Investigation to Enhance the Performance of Computer Processor Cooling System

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Abstract. In the recent past, cooling via thermoelectric technology has arisen to be as one of the capable cooling technology which helps in lowering the energy intake in a device. In this study, the performance enhancement of cooling system for the computer processor using thermoelectric cooler is investigated. An open loop cooling system was taken into consideration, where the main parameters are focused on computer load conditions, temperature carried by nanofluid or output temperature of nanofluid at water block and heat flux. The thermoelectric cooler (TEC) made of Bismuth Telluride (BiTe₃) material for pn junctions is used with Delta Tₘₐₓ of 67°C in this analysis to extract the heat from processor. The Aluminium Oxide (Al₂O₃) and copper oxide (CuO) ranging from 40nm - 50nm size dispersed in distilled water with various volume concentrations were used for dissipation of heat from the hot surface of the TEC. Liquid flow is varied from 0.1LPM - 0.9LPM. Results demonstrate that by maintaining the lower Delta Tₘₐₓ value, higher Coefficient of performance (COP) is achieved. There is a considerable reduction in operating temperature of processor when using the nanofluids. Both the nanofluids exhibited higher thermal conductivity on comparing with base fluids. The enhancement observed in output temperature is about 15°C to 20°C by using nanofluids. Higher the flowrate used higher the heat flux generated.

Keywords: Thermoelectric cooling, Thermal Conductivity, Heat Flux, Coefficient of Performance

1. Introduction

In modern world the computers are becoming a crucial technology in sectors such as business, finance, internet, education, entertainment etc., because of its speed and accuracy. The Central Processing Unit is responsible for data processing and often referred as computer processor or processor where the transistors are placed or packed inside. Advance in semiconductor technology allows one to make transistors which are small enough to pack hundreds of million of them onto a
single computer chip. While operation the chips release heat. This waste heat need to be removed or that will result in reducing the processor speed, clock speed and also lead to temporary malfunction or permanent failure. Among all the cooling technologies that are being developed, thermoelectric cooling seems to be achieving all the possibilities of reaching its demand. Kai-lun Zhang et al. [1] this paper proposes a micro-scale thermosyphon thermal tube technology which utilizes a 3D chip specific microchannel structure as a vapourising segment. The maximum heat flux is improved by 50-130% for nanofluid(CuO) and critical heat flux improved by 45-90% at 1.0 wt%. M. Rafati et al. [2] the main focus of this research is to utilize the enhanced properties of nanofluids(Al₂O₃, SiO₂ and TiO₂) for the cooling of computer microchips. The largest reduction of operating temperature is observed for alumina nanofluid from 49.4 to 43.9 °C for 1.0 vol% at a flowrate of 1.0 LPM. M. K. Russel et al. [3] the paper investigates thermoelectric cooler (TEC) performance for the design of electronic packing. The results show that when the system operated at higher COP there is a trade-off among the extent of ambient temperatures and off peak heat fluxes. Mohamed S. El-Genk et al. [4] investigated the performance of composite spreaders(porous graphite and copper substrate) with FC-72 dielectric liquid for enhanced cooling. Dongsheng Wen et al. [5] investigated the heat transfer behaviour under nucleate pool boiling conditions using nanofluids(s-alumina). Mohamed S. El-Genk [6] an experimental on composite spreader, copper spreader and porous graphite spreader upon the 10x10 mm computer chip at 0⁰, 90⁰, 180⁰ inclination with dielectric fluids(FC-72, HFE-7100). Paisarn Naphon et al. [7] an experimental study on rectangular heat fin sink with or without the thermoelectric inside a CPU by using liquid cooling. Ping-yang Wang et al. [8] experiments were carried out using two unadulterated solutions (deionized water, R113) and two supermoist liquid solutions (deionized water + surfactant and R113+ surfactant) for a micro-channel structure. The results showed that the critical flux is improved by 70-100%. Guohui Zhou et al. [9] analysed a 1mm thick ultrathin heat pipe miniature loop with ambient air and forced air convectional cooling for a flat evaporator used in high end ultra slim laptop.

