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2D CFD Simulation to Investigate the Thermal and Hydrodynamic Behavior of Nanofluid Flowing Through A Pipe in Turbulent Conditions

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ABSTRACT

The thermal coolant proprieties are a potential indicators of heat transfer performance, however, the coolant often remains less efficient because of its inability to absorb the excess heat. Thanks to nanotechnology, a new concept has been introduced to prepare nano-sized particles that can be dispersed in the coolant to form a stable nanofluid with excellent thermal properties. Nevertheless, the addition of the nanoparticles leads to an increase in viscosity which augments the shear stress affecting the performance of the cooling system. This study aims to investigate both the thermal and hydrodynamic behavior of nanofluid flowing in turbulent conditions through a cylindrical copper pipe while maintaining at constant temperature by using a single-phase approach. The governing equations are solved by using the shear stress transport (SST) k-ω turbulence model along with the finite element method. In this work, the temperature and velocity distribution of Al_2O_3-water nanofluid for different volume fractions are studied. The effects of Reynolds number (Re) and volume fraction of nanoparticles (φ) on both the Nusselt number and shear stress are also investigated thoroughly. Moreover, the impact of these types of nanoparticles (Al_2O_3 and Cuo) on the Nusselt number and pressure drop is examined. The obtained results show how the concentration of nanoparticles influences the radial distribution of temperature and velocity by giving the flow a certain homogeneity which enhances heat transfer but it also affects the hydrodynamic behavior of nanofluid leading to an increase in the shear stress. Based on these two investigations the nanofluid containing Al_2O_3 particles is better than that of CuO even though the thermal conductivity of CuO is higher than that of Al_2O_3.

1. Introduction

It is often necessary to remove the excess heat from equipment as a way to keep it functioning in good conditions for a long time and prevent any possible damage, and to do that, a heat exchanger could be used for this purpose. In order to enhance the heat exchanger effectiveness, one of the techniques suggested to do that is to enlarge the heat exchange surface. However, the

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implementation of such a technique takes up too much room and makes the heat exchanger more expensive. In most recent years, a new technology has been developed to boost the heat exchange by adding well-chosen nanoparticles to the coolant (base fluid) which results in forming a colloidal solution called nanofluid that is characterized by an excellent thermal property. This technique makes it possible to avoid altering the dimensions of the cooling system. This type of fluid was first introduced in 1995 by Choi *et al.,* [1].

The thermal performance of nanofluid largely depends on both the nanoparticles transport properties (type) and volume fraction although this parameter is limited for each nanoparticle for the stability concern. The analysis of transport properties was investigated by several authors including. Garg *et al.,* [2] who studied the effect of the volume fraction of the copper oxide (CuO) nanoparticles in ethylene glycol on the thermal conductivity and viscosity of the nanofluid. The nanofluid flows into a tube whose wall is kept at constant heat flux. This investigation revealed that there was a slightly higher increase in the dynamic viscosity of nanofluid than in the thermal conductivity which results in slowing down the heat transfer. Another experiment was conducted by Raja and Sharma [3] on the specific heat capacity and viscosity of a nanofluid composed of water with a low concentration of Al_2O_3 nanoparticles (47 nm in diameter, the concentration ranged between 0.01 % and 1 %). The results indicated a non-linear increase in viscosity with nanoparticle concentration due to the aggregation of particles. On the other hand, a decrease in the specific heat capacity of the nanofluid with the increase in the volume fraction was recorded.

For the purpose of enhancing the efficiency of cooling systems many researchers have carried out experimental studies to examine the impact of nanofluids on the heat transfer coefficient for different cooling equipment. Kulkarni *et al.,* [4] suggested the use of aluminum oxide nanofluid as a coolant in the heat exchanger of diesel electric generator. Their result indicated that the nanofluid helps to reduce the waste of heat as a result of improving the heat transfer coefficient. Similarly, Nnanna *et al.,* [5] designed a compact heat exchanger for cooling electronic devices. They showed how this new cooling system with nanofluid is more efficient than the conventional one because it saves energy and its weight and size make it more convenient. More recently a very interesting review was presented by Japar *et al.,* [6] about the use of nanofluid as a coolant in microchannel heatsink to improve heat transfer performance. The thermal performance of this cooling system mainly depends on the type and size of nanoparticles as well as the type of the base fluid. They pointed out that the use of Al_2O_3 nanoparticles in water leads to the highest heat transfer performance with the lowest pressure drop compared to the other base fluid. In addition, the thermal conductivity of nanoparticles is claimed to be the potential factor determining the thermal performance of nanofluids.

