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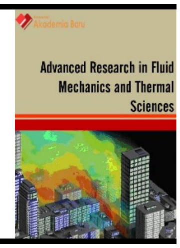

Heat Transfer Enhancement Using Nanofluids For Cooling A Central Processing Unit (CPU) System

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ABSTRACT

The effect of using different types of nanofluids as a coolant fluid in a CPU cooling on the heat transfer enhancement and fluid flow were studied numerically. The continuity, momentum and energy equations were solved by means of a finite volume method (FVM). This study covers the Reynolds number range of 5000 to 15000. Four different types of nanoparticles, Al_2O_3, CuO, SiO_2, and ZnO with different nanoparticle diameters in the range of 20nm to 50nm have been used. The volume fraction of the different types of nanofluid are considered as 1%,2%,3% and 4% have been also employed in water for the cooling process. The numerical results indicated that the Nusselt number increased with the increase of the Reynolds number in case of using water as coolant fluid. The skin friction coefficient increased with the increase of the Reynolds number in case of using water as coolant fluid. The SiO_2 nanofluid has the highest Nusselt number value, followed by Al_2O_3, ZnO and CuO. Finally pure water has the lowest Nusselt number. It has been observed that the SiO_2 nanofluid has the highest skin friction coefficient, followed by Al_2O_3, ZnO and CuO. Pure water has the lowest skin friction coefficient. The Nusselt number is improved with the increase of nanoparticle concentration. The Nusselt number increased with the decrease of nanoparticles diameter. The local Nusselt number considerably increased with increasing Reynolds number and local skin friction coefficient considerably increased with increasing Reynolds number.

Keywords:
Cooling Central Processing Unit (CPU), Heat transfer, numerical simulation, Nusselt number

1. Introduction

The generation of great heat is a major problem of modern computers and electronics devises. Computer components are transferred and extracted the heat by cooling system. Since different parts of a computer produce a great amount of heat while working, there should be a mechanism to extract this heat in order to work in a secure working condition. Computer coolers are used for this purpose [1] and using suitable coolant fluids. The cooling performance of the system will have a great

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effect on improving Computer components. Cooling of several chips by using Fluid heat sinks are capable of concurrent. They cooling the central processor, Central Processing Unit CPU, graphic card and processor supply circuits simultaneously. Looking for an effective and integral cooler for inner parts of their computer has encouraged many users to use it. Theoretically, fluid heat sinks can cooling the chip to the temperature of cooling fluid. These heat sink generate a noise while working due to their low operational flow rates. Also, in the case of utilize the fan with radiator (of the heat sink), the generate noise of the system remains low [2].