Amir F. Ali et al. [10] numerical investigation for composite spreaders of 10x10 mm comprised of copper substrate and copper microporous surfaces at different thickness with dielectric liquids(FC-72, HFE-7100, PF-5060). Songkran Wiriyasart et al. [11] studied experimentally by using thermoelectric air cooling and its enhancement for dual processors workstation computer. Compared to conventional cooling system the thermoelectric air module there is decrease in temperature of 5-10°C. Nizar Ahammed et al. [12] experimental investigation on the performance of TEC used for cooling of electronic devices with nanoparticle Al₂O₃ is blended in water for a multiport minichannel heat exchanger. It is observed that there is 40% increment in COP for TEC at 0.2 vol% concentration. Yang Cai et al. [13] analysis of this paper reveal that by increasing number of TEC's on hot side of thermoelectric system there will be an enhancement in higher heat flux. Liu D et al. [14] studied the proposed micro thermosyphon cooler which is coupled with TEC used in CPU to remove the unwanted heat from the processor. M. Chandrasekar et al. [15] studied experimentally about the heat transfer coefficient and characteristics of friction factor for a laminar flow at fully developed condition by using Al₂O₃ nanoparticle dispersed in water. Majid Hejazian et al. [16] numerically analysed the circular tube placed horizontally which exposed to convection and saturation steam at the wall with turbulent flow of Al₂O₃/water nanofluid. Hwa Ming Nieh et al. [17] investigated the performance for dissipation of heat for a radiator which cooled by air with Al₂O₃ and TiO₂ nanofluids. M. M. Elias et al. [18] experimented the enhancement of thermal properties such as thermal conductivity, density, specific heat and viscosity for car radiator coolant with Al₂O₃ dispersed in EG and water.

Based on the literature reviews, the liquid cooling system has higher heat absorbing capacity. Also, the improvement in thermal performance for liquid cooling components with reduction in their geometry was a technical challenge. Research towards TEC shows that it can maintain optimum temperature for the computer processor. The main objective is to enhance the TEC cooling system for the computer processor by replacing nanofluids instead of basefluids. The main parameters focused on heat carried away by the nanofluid and heat flux. The monitored results guide to the enhance of cooling performance for processor.
2. Preparation of Nanofluid

The preparation of nanofluid involves two steps. In first step addition of nanoparticles and second step involves the stabilization of nanofluid. The volume fraction for nanofluid varying the range from 0.1%-1.0% is calculated by using the equation,

\[
\phi = \frac{n_{NP}}{n_{NP} + n_{BF}}
\]  

The basefluid Deionised water is prepared by adding SDS(Sodium Dodecyl Sulfonate) inorder to maintain proper dispersion of nanoparticles. The solution is checked for pH scale inorder to avoid the damage for instruments. If the pH scale lies in acidic range then the solution is diluted by adding NaOH, 1M solution. The nanoparticles of Al₂O₃ and CuO were considered for experimentation in the range of 40 nm-50 nm diameter. The TEM (Transmission Electron Microscopy) of Al₂O₃ and CuO nanoparticle is shown in figure(1) and (2). The specifications of basefluid and nanoparticles are indicated in Table(1) and (2).

| Properties at 30°C | Deionized Water |
|--------------------|-----------------|
| Density (Kg/m³)    | 997             |
| Specific Heat (J/Kg-K) | 4178          |
| Thermal Conductivity (W/m-K) | 0.613  |
| Viscosity (Kg/m-s) | 0.000798        |

| Table 1. Nanoparticles parameters |
|-----------------------------------|
| Properties | Al₂O₃ | CuO |
| Average Size of Nanoparticle (nm) | 43    | 50  |
| Density (Kg/m³) | 3970 | 6510 |
| Color       | White | Black and Brown |
| Morphology  | Spherical | Spherical |
| Melting Point (°C) | 2055 | 1201 |
| Specific Heat (J/Kg-K) | 765  | 540  |
| Thermal Conductivity (W/m-K) | 40   | 18   |

Figure 1. Al₂O₃ nanoparticle     Figure 2. CuO nanoparticle
The fractions of 0.2%, 0.4%, 0.6% and 1.0% were added to the basefluid. The addition of nanoparticles is done by using homogenizer at 6000rpm for 30 minutes to avoid agglomeration. For the proper suspension of nanoparticles and its constant dispersion in the fluid is carried out under ultrasonification at 600rpm for 6 hours. The ultrasonicator used here with specifications of 400W power and frequency of 36±3 KHz. The prepared nanofluid is kept under observation for sedimentation up to 72 hours in stable condition.

