THERMAL PERFORMANCE AND RELIABILITY OF PROCESSOR INVESTIGATION USING TiO_2 AND CuO-WATER NANOFLUIDS

by

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Continuous miniaturization of feature size, faster operation and high-end performance of processor are facing serious problems to dissipate heat. In this numerical work, the surface temperature of the processor, heat transfer rate, power consumption and reliability of channel heat sink for processor handling TiO_2--water and CuO-water nanofluids at three-volume fractions as a coolant are studied using CFD software package. The power dissipation of the Intel processor was in the range of 16-135 W. The TiO_2-water and CuO-water nanofluids at a volume fraction of 0.3%, 0.6%, and 0.9% was used as a coolant. It is observed that the heat transfer rate of CuO-water nanofluids at 0.3%, 0.6%, and 0.9% are 5%, 7%, and 9%, respectively, higher than that of TiO_2-water nanofluid. It is found that the power consumption of the processor reduces by 2%, 3%, and 5% at the volume fraction of 0.3%, 0.6%, and 0.9%, respectively, than TiO_2-water nanofluids as coolant. The failure rate of the processor using CuO-water nanofluid was found to be 17%, 10%, and 8% lesser than the TiO_2-water nanofluids at the three-volume fractions, respectively.

Key words: *channel heat sink, nanofluids, central processing unit, electronic cooling, heat transfer and reliability*

Introduction

One of the crucial problems in modern processors is the generation of abundant heat while working. In addition, CPU lifetime can be significantly decreased because of huge thermal stresses and large power dissipation. The effective taking away of the generated heat is the major role of the cooling system to guarantee the processor are at a safe operating temperature and to ensure the reliability. Consequently, there was a need to replace the existing conventional heat transfer methods such as air coolers, heat pipes, refrigeration systems, and thermoelectric modules, *etc.*, because of limitations in heat dissipation. Hence, developing novel heat sinks and heat transfer fluids with high thermal conductivity has become unavoidable. The innovative heat transfer fluids with a mixture of base fluids (water, ethylene glycol, engine oil, *etc.*) and nanoparticles, called nanofluids [1]. The numerical and experimental research work shows that nanofluids have an effective thermal conductivity and remarkable im-

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provement in heat transfer than the base fluids [2-4]. Kandlikar *et al.* [5] observed the transfer of heat and fluid-flow in the mini-channel and micro-channel under the concept of single-phase and plays a vital role to remove large heat dissipation. Al-Rashed *et al.* [6] experimentally and numerically investigated the heat enhancement of the CPU heat sink with water as a coolant in the influence of nanofluids. The influence of CuO distilled water nanofluids on heat dissipation from rectangular and circular cross-sectional shaped heat sinks was studied numerically by Ghasemi *et al.* [7]. Besides, Ghasemi *et al.* [8] explored experimentally the cooling performance of heat sinks with different hydraulic diameters of the channel. Korpys *et al.* [9] studied numerically and experimentally the commercial heat sink for cooling of the PC processor using water and CuO-water nanofluids. Jeng *et al.* [10] revealed that using Al_2O_3-water nanofluid for electronic chips brings about better heat dissipation performance and lower power consumption than the distilled water.

Zhao *et al.* [11] experimentally investigated the characteristics of heat transfer and flow of nanofluids inside a CPU heat sink with different structures like rectangular grooves and cylindrical bulges. The finding indicates that TiO_2-water nanofluids with a low mass fraction (0.1%) show the highest exergy efficiency. Palanisamy and Mukesh Kumar [12] conducted an experimental study to examined the heat enhancement and pressure drop of cone helically coiled tube heat using MWCNT-water nanofluids. They reported that the heat transfer coefficient 14%, 30%, and 41% higher than the water at 0.1%, 0.3%, and 0.5% volume concentration of MWCNT-water nanofluid respectively. Shi *et al.* [13] performed the numerical study the heat transfer performance of the micro-channel heat sink by the single-phase model using nanofluid. They concluded that the heat transfer coefficient of nanofluids is 5.86% and 8.49% higher than that of deionized water. Saeed and Kim [14] observed the heat transfer performance using nanofluids Al_2O_3-water with two different volume concentrations as a coolant in three different channel configured mini-channel heat sink. The result shows that the 24.9%, 27.6%, and 31.1% enhancement in convective heat transfer coefficient of the heatsink with fin spacing of 1.5 mm, 1.0 mm, and 0.5 mm, respectively. Ho *et al.* [15] performed an experimental to study the heat transfer of Al_2O_3-water nanofluid flowing through a parallel mini channel heat sink.