Nanofluid is a fluid containing mixture of base fluid and nanometer-sized particles. Suspensions of nanoparticles in a base fluid are engineered in order to increase the thermal conductivity of working fluid. Many Previous researchers have shown improved the thermal performance by using nanofluids compared with conventional fluids in various systems. Nanofluids which include fine particles of nano-scale (commonly less than 100 nm) in liquids have shown up as a candidate for designing heat transfer systems. Many experimental and numerical investigation examined the effect of nanofluids on heat transfer enhancement which have been developed largely in the last decade [3]. Rafati *et al.,* [4] investigated the effect of Alumina nanofluid in Central Processing Unit (CPU) cooling on heat transfer performance at various Reynolds numbers. Korpyś *et al.,* [5] studied experimentally and numerically the influence of using water and CuO nanofluids to study a commercial heat sink for cooling of PC processor. Jeng *et al.,* [6] test the effect of using Al_2O_3/water nanofluid instead of distilled water (in hybrid cooling system) for electronic chips on heat dissipation performance, greater power consumption for the water pump, and a lower surface temperature on the heater. Yousefi *et al.,* [7] observed that using 0.5% Al_2O_3 nanoparticles with water as a coolant for Central Processing Unit CPU coolers heat pipe leads to a decrease the thermal resistance. From the results, it was clearly seen that at 10 W, the presence of nanofluid reduced the thermal resistance by 15%, while at 25 W, the thermal resistance dropped by 22%. Selvakumar *et al.,* [8] showed that an improve of 29.63% in the convective performance by using CuO/water nanofluid at 0.2% volume fraction in an electronic heat sink. Garg *et al.,* [9] studied the effect of dispersing energy on viscosity of multi-wall carbon nanotube-based aqueous nanofluids. The effect of dispersing energy on viscosity, thermal conductivity, and the laminar convective heat transfer was studied by authors. Results indicated that thermal conductivity and heat transfer enhancement increased until an optimum time was reached, and decreased on further ultra-sonication. Heat transfer behavior of aqueous suspensions of multi-walled carbon nanotubes (CNT nanofluids) flowing through a horizontal tube was analyzed by Ding *et al.,* [10] Significant enhancement of the convective heat transfer is observed and the enhancement depends on the flow conditions and CNT concentration. It is clear from the above literature survey that Al_2O_3 nanofluid and especially CNT cooling of Central Processing Unit CPU is not studied in earlier works completely. Also, the heat transfer behavior of CNT nanofluids need more study. In this article, we intend to use both Alumina and CNT nanofluids as new working fluids in Central Processing UNIT CPU coolers. The highlights of the present study can be summarized as: The thermal performance of CNT is compared with Alumina nanofluid to show the better thermal performance of CNT nanofluid. The heat transfer enhancement of nanofluids is calculated for both cases of CNT and Alumina. The results showed heat transfer increment of 6% for Alumina and 13% for CNT nanofluids. Final processor temperature is reported for a wide range of parameters. The results showed that the final Central Processing Unit (CPU) temperature is decreased about 22% by using CNT and 20% in the case of Alumina nanofluid. Harmand *et al.,* [11] applied a transient model with the coupling 3D thermal model to analyze the thermal cooling of a flat heat pipe for cooling of multiple electronic components. Li and Chiang [12] investigated the effects of a shield on the thermal and hydraulic characteristics of plate-fin vapor chamber heat sinks under cross flow cooling. Attia and El-Assal [13] considered the effects of working fluid surfactant on the thermal performance vapor chamber with different charge ratios. Ji *et al.,* [14] considered the effects of an extended vapor chamber which consisting of an evaporator part and an extended condenser part on the vapor chamber thermal performance. Tsai *et al.,* [15] investigated the influence of inclination on the vapor chamber performance and temperature uniformity. Chen *et al.,* [16] studied thermal resistance of sintered aluminum powders vapor chamber. Hassan and Harmand [17] studied the three-dimensional transient model for considering the thermal performance of vapor chamber. Egan *et al.,* [18] analyzed the finite element numerical simulations in order to understand the thermal phenomena of embedded electronics design and to explore the thermal design space. The results show that the exposed surface area of the heat spreader and the conductivity of the substrate are the most important parameters affecting the thermal performance of the embedded electronic artifact. Gauch *et al.,* [19] examined the modeling phase change using the conventional material properties and a transient analysis for system level thermal models. They considered a case study in which a system level CFD model of an electronic enclosure is modeled without PCM and with PCM retro-fitted in three configurations. Kitamura *et al.,* [20] studied natural the effect of air cooling in electronics casing on heat transfer by natural convection. They presented the results of experimental and numerical studies on the effect of casing inclination on the temperature rise across the casing. They obtained a thermal design guide regarding how the cooling effect is improved by increasing the inclination angle. Nakayama *et al.,* [21] studied numerically the effects of component placement on the junction temperature. They observed the methodology of CFD analysis for the heat sink/duct design, and described experimental procedures to validate the predictions. Rodgers *et al.,* [22] studied numerically the component-printed circuit board (PCB) heat transfer in forced convection using a widely used computational fluid dynamics (CFD) software. They showed that the full complexity of component thermal interaction is not to be fully captured. Leon *et al.,* [23] studied numerically three different models to obtain the ratio between the heat removed and the energy spent for the coolant flow going through the cooling fins. The use of a staggered heat sink always leads to a maximization of the heat transfer flux. In this study, the effect of different types of nanofluids on cool central processing units (CPU) of desktop computers are investigated.

2. Mathematical model and numerical solution

2.1 Schematics of the Central Processing Unit

Schematic diagrams of the Central Processing Unit (CPU) cooling system are shown in Figure 1. The inlet and outlet diameter are 5mm diameter as shown in Figure 1.The dimension of rectangular base are 50mm × 50mm. Different types of nanofluids are selected as the working fluids.