2.1 Thermophysical Properties of Nanofluids

The thermophysical properties of nanofluids such as Thermal Conductivity, Specific Heat, Viscosity, Density are calculated by using the correlations. [5] [11]

2.1.1 Thermal Conductivity

The overall effective thermal conductivity is calculated by adding static and dynamic thermal conductivity. The static thermal conductivity is based on Maxwell Theory and dynamic thermal conductivity is based on the Brownian motion of nanoparticles.

\[ k_{\text{eff}} = k_{\text{static}} + k_{\text{Brownian}} \]  \hspace{1cm} (2)

for spherical nanoparticles static thermal conductivity is given by,

\[ k_{\text{static}} = k_{BF} \left( \frac{(k_{NP} + 2k_{BF}) - 2\delta(k_{BF} - k_{NP})}{(k_{NP} + 2k_{BF}) + \delta(k_{BF} - k_{NP})} \right) \]  \hspace{1cm} (3)

Brownian motion of nanoparticle is calculated by

\[ k_{\text{static}} = 5 \times 10^4 \beta \phi \rho_{BF} c_{p,BF} \sqrt{\frac{k_B T}{\rho_{NP} D_{NP}}} \]  \hspace{1cm} (4)

where, \( \rho_{NP} \) and \( D_{NP} \) are the density and diameter of nanoparticles. \( k_B \) is Boltzmann constant(1.3807x10\(^{-23}\) J/K) and \( f(T,\phi) \) value is 1

where, \( \beta = 0.0011(1000)^{-0.7272} \) \( \phi > 0.01 \) \hspace{1cm} (5)

2.1.2 Dynamic Viscosity

Viscosity of nanofluid is calculated by using the correlations

\[ \mu_{\text{eff}} = \mu_{\text{static}} + \mu_{\text{Brownian}} \]  \hspace{1cm} (6)

where, \( \mu_{\text{static}} = \mu_{BF} \frac{1}{(1-\phi)^{2.5}} \) and \( \mu_{\text{Brownian}} = \frac{k_{\text{Brownian}}}{k_{BF}} \frac{\mu_{BF}}{Pr_{BF}} \) \hspace{1cm} (7)

2.1.3 Specific Heat

The Specific Heat of nanofluid for different volume concentrations is calculated by following equation,
2.1.4 Density

The nanofluid density for volume concentration 0.1%-1.0% is calculated by below equation,
\[ \rho_{NF} = \frac{(1-\phi)(\rho_{cP})_{BF} + \phi\rho_{cP})_{NP}}{(1-\phi)(\rho_{BF} + \phi\rho_{NP})} \] (8)

2.1.5 COP of TEC

The efficiency of the cooling or heating device is calculated by using Coefficient of Performance (COP), which is defined as the ratio of the cooling power to the input power.

\[ \text{COP} = \frac{Q_C}{W} \]

Where, \( W = Q_h - Q_c \) and \( W = SI(T_h - T_c) + I^2R \)

\[ Q_c = -[SIT_c - 0.5I^2R - k(T_h - T_c)] \]
\[ Q_h = SIT_h + 0.5I^2R - k(T_h - T_c) \] (10) (11)

3. Experimental Apparatus and Method

3.1 Experimental Apparatus

The experimental apparatus consists of high performance computer chip of current generation. During experiment the processor is placed with the heater based on the temperatures of computer processor during different load conditions. The heater used in this experiment has specifications of 220AC/DC input voltage with 200W power supply and the surface maximum temperature of 200°C. Thermoelectric cooler is placed above the heater in such a way that the cold surface of TEC is placed upon heater and hot side of TEC attached to the water block. TEC model used here is TEC-12706, which consists of 127 p-n junctions. The material used for p-n junctions are Bismuth-Tin(BiSn). The details of TEC-12706 is given in below table.

