 2.8 GHz CPU chip with load and no-load operation condition at different mass flow rates; (a) $\dot{m}$ = 0.0044 kg/s; (b) $\dot{m}$ = 0.0066 kg/s; (c) $\dot{m}$ = 0.011 kg/s.

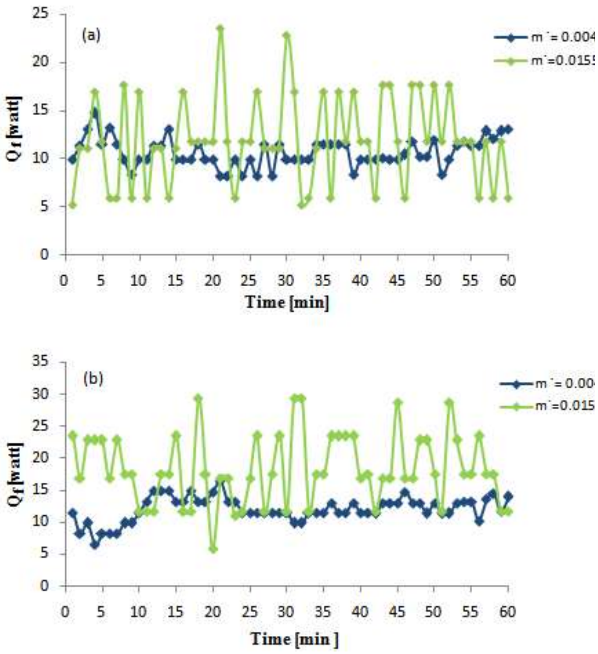


**Fig. 9** Variation of heat transfer to coolant water with time of 2.8 GHz CPU chip for three different mass flow rate; (a) no-load operation conditions; (b) load operation conditions.

### 3.3 Convective Thermal Resistances ($R_{Th}$):

The decreasing in thermal resistance of coolant water from 1.27 K/W to 0.213 K/W at load operation condition and decreasing from 1.61 K/W to 0.338 K/W at no-load operation condition with increases the mass flow rate from 0.0044 kg/s to 0.011 kg/s was illustrated in Fig. 10. The thermal resistance at no-load operation conditions is greater than at load operation conditions becauce the thermal resistance is a function of heat transfer to coolant water, and the heat transfer at load condition is greater than at no-load condition.

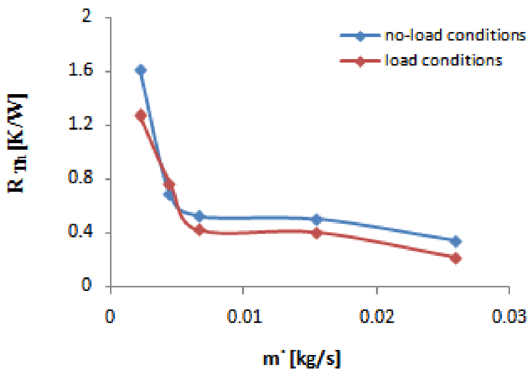


**Fig. 9** Variation of thermal resistance versus mass flow rate at different load operation conditions in 2.8 GHz CPU chip.

### 3.4 Nussle Number (*Nu*):

Some one can see from the Fig .11 that irregular fluctuations in *Nu* number for all period of time in load and no-load operation condition is due to maldistribution of mass flow in parallel channels of minichannel, and the non-uniformity distribution of inlet velocity to minichannel and outlet velocity from minichannel which caused by the design the inlet and outlet manifolds of minichannel heat sink. All the previouse reasons lead to non-uniformity in heat transfer rate of coolant water [30, 31]. therefore *Nu* number and convective heat transfer coefficient is not constant and affecte by the non-uniformity distribution the mass flow rate, heat transfer rate and change the load operation conditions of CPU chips.

The variation of Nusslte number with Reynolds number at different mass flow rate of coolant water was illustrated in Fig. 12, the *Nu* increases with increases *Re* at constant hydraulic diameter for rectangular minichannel due to increase the convective heat transfer coefficient with increase mass flow rate. The *Nu* at load operation condition is greater than at no-load operation condition at the same mass flow rate because the convective heat transfer coefficient at load operation conditions is high comparison with no-load operation conditions.