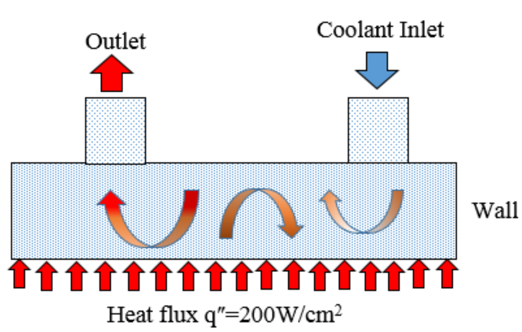

Fig. 1. Schematic diagram of Central Processing Unit CPU cooling system

2.2 Governing Equations

It is important to set the governing equations (continuity, momentum, and energy) to complete the CFD analysis of Central Processing Unit (CPU) cooling system. The phenomenon under consideration is governed by the steady 2-dimensional from of the continuity, the time-averaged incompressible Navier-Stokes equations and energy equation. In the Cartesian tensor system these equations can be written as

Continuity equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{2}{3}\mu\frac{\partial u_k}{\partial x_k}\delta_{ij} \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial x_j}\left(\rho u_j C_p T - k\frac{\partial T}{\partial x_j}\right) = u_j\frac{\partial p}{\partial x_j} + \left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\mu\frac{\partial u_k}{\partial x_k}\delta_{ij}\right] \tag{3}$$

Where C_P is the specific heat at constant pressure, $(kJ/kg.K)$, k is the turbulent kinetic energy, (m^2/s^2), ε is the turbulent dissipation rate, (m^2/s^3).

2.3 Thermophysical Properties of Nanofluids

In order to carry out the simulations for nanofluids, the effective thermophysical properties of nanofluids must be calculated first. In this case, the nanoparticles being used are Al_2O_3, CuO, SiO_2 and ZnO. Basically the required properties for simulations are effective thermal conductivity (k_{eff}), effective dynamic viscosity (μ_{eff}), effective mass density (ρ_{eff}), and effective specific heat (cp_{eff}). Regarding these, the effective properties of mass density, specific heat, thermal conductivity, and viscosity are actually calculated according to the mixing theory. The density of nanofluid, ρ_{nf} can be obtained from the following equation.

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_{nf} \tag{4}$$

Where ρ_f and ρ_{nf} are the mass densities of the based fluid and the solid nanoparticles, respectively. For the heat capacity the effective heat capacity at constant pressure of nanofluid, can be calculated from the following equation.

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_{np} \tag{5}$$

Where $(\rho c_p)_f$ and $(\rho c_p)_{np}$ are the heat capacities of the based fluid and the solid nanoparticles, respectively.

The effective thermal conductivity can be determined by using Brownian motion of nanoparticles in Central Processing Unit (CPU) cooling system, the effective thermal conductivity can be obtained by using the following mean empirical correlation.

$$k_{eff} = k_{static} + k_{Brwnian} \tag{6}$$

$$k_{static} = k_f \left[\frac{(k_{np}+2k_f)-2\Phi(k_f-k_{np})}{(k_{np}+2k_f)+\Phi(k_f+k_{np})}\right] \tag{7}$$

$$k_{Brwnian} = 5 * 10^4 \beta\phi\rho_f C_{p_f}\sqrt{\frac{KT}{2}} f(T,\phi) \tag{8}$$

Boltzmann constant, $k = 1.3807 * 10^{-23}\frac{J}{K}$ and values of β for different particles are listed in Table 1.

Table 1
Values of β for different nanoparticles

Type of partials	β	Concentration (%)	Temperature(K)
Al_2O_3	$8.4407(100\phi)^{-1.07304}$	1% ≤ ϕ ≤ 10%	298K ≤ T ≤ 363K
CuO	$9.881(100\phi)^{-0.9446}$	1% ≤ ϕ ≤ 6%	298K ≤ T ≤ 363K
SiO_2	$1.9526\,(100\phi)^{-1.4594}$	1% ≤ ϕ ≤ 10%	298K ≤ T ≤ 363K
ZnO	$8.4407(100\phi)^{-1.07304}$	1% ≤ ϕ ≤ 7%	298K ≤ T ≤ 363K

$f(T,\phi)$ can be determine using the following equation.

$$f(T,\phi) = (2.8217 * 10^{-2}\phi + 3.917 * 10^{-3})\left(\frac{T}{T_\circ}\right) + (-3.0669 * 10^{-2}\phi - 3.3991123 * 10^{-3}) \quad For\ 1\% \le \phi \le 4\%\ and\ 300K \le T \le 325K \tag{9}$$

The effective viscosity can be obtained by using the following mean empirical correlation.

$$\mu_{eff} = \mu_f * \left(\frac{1}{1-34.87\left(\frac{d_p}{d_f}\right)^{-0.3} * \phi^{1.03}}\right) \tag{10}$$

$$d_f = \left[\frac{6M}{N\pi\rho_{f_0}}\right]^{1/3} \tag{11}$$

M is the molecular weight of base fluid, N is the Avogadro number = 6.022*1023 mol^{-1}, ρ_{f_0} is the mass density of the based fluid calculated at temperature T_0=293K. Table 2 shows the thermophysical properties of water and nanoparticle.