| Table 3. TEC Parameters |
|-------------------------|
| HOTSIDER TEMPERATURE    | 25°C | 50°C |
| Qmax(W)                 | 50   | 57   |
| Delta Tmax(°C)          | 66   | 75   |
| Imax(Amps)              | 6.4  | 6.4  |
| Vmax(Volts)             | 14.4 | 16.4 |
| Module Resistance(Ohms) | 1.98 | 2.30 |

The TEC has dimensions of 40mmX40mmX3.8mm. The top surfaces of TEC are made up of ceramic material Alumina(Al₂O₃) and it has a maximum operating temperature of 138°C. The voltage and current for the TEC is controlled by TEC controller. Water block is placed above the TEC i.e, hot side of TEC with dimensions, 40mm X 40mm X 12mm as shown in figure 1. The water block is made up of aluminium material. The TEC, heater and waterblock are made in contact with each other by surfaces using the Thermoelectric paste inorder to have the maximum heat transfer between the surfaces. The thermoelectric paste used here has a thermal conductivity of 1.85W/m-K. The inlet and outlet connections of water block is connected to the pump and radiator respectively.

A Diaphragm pump of 12V, 80W is used in this current experiment with a capacity of 5LPM. A flow meter is used in between pump and inlet such that required flow is maintained. The main advantage to use diaphragm pump is it has less moving parts.

A Storage Tank Capacity of 2-3 Litres were used. The inlet pipe of pump is directly connected to the storage tank. The storage is filled with nanofluid in required amount as specified above. The Outlet of water block is connected to the radiator. The radiator used in this setup has dimensions of 60mmX82.5mmX25.7mm. The hot fluid enters into the radiator from waterblock and it is cooled by air cooling as the liquid flows inside the radiator. A CPU fan is fixed above the radiator for faster
cooling purpose. A CPU fan with rated power of DC 12V and 0.1A and dimensions of 60mmX60mmX15mm is utilized.

Thermocouples are placed at radiator outlet, inlet and outlet of waterblock. Thermocouples are connected to Digital Temperature indicator. A digital temperature indicator with multichannel is used to monitor the readings.

3.2 Experiment Method:

The experiment is conducted for three different temperature that were obtained during load conditions of processor i.e, idle condition, half load and full load conditions. These different load conditions are also tested for flow rates ranging from 0.1LPM-0.9LPM. The setup is also tested for different nanofluid concentrations upto 1.0vol%.

Initially the storage tank is filled with nanofluid and checked for leakages. The connections are made according to the circuit. Now, the heater is supplied with power, so that the required temperature is attained on surface of heater by using voltage regulator. Now, the power is supplied to the TEC and it starts creating the cold and hot side surfaces(Peltier effect). The TEC controller is used to control the TEC for maintaining constant Delta T_max and temperature on cold side surface. Here, a constant delta T_max is considered in order to reduce the power consumption and maintain higher COP of TEC. The pump is switched on and the flowrate is maintained or varied for different experiments. As the nanofluid flows inside the waterblock the maximum amount of heat is absorbed basing on the properties of nanofluid. The output temperature of nanofluid is measured and displayed on digital temperature indicator. A heat flux sensor is used to measure the heatflux at waterblock surface. Now, the hot fluid enters into the radiator and cooled. The output temperature of radiator is also recorded. The experiment is conducted for 300 seconds and values are noted.

4. Results and Discussion

4.1 Effect of computer operating load conditions:

The experiment was conducted at room temperature that is the inlet fluid is maintained at 30°C. In present study, the cold side of TEC is attached to the processor and the hot side of TEC is attached to the waterblock(heat exchanger). The setup is tested for three load conditions such as Idle, Half and Full load conditions. The processor temperature is removed by TEC when power is supplied to it. The maximum amount of heat is present on hot side of TEC since the processor is being cooled by the cold surface of TEC, this heat is removed by circulating the nanofluid inside the waterblock which is present on the hot surface of TEC. The experiment is tested for different nanofluid concentrations inorder to carryout maximum heat.
4.1.1 Output Temperature(°C):

The Al₂O₃ and CuO nanofluids are tested for different load conditions. The variation in output temperature with respective both nanofluids are as depicted in the figures 5-10. The maximum amount of heat is carried out at 0.1LPM when compared to the other flowrates. This is because at lower flowrate the volume of liquid circulated is less compared to higher flowrate which means the fluid particles flow through the component is less compared to higher fluid volume circulation. Also, the vast amount of heat carried by Al₂O₃ nanofluid compared to the CuO nanofluid and basefluid. The 1.0 Vol% concentration of nanofluids show the maximum heat transfer among the other concentrations. But, for copper the heat carried away by the different volume concentrations at different flowrates is almost same (with a difference upto 1-2 °C) which is lesser when compared to Al₂O₃ nanofluid.