Bakhti and Si-Ameur [16] studied numerically on the mixed convection of various nanofluids such as TiO_2-water, Al_2O_3,-water, and Cu-water in heatsinks with perforated circular fins. Mukesh Kumar *et al.* [17] studied numerically the heat transfer rate of a heatsink, reliability and power consumption of an electronic chip with a different aspect ratio of fins and coolants. Chandrasekar and Mukesh Kumar [18] conducted an experimental study to investigate heat transfer and pressure drop of a double helically coiled tube heat exchanger using MWCNT-water nanofluid. They concluded that the heat transfer coefficient could by enhanced by 56% than water at 0.6% nanofluid at 1460 Dean number. Mukesh Kumar and Arun Kumar [19] numerically evaluate the heat transfer rate enhancement and reliability of electronic chip in the six circular channel heatsink. They concluded that the reliability of electronic chip is 70% higher than water using Al_2O_3-water nanofluids as coolants. It is clear from the literature that there has been limited work on the processor with channel heat sink by using CuO-water and TiO_2-water nanofluid and compared their performances. Therefore, in this paper, the surface temperature of the processor, heat transfer rate, power consumption and reliability of channel heat sink with CuO-water and TiO_2-water nanofluids has been carried out numerically.

Model formulation and numerical procedure

In order to study numerically, the effects of a channel heat sink on the heat transfer enhancement of the Intel Core 2 duo processor was cooled by CuO-water and TiO_2-water nanofluids as shown in fig. 1. The channel heat sink was designed with a length of 75 mm, 1.5 mm wall thickness, and 50 mm width. The inlet and outlet diameter of the channel were 2.5 mm, respectively. The channel heat sink was made of aluminium to extract more heat from the processor surface. Figure 1 shows the Intel Core 2 duo processor to replace the conventional heat sink with channel heat sink. The CuO-water and TiO_2-water nanofluids include the particle volume fractions (φ = 0.3%, 0.6%, and 0.9%) that pass through the channel and carry away the heat dissipation of the processor. The size of the nanoparticles under consideration is the same. The thermophysical properties of CuO and TiO_2 nanoparticle and distilled water have been taken from the literature [8].

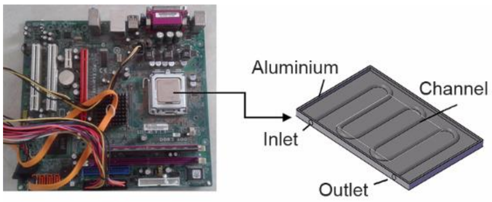

Figure 1. The Intel Core 2 duo processor with heat sink

Results and discussion

The heat transfer rate of a channel heat sink and hydrodynamic parameters of CuO--water and TiO_2-water nanofluids with different volume fractions such as 0.3%, 0.6%, and 0.9% were numerically studied and analyzed by CFD simulations. Figure 2 shows the inlet velocity of the coolant in the channel heat sink by using ANSYS CFD. This shows that the cooling performance of the channel heat sink can be enhanced by a higher inlet velocity.

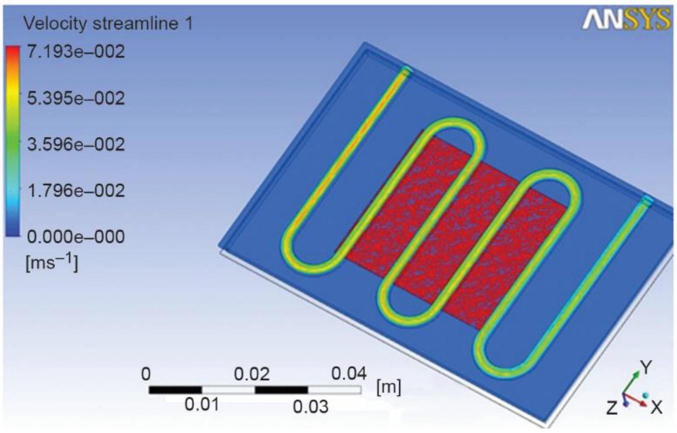

Figure 2. Velocity of coolant in the channel heatsink using ANSYS

Heat transfer in a channel heat sink

In this section, hydrodynamic parameter and heat transfer of CuO-water and TiO_2--water nanofluids with different volume fractions were studied and the CFD outcomes were compared with the numerical data. Figure 3 shows the variation in enhancement of heat transfer coefficient for the given volume fraction (ϕ = 0.9%) as a function of Reynolds number. It is observed that the channel heat sink with CuO-water nanofluid has a higher heat transfer coefficient in comparison with TiO_2-water nanofluids. The CuO-water nanofluid also has high thermal conductivity and thus the addition of these nanoparticles has led to an increase in flu-