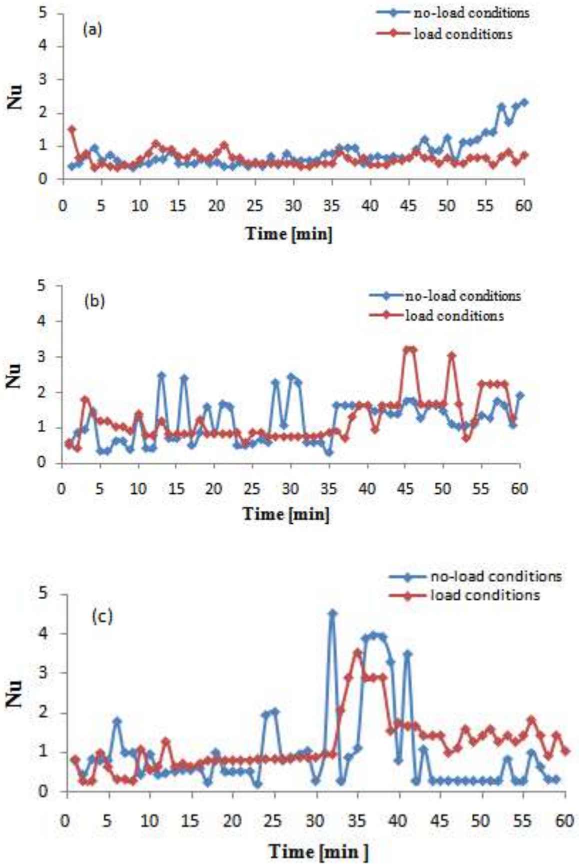


**Fig. 11** Variation of Nusselt number with time for 2.8GHz CPU chip at load and no-load operation conditions for different mass flow rate; (a) m˙= 0.0044 kg/s; (b) m˙= 0.0066 kg/s; (c) m˙= 0.011 kg/s.

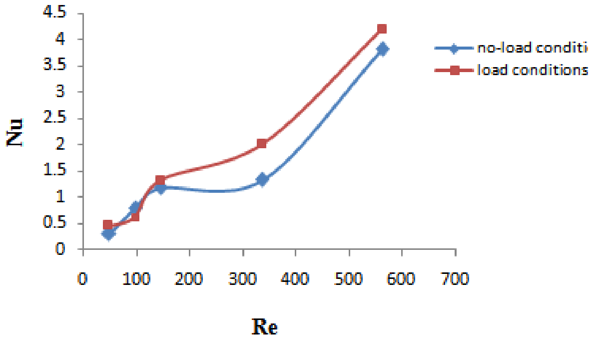
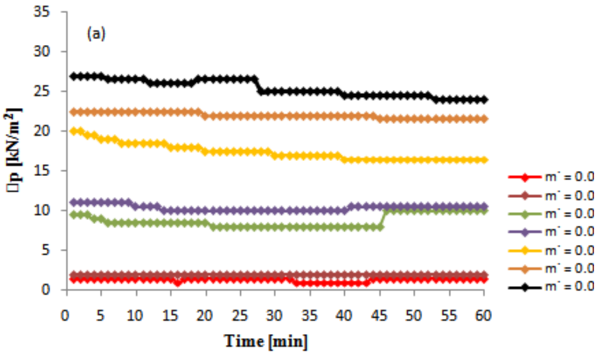


**Fig. 12** Variation the Nusselt number with Reynolds number at load and no-load operation condition in 2.8 GHz CPU chip.

### 3.5 The Pressure Drop (Δ*p*):

The variation of pressure drop through minichannel with time at no-load and load operation conditions for different mass flow rates was shown in Fig. 11. One can see from the curves the non-uniformity in pressure drop between inlet and outlet manifolds of minichannel heat sink. The pressure drop increases with increase the Reynolds number or mass flow rate and inlet velocity of coolant water as shown in Fig. 14, also the presssure drop at load operation condition is greater than at no-load operation condition this may be due to appeare some bubbles near the heated surface of the channel cause by high heat transfer at load operation condition.



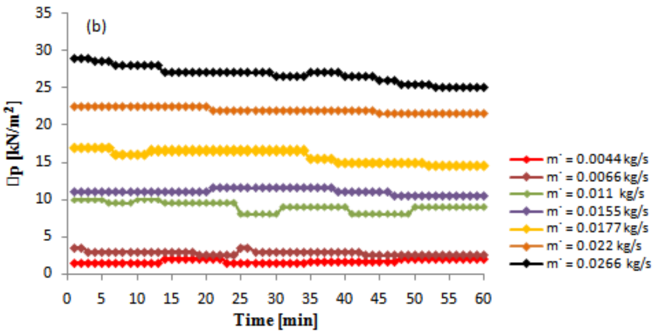


**Fig. 13** Variation of pressure drop with time for 2.8 GHz CPU chip; (a) no-load operation conditions;(b) load operation conditions.