Table 2
The thermo-physical properties of water and different nanoparticles at T=300K

Thermo-physical Properties	Water	Al_2O_3	SiO_2	CuO	ZnO
Density $\boldsymbol{\rho}$ $(\boldsymbol{Kg/m^3})$	998.2	3600	2200	6500	5600
Dynamic viscosity, $\boldsymbol{\mu}$ $(\boldsymbol{Ns/m^2})$	1.00E-03	0	0	0	0
Thermal conductivity, $\boldsymbol{k}$ $(\boldsymbol{W/m.K})$	0.6	36	1.2	20	13
Specific heat, $\boldsymbol{C_P}(\boldsymbol{J/kg.K})$	4182	765	703	535.6	495.2

2.4 Boundary Conditions

The boundary conditions for the present problem are specified for the computational domain as shown in Figure 1. These figures show the Central Processing Unit (CPU) cooling system model selected from this study, bottom wall is subjected to uniform heat flux while the right side is subjected to velocity inlet and the left side is subjected to pressure outlet. The value of heat flux of 200 W/cm^2 is subjected at the bottom wall of the heat exchanger. The standard $k-\varepsilon$ turbulence model, the Renormalized Group (RNG) $k-\varepsilon$ turbulence model were selected. The time-independent incompressible Navier-Stokes equations and the turbulence model analysis were solved using finite volume method. To evaluate the pressure field, the pressure-velocity coupling algorithm SIMPLE (Semi Implicit Method for Pressure-Linked Equations) was selected. At the inlet, fully developed velocity profile was imposed. The turbulence intensity was kept at 1% at the inlet. The solutions are considered to be converged when the normalized residual values reach 10^{-5} for all variables.

2.5 Code Validation

Code validation is very important for any numerical work in order to check the numerical code is validated with other previous works and it is ready for further runs. It should give same results or very close to previous works that have been investigated. Besides that, it is not only important to get high accuracy of any numerical code but also to gain a better understanding on its capabilities and limitations. In order to validate the numerical model, the study has conducted by Nazari *et al.,* [24] was used. They investigated experimentally the effect of using nanofluids on heat transfer enhancement. The comparison of the present results of heat transfer coefficient with different flow rate with the results of Nazari *et al.,* [24] is presented in Figure 2. In this figure, the results of the present work reasonably agree well with the results of Nazari *et al.,* [24] for Central Processing Unit (CPU) cooling.

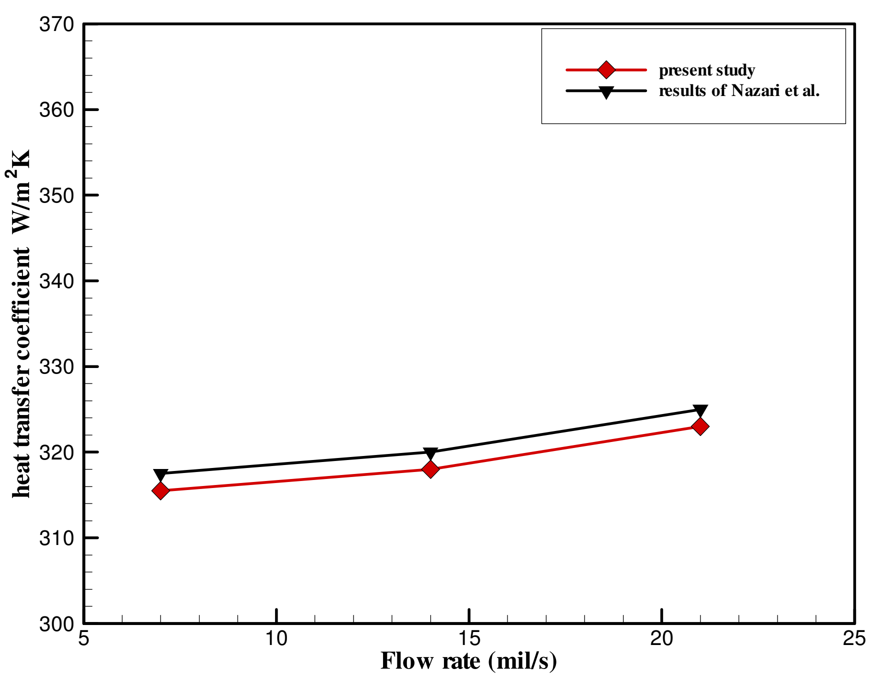

Fig. 2. Comparison of the present results with the results of Nazari *et al.,* for different flow rates [24]