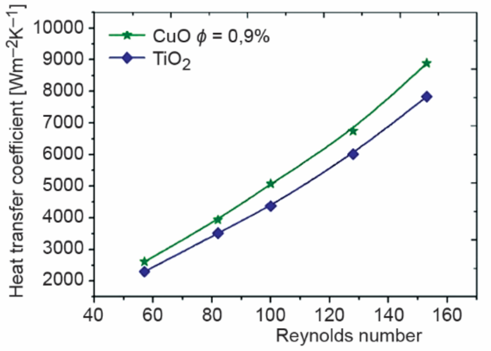

Figure 3. Variation of heat transfer coefficient with Reynolds number (φ = 0.9%)

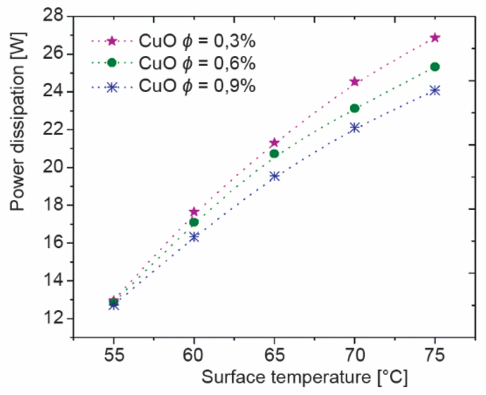

Figure 4. Power consumption of the processor using coolant CuO-water nanofluids

id thermal conductivity. From fig. 3, it is found that the heat transfer coefficient was increasing by 9% at 0.9% CuO-water nanofluids, when compared with TiO_2-water nanofluids.

Power consumption and reliability of a channel heat sink

The reduction of processor size, enormous integrated components, and larger power density yields very high temperatures that limit the performances which lead to an increase in the failure rate. At high temperatures, larger power dissipation occurs which can significantly increase the on-chip temperature and reduces the durability of the processor. In general, power consumption and temperature have an interrelated dependence, fig. 4. Here, power dissipation is calculated by eq. (1) that is proposed in [12].

$$T_j = T_a + R_{th(j-a)}P \tag{1}$$

Figures 5(a) and 5(b) show the relationship between power dissipation and surface temperature using CuO-water nanofluids and TiO_2-water nanofluids as coolants. The figures illustrate that the power dissipation is lower for less surface temperatures of the channel heat sink. It was observed that the power dissipation was 2%, 3%, and 5% lower than TiO_2-water nanofluids at 0.3%, 0.6%, and 0.9% volume fractions, respectively. Consequently, this higher transfer capability leads to a decrease in power consumption and increase in durability of the processor.

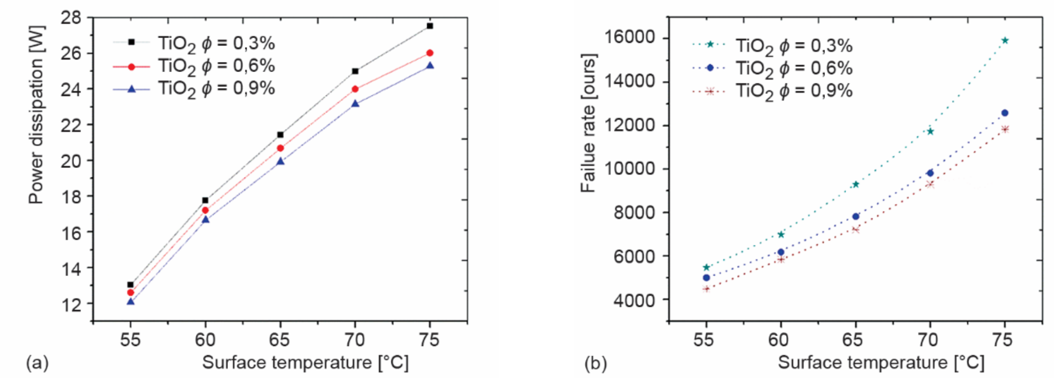

Figure 5. (a) Power consumption of the processor using coolant TiO_2-water nanofluids, (b) failure rate *vs.* surface temperature of TiO_2-water nanofluids

The reliability of distinct transistor exponentially depends on the operating temperature and the median time to failure (MTF) in hours can be estimated by the eq. (2) suggested by Black's correlation [20].