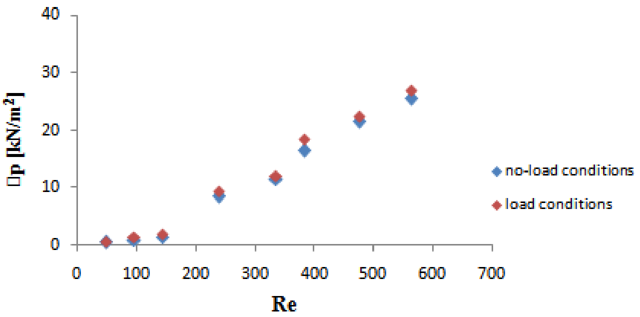


**Fig. 14** Variation of pressure drop through minichannel with Reynolds number at load and no-load operation conditions for 2.8 GHz CPU chip.

### 3.6 The Failure Rate and Mean Time to Failure:-

The pattern of failure rate with maximum CPU temperature at various mass flow rates for no-load and at load operation conditions was shown in Fig. 15. The failure rate is depending on the maximum CPU temperature or junction temperature (hot spot region), a hot spot created inside the CPU chips because of low transfer rates in this region which leads to main failure problem in CPU [20], that means the failure rate of CPU chip increases with increase of the junction temperature. As shown the failure rate at load operation conditions is higher than no-load operation conditions this due to the junction temperature at load operation conditions is higher than at no-load operation conditions.

The mean time to failure (MTTF) decreasing with increase the junction temperature as shown in Fig. 16 for no-load and load operation conditions. the MTTF is inverse of failure rate, therefore increasing the junction temperature leads to increase failure rate and decrease the mean time to failure. Hence the MTTF at no-load operation condition is higher than load operation conditions due to CPU temperature at no-load operation conditions is lesser than at load operation conditions.

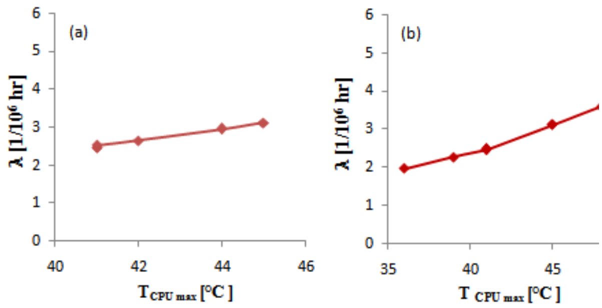


**Fig. 15** Variation of failure rate with maximum CPU temperature for 2.8 GHz CPU chip; (a) no-load operation conditions; (b) load operation conditions.

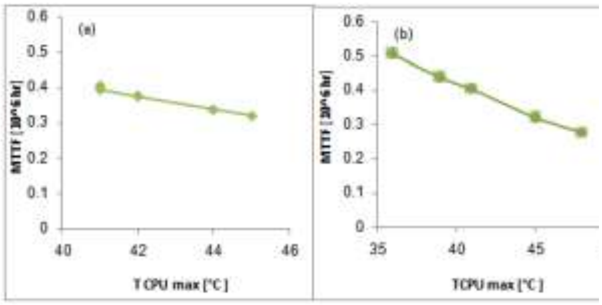


**Fig. 16** Variation of MTTF with maximum CPU temperature for 2.8 GHz CPU chip; (a) no-load operation conditions; (b) load operation conditions.

### 3.7 Air Cooled CPU Chip:-

A comparison between water cooling system with air cooling system for effect on CPU temperature was illustrated in Fig. 17. The water cooling system is more effective way to absorbing the heat dissipating from the CPU chips and throw-out of the system [1], then decreases the CPU temperature because the heat transfer coefficient of water is about 1500 W/m$^2$ C compare with the heat transfer coefficient of air which is about 30 W/m$^2$ C also the air is a bad thermal conductor, were it's conductivity coefficient is 0.024 W/m˚C compared with water which it's conductivity coefficient is 0.58W/m˚C at 25˚C [32, 33]. For the previous reasons the water cooling system has high ability to decrease the CPU temperature and maintain the reliability of CPU chips higher than the air cooling system [34].

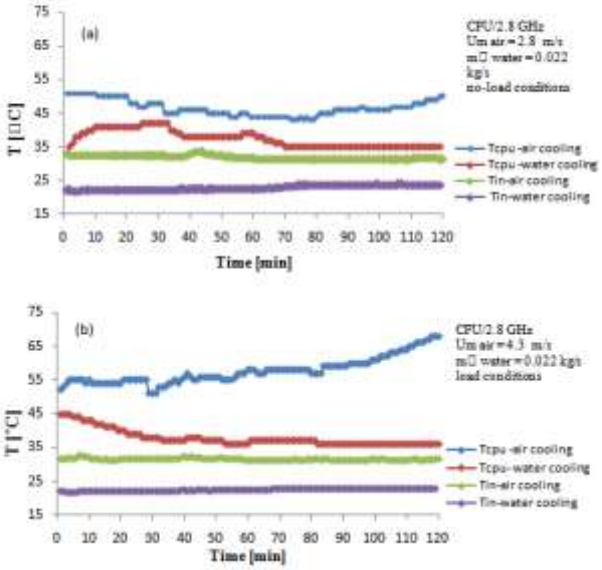


**Fig. 17** Comparison between CPU temperature for water cooling system and air cooling system; (a) no-load operation conditions :(b) load operation conditions.