3. Results and Discussion

3.1 The Effect of Different Types of Nanoparticles

The effect of four different types of nanoparticles which are SiO_2, Al_2O_3, CuO and ZnO with pure water as a base fluid are used in this section. In order to study the effect of different nanofluids on the heat transfer enhancement in the Central Processing Unit (CPU) cooling system and all other parameter of the system of heat transfer were fixed. The variation of Nusselt number versus different Reynolds number is shown in Figure 3 with using four types of nanofluids for volume fraction of 0.04 and practical diameter of 20nm of nanofluid and pure water in this case. As shown in this figure, the Nusselt number of nanofluid is higher than that of the base fluid (water) as the presence of nanoparticles directly results in an increase of thermal conductivity. Besides, the heat transfer improvement is also associated by the collision among nanoparticles and also between the nanoparticles and tube wall, leading to an increase in the energy exchange rate. Nusselt number increases with increasing Reynolds number due the intensification of the nanofluid mixing fluctuation. Among test fluids, it is clearly noted that the greater enhancement in heat transfer shown by SiO_2/water nanofluid, followed by Al_2O_3/water, ZnO/water, CuO/water nanofluids and pure water because of the greater surface to volume ratio and higher thermal conductivity of SiO_2 nanoparticles compared with others nanoparticles. The effect of Reynolds number levels on the skin friction coefficient of bottom wall of the Central Processing Unit (CPU) cooling system is displays in Figure 4 with utilization of different nanofluids and pure water while the particle volume fraction and nanoparticle diameter are kept constant in this case. It is clearly seen that the skin friction coefficient of the bottom wall of the Central Processing Unit (CPU) cooling system increases when Reynolds number increases for all types of nanofluids. Among the fluids tested, the SiO_2 nanofluid has the highest skin friction coefficient, followed by Al_2O_3, ZnO, CuO nanofluids and finally pure water. The suspension of nanoparticles in the base fluid causes a slight increase in the skin friction coefficient.

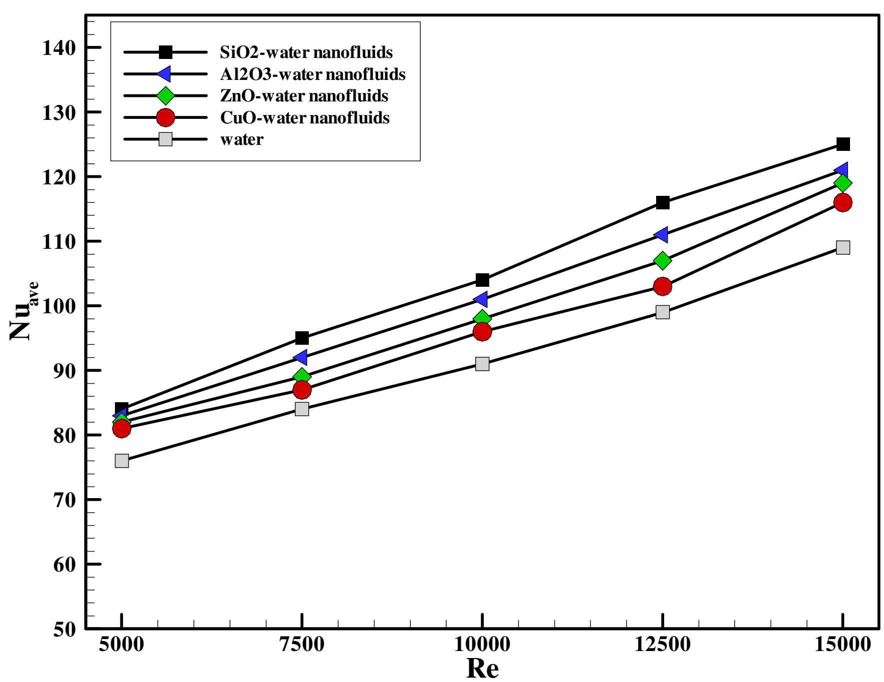

Fig. 3. Variation of average Nusselt number with Reynolds number for different types of nanofluids and pure water