![Figure 5. Al₂O₃ NF at idle load](image)

![Figure 6. Al₂O₃ NF at half load](image)

![Figure 7. Al₂O₃ NF at full load](image)

![Figure 8. CuO NF at idle load](image)
Figure 9. CuO NF at half load

Figure 10. CuO NF at full load

4.1.2 Heat Flux (W/m$^2$):

Figure 11. Al$_2$O$_3$ NF at idle load

Figure 12. Al$_2$O$_3$ NF at half load

Figure 13. Al$_2$O$_3$ NF at full load

Figure 14. CuO NF at idle load
At idle, half and full load condition, from experiment observed that, there is a decrease in temperature as the flow rate increases. Also, observed there is rise in heat flux as flow rate increases. At idle load condition, compared to basefluid the enhancement was observed from 42°C to 50°C and 49°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively. At half load condition, compared to basefluid the enhancement was observed from 51°C to 65°C and 63°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively. At full load condition, compared to basefluid the enhancement was observed from 58°C to 76°C and 73°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively. At idle load condition, compared to basefluid the enhancement was observed from 42°C to 51°C and 49°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively. At half load condition, compared to basefluid the enhancement was observed from 51°C to 67°C and 64°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively. At full load condition, compared to basefluid the enhancement was observed from 58°C to 78°C and 74°C for Al₂O₃ and CuO nanofluids at 0.2Vol% for 0.1LPM respectively.

This phenomenon is observed because as the concentration of nanoparticle is increased in the base fluid the thermal properties such as thermal conductivity, specific heat etc., will increase. Hence the fluid tends to absorb more amount of heat. The higher heat flux is observed for full load condition at 0.9LPM is 242053 W/m² and 246664 W/m² for Al₂O₃ and CuO nanofluids respectively. The CuO nanofluid has higher heat flux in all load conditions and flowrates when compared to Al₂O₃ nanofluid. This is because the specific heat is higher for CuO nanofluid.

### 4.2 Performance of TEC:

Delta T max is the temperature difference between the cold side and hot side plate. From the data sheet of the model used in this experiment TEC1-12706, for 25°C and 50°C on hot side plate of TEC it can create a temperature difference of 66°C and 75°C. Nizar Ahammed et.al [12] observed that for Al2O3 nanofluid 0.2Vol% there is 40% enhancement of COP of TEC. The maximum temperature difference can be attained by supplied maximum current and voltage. But, increase in Delta T max value results in decrease in COP of TEC. In present experiment a TEC controller is used to maintain the required temperature difference by regulating the power supply to the TEC. In this problem the Delta Tmax for TEC is varied from 12°C-22°C. The COP value at idle, half and full load conditions are 0.718, 0.808 and 0.844 respectively. Hence, we can conclude from experiment that for same current value at lower Delta T max, maximum COP is attained for TEC.
5. Conclusion

In this work, an open loop thermoelectric liquid cooling system with nanofluid is developed for computer processor cooling. The TEC is characterized by considering its input power and coefficient of performance response. The experiment is performed for different load conditions, flowrates and two nanofluids (Al$_2$O$_3$ and CuO) with different volume concentrations. The results show that thermal conductivity of nanofluid increases with increase in particle concentration. From the data it can be concluded that higher heat flux is achieved for CuO nanofluid at 0.9LPM when compared to Al$_2$O$_3$ nanofluid. The heat carried away by the Al$_2$O$_3$ coolant is 2-5°C higher than CuO coolant. The higher coefficient of performance of 0.84 was achieved at Delta $T_{\text{max}}$ of 22°C. The thermal effectiveness of cooling system increases with increase in volume concentration. The experimentation is done by using TEC1-12706 thermoelectric module with nanofluid for a computer processor cooling, the further analysis can be done on less power consuming thermoelectric modules and also the cooling technology in a compact model.

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