$$MTF = \frac{1}{AJ^2}\exp\left(\frac{E_A}{K_B T}\right) \tag{2}$$

where A is a constant, J – the current density (per cm^2), E_A [eV] – the active energy which is approximately 0.68 eV for typical silicon failures, K_B – the Boltzmann constant, and T – the absolute operating temperature. The failure rate of processor *vs.* surface temperature in the channel heat sink using the two coolants is shown in fig. 5. It can be seen that CuO-water nanofluids can improve the reliability of a processor. Also, it is observed that the failure rate is 17%, 10%, and 8 % at 0.3%, 0.6%, and 0.9% of CuO-water nanofluids in the channel heat sink which is lower than TiO_2-water nanofluids. Figure 6 shows the contour diagram of failure rate and power dissipation using the coolant TiO_2-water nanofluids with design expert software. It was observed that the CuO-water nanofluids possesses better heat transfer coefficient which leads to better cooling performance and lesser failure rate than TiO_2-water nanofluids. In particular, the effect of Brownian motion of CuO nanoparticles, movement of tiny particles in base fluids, is more effective than the TiO_2 nanoparticles.

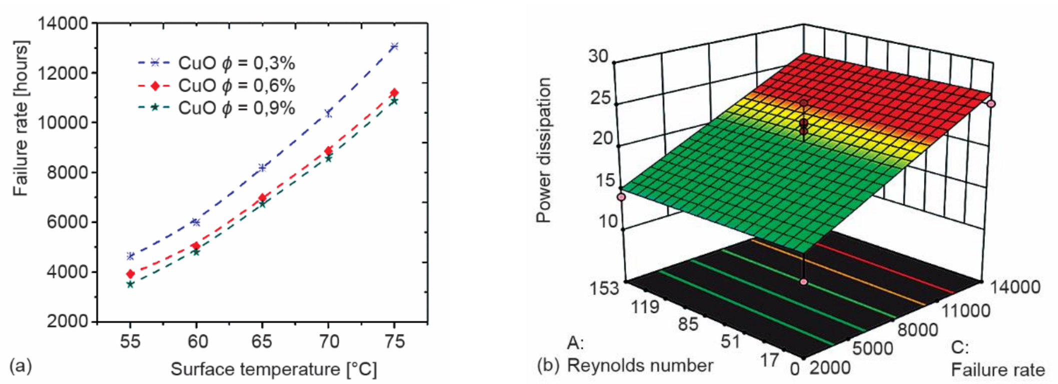

Figure 6. (a) Failure rate *vs.* surface temperature of CuO-water nanofluids, (b) failure rate and power dissipation of TiO_2-water nanofluids

Conclusions

In this work, the thermal performance of a processor using CuO-water and TiO_2--water nanofluids at different volume fraction of nanofluids such as 0.3%, 0.6%, and 0.9% was investigated numerically by using ANSYS FLUENT (V12) software package. It was observed that higher the Reynolds number, higher the heat transfer coefficient of CuO-water nanofluids and were found to be 5%, 7%, and 9% higher than TiO_2-water nanofluids. These enhancements are due to higher thermal conductivity of nanofluid, superior mixing of the fluid, and Brownian motion of nanoparticles which carry more heat energy. The power consumption of CuO-water nanofluids was 5% lower than TiO_2-water nanofluids and failure rate of the processor was 17%, 10%, and 8% lower than TiO_2-water nanofluids for volume fractions of $\varphi = 0.3\%$, 0.6%, and 0.9% respectively. The developed CFD model gives a better a prediction for heat transfer rate, velocity streamline in a channel heat sink. It is concluded that the CuO-water nanofluid shows desirable performances than TiO_2-water nanofluids in sense of cooling effect, lowering thermal resistance and component failure rate.

Nomenclature

A	– constant
E_a	– activation energy, [eV]
h	– heat transfer coefficient, [$Wm^{-2}K^{-1}$]
J	– current density, [per cm^2]
K_B	– Boltzmann's constant
P	– power dissipation, [W]
$R_{th(j-a)}$	– thermal resistance between junction and ambient temperature
T_a	– ambient temperature, [°C]
T_j	– junction temperature, [°C]
T	– absolute operating temperature, [°C]
t	– surface temperature, [°C]
t_o	– on-chip temperature, [°C]
Re	– Reynolds number