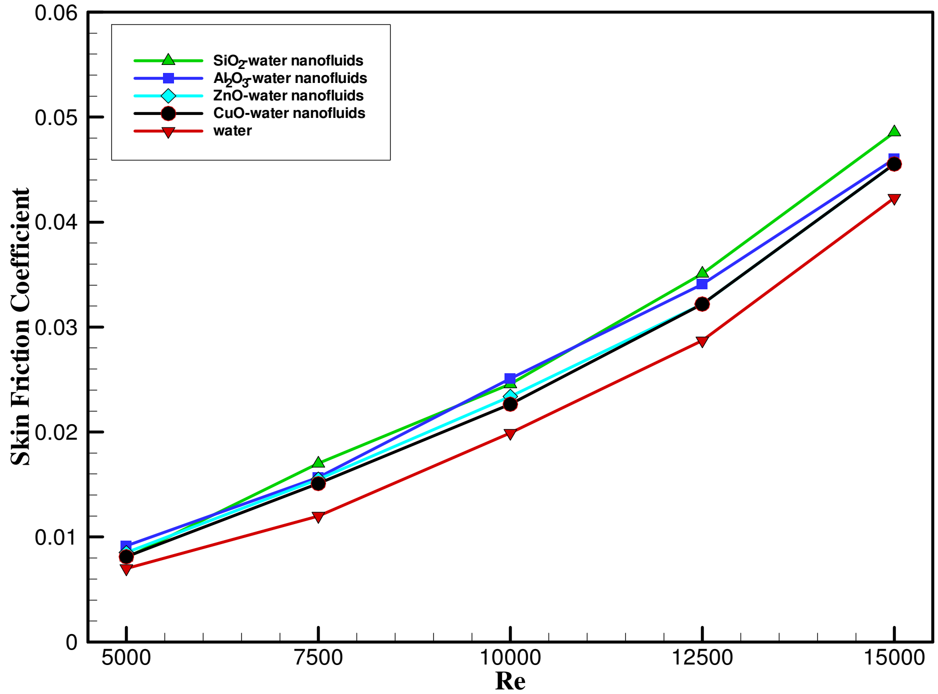

Fig. 4. Variation of skin friction coefficient with Reynolds number for different types of nanofluids and pure water

3.2 The Effect of Different Volume Fractions, φ of Nanoparticles

This section analyses the effects of different nanoparticle concentrations of SiO_2 nanofluid on the Nusselt number and skin friction coefficient. The effect of various volume fractions on Nusselt number is shown in Figure 5. In this study the Reynolds number varies from 5000 to 150000 and the nanoparticle concentration in the range of 0-4% is investigated. From the results, it is clearly seen that SiO_2 nanofluid with highest volume fractions of 4% has the highest average Nusselt number at all Reynolds numbers. In fact, by increasing the volume fractions of nanofluid lead to increase the thermal conductivity of the fluid and the increases of thermal conductivity and collision of nanoparticles which are favorite factors for heat transfer enhancement. Pure water has zero volume fractions and provides the lowest average Nusselt number. It is also found that the average Nusselt number increases with the increase of Reynolds number. The variation of skin friction coefficient with Reynolds number for different volume fractions is presented in Figure 6. In concentration range studied, the skin friction coefficient slightly increases with the increase of nanofluid concentration. In general, the increase of nanofluid concentration results in an increase of fluid viscosity which diminishes the fluid movement.

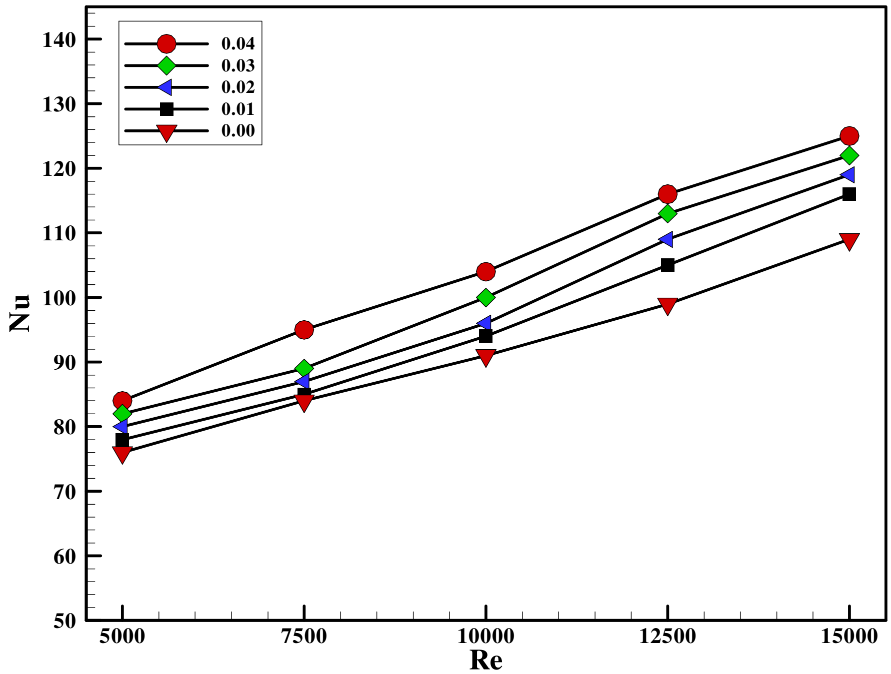

Fig. 5. Variation of average Nusselt number with Reynolds number for different volume fractions, φ