## IV. CONCLUSIONS AND RECOMMENDATIONS:

the present experimentail study the water cooled of minichannel heat sink for cooled the CPU chips model Intel ® Celeron ® Process running at 2.8 GHz for a personal computer. A discuss the effects of varying mass flow rates of coolant water through minichannel on CPU temperature and pressure drop thruogh minichannel. Also study effect of junction temperature on failure rate and mean time to failure of CPU. The following conclusions can obtained from the results of this study:

1. The CPU temperature is dependent on the coolant water temperature, which is increasing if the temperature of coolant water increase and vice-versa.
2. Increase the heat transfer rate to coolant water with increasing the mass flow rate of coolant water, the amount of heat transfer rate is 889.02 W at mass flow rate equal 0.011 kg/s for 2.8 GHz CPU chip after 60 minutes of computer operation at load conditions.
3. Decreasing the convective thermal resistance with increasing the mass flow rate of coolant water, the amount of thermal resistance decrease from 1.27 K/W to 0.213 K/W at mass flow rate changed from 0.0044 kg/s to 0.011 kg/s with load operation condition.
4. Increasing the Nusselt number with increasing the mass flow rate of coolant water, and the Nussalt number at load operation conditions is greater than at no-load operation conditions.

5. Increasing the non-uniformity CPU temperature with increasing the mass flow rateand the CPU temperature at load operation conditions is greater than at no-load operation conditions
6. Increases the CPU temperature cause to increase the failure rate and decrases the mean time to failure.
7. for the future work can some one study the effect of different hydraulic diameter of minichannels on CPU temperature.

**NOMENCLATUE**

| | |
|---|---|
| $A$ | width of finned section on heat sink (m) |
| $A_b$ | area of heat sink base plate ($m^2$) |
| $A_c$ | channel area ($m^2$) |
| $A_{eff}$ | effective surface area ($m^2$) |
| $B$ | un-finned length of heat sink (manifold) (m) |
| $C_1$ | empirical constant ( microprocessor die complexity failure rate) |
| $C_2$ | empirical constant (package failure rate for microprocessor) |
| $C_p$ | specific heat (J/kg ˚C) |
| $D_h$ | hydraulic diameter (m) |
| $E_a$ | effective activation energy (eV) |
| $H_b$ | thickness of heat sink base plat (m) |
| $H_{ch}$ | height of the channel (m) |
| $h$ | heat transfer coefficient ($W/m^2$ K) |
| $k_f$ | thermal conductivity of fluid (W/m K) |
| $L$ | length of fins (m) |
| $L_{ch}$ | length of the channel (m) |
| $MTTF$ | mean time to failure ($10^6$/failure rate) hours |
| $\dot{m}$ | mass flow rate (kg/s) |
| $N$ | number of channel |
| $N_{fin}$ | number of fins |
| $N_P$ | number of copper pins inside the CPU chip. |
| $Nu$ | Nusselt number |
| $\Delta P$ | pressure drop ($kN/m^2$) |
| $Q_f$ | heat transfer to coolant water (W) |
| $Re$ | Reynolds number |
| $R_{th}$ | convective thermal resistance of heat sink (K/W) |
| $T_b$ | base temperature of heat sink (˚C) |
| $T_{CPU}$ | central processing unit temperature (˚C) |
| $T_{CPU,max}$ | maximum central processing unit temperature (˚C) |
| $T_{in}$ | temperature of coolant at inlet (˚C) |
| $T_j$ | junctions temperature (˚C) |
| $T_{mf}$ | mean fluid temperature (˚C) |
| $T_{out}$ | temperature of coolant at the outlet (˚C) |
| $\Delta T_{LMTD}$ | logarithm mean temperature difference (˚C) |
| $t$ | time (min) |
| $U_{in}$ | inlet velocity (m/s) |
| $U_m$ | mean velocity (m/s) |
| $W_{ch}$ | width of the channel (m) |
| $W_{fin}$ | width of the fine (m) |
| $W_W$ | thickness of fine (m) |

**Greek Symbols**

| | |
|---|---|
| $\Delta$ | difference |
| $\eta_{fin}$ | fin efficiency %. |
| $\lambda$ | failure rate (Failures/$10^6$ ) hours |
| $\pi_E$ | environmental factor |
| $\pi_L$ | learning factor |
| $\pi_Q$ | quality factor |
| $\pi_T$ | temperature factor |
| $\rho_f$ | Density of fluid ($kg/m^3$) |
| $\vartheta$ | kinematic viscosity ($m^2/s$) |

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