Greek symbol

ϕ	– nanoparticle volume fraction

References

[1] Choi, S. U. S., Eastman, J. A., Enhancing Thermal Conductivity of Fluids with Nanoparticles, *Proceedings,* ASME International Mechanical Engineering Congress and Exposition, San Francisco, Cal., USA, 1995, 1, pp. 99-105
[2] Lee, S., *et al.,* Measuring Thermal Conductivity of Fluids Containing Oxide Nanopracticles, *Journal of Heat Transfer, 121* (1999), 2, pp. 280-289
[3] Wang, B. X., *et al.,* A Fractal Model for Oredicting the Effective Thermal Conuctivity of Liquid with Suspension of Nanoparticles, *International Journal of Heat and Mass Transfer, 46* (2003), 14, pp. 2665-2672
[4] Koo, J., Kleinstreuer, C., A New Thermal Conductivity Model for Nanofluids, *Journal of Nanoparticle Research, 6* (2004), 3, pp. 577-588
[5] Kandlikar, S. G., *et al., Heat Transfer and Fluid Flow in Minichannels and Microchannels,* Elsavier, Amsterdam, The Netherlands, 2014
[6] Al-Rashed, M. H*., et al.*, Investigation on the CPU Nanofluid Cooling, *Microelectronics Reliability, 63* (2016), 1, pp. 159-165
[7] Ghasemi, S. E., *et al.*, Numerical Study on Effect of CuO-Water Nanofluid on Cooling Performance of Two Different Cross-Sectional Heat Sinks, *Advanced Powder Technology, 28* (2017), 2, pp. 1495-1504
[8] Ghasemi, S. E., *et al.*, Experimental and Numerical Investigation of Circular Minichannel Heat Sinks with Various Hydraulic Diameter for Electronic Cooling Application, *Microelectronics Reliability, 73* (2017), June, pp. 97-105
[9] Korpys, M., *et al.,* CPU Heat Sink Cooled by Nanofluids and Water: Experimental and Numerical Study, in: *Computer Aided Chemical Engineering, 12* (2013), 2, pp. 409-414
[10] Jeng, L. Y., Teng, T. P., Performance Evaluation of a Hybrid Cooling System for Electronic Chips, *Experimental Thermal and Fluid Science, 45* (2013), 1, pp. 155-162
[11] Zhao, N., *et al.*, Experimental Study on Thermo-Hydraulic Performance on Nanofluids in CPU Heat Sink with Rectangular Grooves and Cylindrical Bugles Based on Exergy Efficiency, *Energy Conversion and Management, 181* (2019), Feb., pp. 235-246
[12] Palanisamy, K., Mukesh Kumat, P. C., Experimental Investigation on Convective Heat Transfer and Pressure Drop of Cone Helically Coiled Tube Heat Exchanger Using Crbon Nanotubes/Water Nanofluids, *Heliyon, 5* (2019), 5, pp. 1-10
[13] Shi, X., *et al.,* Numerical Investigation of Laminar Convective Heat Transfer and Pressure Drop of Water-Based Al_2O_3 Nanofluids in a Microchannel, *International Communications in Heat and Mass Transfer, 90* (2018), 1, pp. 111-120
[14] Saeed, M., Kim, M. H., Heat Transfer Enhancement Using Nanofluids (Al_2O_3-H_2O) In Mini-Channel Heatsinks, *International Journal of Heat and Mass Transfer, 120* (2018), 1, pp. 671-682
[15] Ho, C. J., *et al.*, Experimental Study of Cooling Characteristics of Water-Based Alumina Nanofluid in a Minichannel Heat Sink, *Case Studies in Thermal Engineering, 14* (2019), 1, pp. 6-10
[16] Bakhti, F. Z., Si-Ameur, M., A Comparison of Mixed Convective Heat Transfer Performance of Nanofluids Cooled Heat Sink with Circular Perforated Pin Fin, *Applied Thermal Engineering, 159* (2019), 1, pp. 1-6

[17] Mukesh Kumar, P. C., Arun Kumar, C. M., Influence of Aspect Ratio on Thermal Performance of Heat sink using ANSYS, *Journal of Applied Fluid Mechanics, 19* (2018), Special issue, pp. 45-52
[18] Chandrasekar, M., Mukesh Kumar, P. C., Experimental Investigation on Heat Transfer and Pressure Drop in Double Helically Coiled Tube Heat Exchanger with MWCNT/water Nanofluid, *Journal of Applied Fluid Mechanics, 19* (2018), Special issue, pp. 23-29
[19] Mukesh Kumar, P. C., Arun Kumar, C. M., Numercial Study on Heat transfer Performance using Al_2O_3/water nanofluids in Six Circular Channel Heatsink For Electronic Chip, *Materials Today Proceedings-Journal Elsevier*, On-line first, https://doi.org/10.1016/j.matpr.2019.04.220, (2019)
[20] Sohel Murshed, S. M., Nieto de Castro, C. A., A Critical Review of Traditional and Emerging Techniques and Fluids for Electronics Cooling, *Renewable and Sustainable Energy Reviews, 78* (2017), 1, pp. 821-833

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