3.3 The Effect of Different Nanoparticles Diameters,dp

The effect of different nanoparticles diameters of SiO_2 nanofluid on the Nusselt number and skin friction coefficient with different Reynolds number are investigated in this section. The range of nanoparticles diameter are varied from 20nm-50nm with fixed other parameters such as the concentrations of SiO_2 nanofluid is 4%. As illustrated in Figure 7, the results show that the Nusselt number increases with decreasing the nanoparticles diameter for all Reynolds numbers. The maximum Nusselt number is found at nanoparticles diameter of 20nm. The effective dynamic viscosity of the nanofluid increases with the decrease of the nanoparticles diameter resulting in better heat transfer. The effect of different nanoparticles diameters of SiO_2 nanofluid on skin friction coefficient with different Reynolds number are presented in Figure 8. It is noted that there is a slight change in the friction coefficient when nanoparticles diameters of SiO_2 nanofluid is changed.

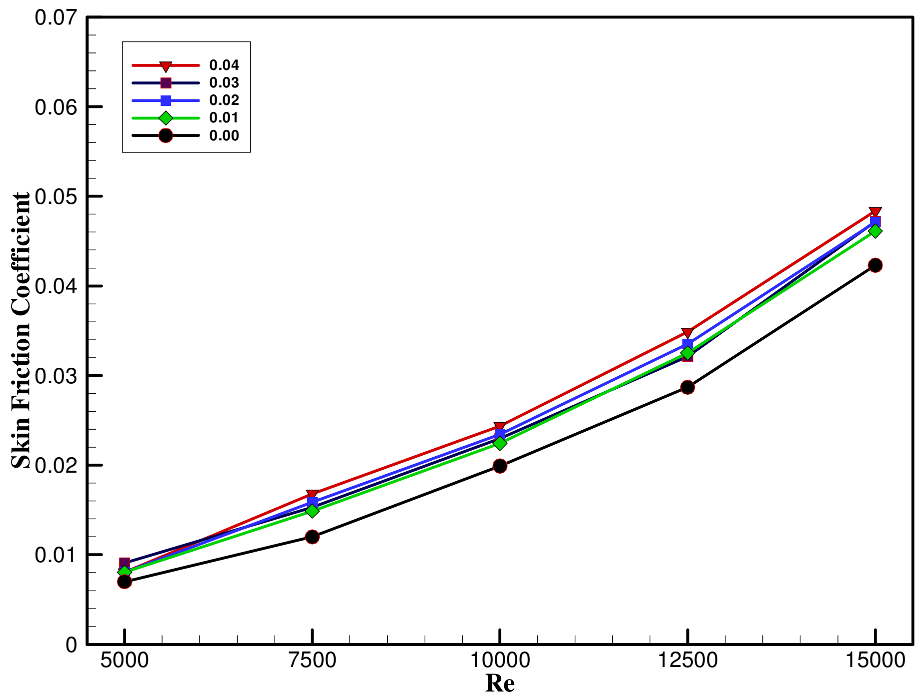

Fig. 6. Variation of Skin friction coefficient with Reynolds number for different volume fraction, φ at dp=20nm

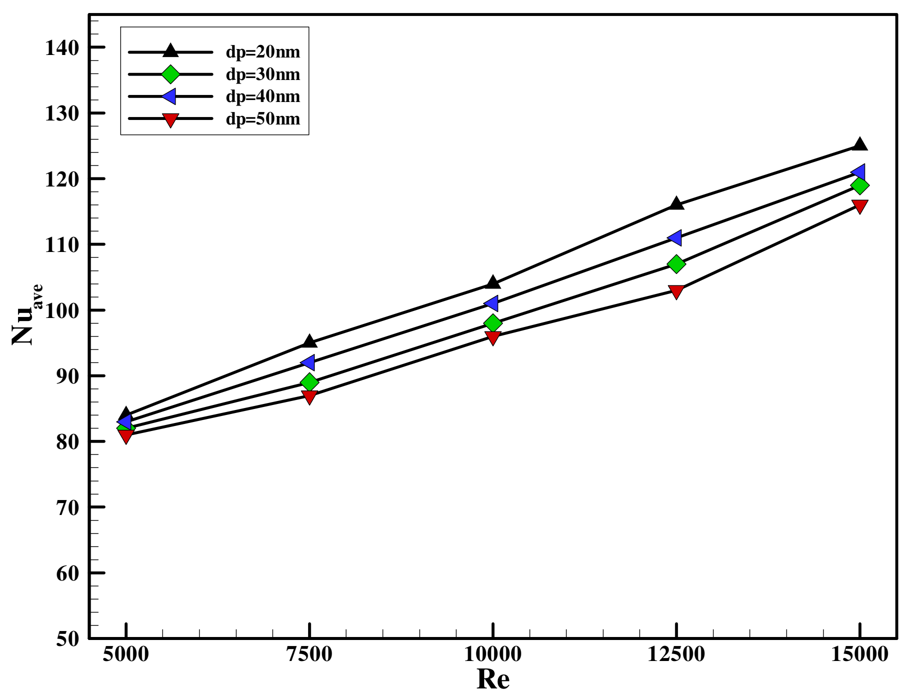

Fig. 7. Variation of average Nusselt number with Reynolds number for different nanoparticles diameter

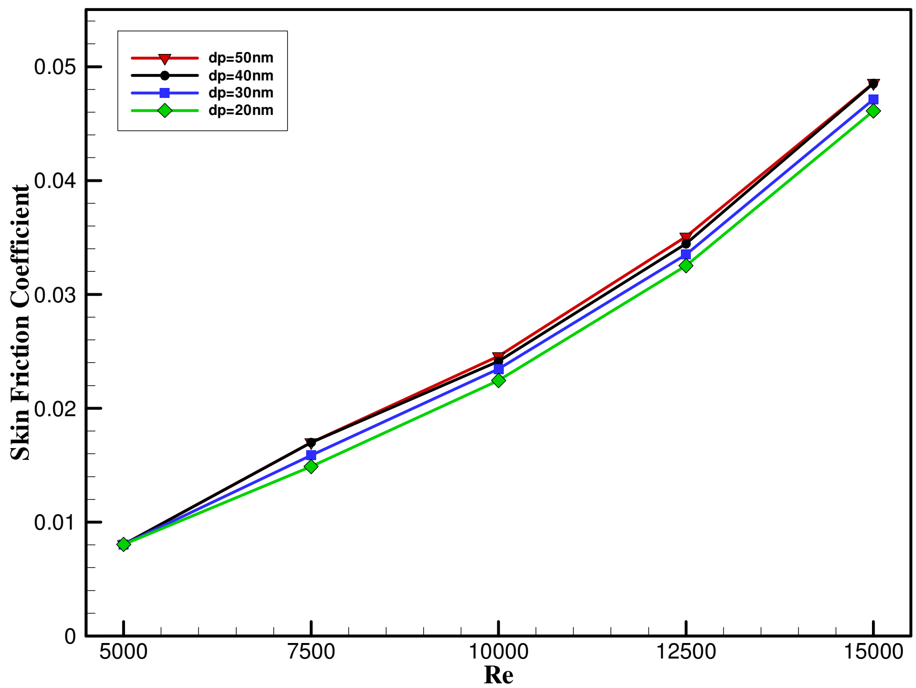

Fig. 8. Variation of Skin friction coefficient with Reynolds number for different nanoparticles diameter

4. Conclusion

A different types of nanofluids were used to enhance the heat transfer in a Central Processing Unit (CPU) cooling system with constant heat flux on the bottom wall. The Nusselt number, and skin friction coefficient were obtained through the numerical simulation. The following conclusions were drawn as follows.

1. The Nusselt number increased with the increase of the Reynolds number in case of using water as coolant fluid.
2. The skin friction coefficient increased with the increase of the Reynolds number in case of using water as coolant fluid.
3. The SiO_2 nanofluid has the highest Nusselt number value, followed by Al_2O_3, ZnO, CuO and finally pure water has the lowest Nusselt number.
4. The SiO_2 nanofluid has the highest skin friction coefficient, followed by Al_2O_3, ZnO, CuO and finally pure water has the lowest skin friction coefficient.
5. The Nusselt number is improved with the increase of nanoparticle concentration.
6. The Nusselt number increased with the decrease of nanoparticles diameter.
7. The local Nusselt number considerably increased with increasing Reynolds number, Re in the range of 5000-15000.
8. The local skin friction coefficient considerably increased with increasing Reynolds number, Re in the range of 5000-15000.

This study proven that the utilization of nanofluids is very important in enhancing the heat transfer compared to conventional heat transfer fluids (water).

Acknowledgements
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