Many numerical investigations were carried out to study the thermal performance of nanofluids flowing in tube under different operating conditions. Moraveji *et al.,* [7] studied numerically the effect of the volume fraction of Al_2O_3 dispersed in water on the heat transfer in the developed region of the tube for different value of Reynods numbers ($500<Re<2500$). The volume fraction ranged from 1% to 6% and the tube was kept at constant heat flux. Their results revealed that the heat transfer coefficient is noticeably improved by adding Al_2O_3 particles. Demir *et al.,* [8] carried out a 2D numerical simulation using a CFD program to investigate the heat transfer in a turbulent forced convection of nanofluid consisting of water TiO_2 and Al_2O_3 in conterflow heat exchanger. They indicated that the addition of Al_2O_3 nanoparticles to the base fluid (water) flowing in the inner pipe of the heat exchanger helps to enhance the heat transfer rate and lowers the pressure drop along the inner tube. In the same context, Jehad and Hashim [9], and Azwadi and Adamu [10] investigated numerically the heat transfer of nanofluid flowing through a circular tube while maintaining a constant heat flux in turbulent conditions. Their results showed that the heat transfer was significantly improved by adding nanoparticles to the base fluid, whereas both the friction factor and the pressure drop increased.

It is worth noting that most numerical studies in the literature about the enhancement of heat transfer by adding nanoparticles in turbulent flow conditions are confined to investigating the variations of Nusselt number and pressure drop under the effect of the volume fractions and Reynolds number without providing any data or information about the temperature and velocity distribution of nanofluid when adding nanoparticles which are both powerful indicators of the heat transfer enhancement. Therefore, in this study a 2D CFD investigation of thermal and hydrodynamic behavior of nanofluid consisting of Al_2O_3/water flowing through a pipe in turbulent flow conditions is thoroughly examined using COMSOL Multiphysics Software by adopting k-ω turbulence model for the purpose of determining the effect of nanoparticles volume fractions and Reynolds Number not only on the Nusselt number but also on the temperature and velocity distribution and the shear stress as well as the friction velocity. In addition, the impact of nanoparticles, Al_2O_3 and CuO, on the thermal and hydrodynamic behavior is also investigated.

2. Thermophysical Properties of Nanofluid

The addition of the nanoparticles to the base fluid changes its physical properties. Given the continuous and Newtonian nature of the nanofluid, the following correlations are selectively chosen and included in this study:

The density ρ_{nf} of the nanofluid is expressed as [11-12]:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \tag{1}$$

The heat capacity of the nanofluid according to Abu-Nadu [13] is expressed as:

$$(\rho c_P)_{nf} = (1-\varphi)(\rho c_P)_{bf} + \varphi(\rho c_P)_{np} \tag{2}$$

The thermal expansion coefficient is calculated according to Khanafer *et al.,* [14].

$$(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_{fb} + \varphi(\rho\beta)_{np} \tag{3}$$

In regard to the viscosity the following correlation [15] is used

$$\mu_{nf} = \mu_{bf}(533.9\varphi^2 + 39.11\varphi + 1) \tag{4}$$

The effective thermal conductivity is determined by using the Maxwell-Garnetts model [16-17]:

$$k_{nf} = \left[\frac{k_{np}+2k_{bf}-2\varphi(k_{bf}-k_{np})}{k_{np}+2k_{bf}+\varphi(k_{bf}-k_{np})}\right]k_{bf} \tag{5}$$

The thermal diffusivity of the nanofluid is as follows:

$$(\alpha)_{nf} = \frac{k_{nf}}{(\rho c_P)_{nf}} \tag{6}$$

The different thermophysical properties of the nanoparticles and the base fluid are summarized in the following Table 1:

Table 1
Thermophysical properties [12, 18]

Parameters	Values	Description
ρ_f	997.1 kg/m^3	Water density
μ_f	880.637x10^{-6} Pa.s	Dynamic viscosity of water
Cp_f	4178 J/kg.k	Specific heat capacity of water
K_f	0.606 W/kg.K	Thermal conductivity of water
α_f	0.146x10^{-6} m^2.s	Thermal diffusivity of water
ρ_p	3970 kg/m^3	Al_2O_3 nanoparticle density
	6510 kg/m^3	CuO nanoparticles density
K_p	42.34 W/m.K	Thermal conductivity of Al_2O_3nanoparticle
	180 W/m.K	Thermal conductivity of CuO nanoparticle
Cp_p	750 J/kg.K	Specific heat capacity of Al_2O_3 nanoparticle
	540 J/kg.K	Specific heat of capacity CuO nanoparticle
d_w	2x10^{-3} m	Thickness of the pipe wall
K_w	45 W/m.K	Thermal conductivity of the pipe
T_w	60° C	Temperature of the pipe wall
l	1.2 m	Tube length
D	4x10^{-2} m	Tube diameter
T_∞	30° C	Nanofluid temperature at the inlet to the pipe

3. The Governing Equations

In order to solve the equations governing the flow of the nanofluid in the pipe as shown in Figure 1, thus the following assumptions are adopted:

i. The fluid phase and the nanoparticles are in thermal equilibrium and no relative movement occurs between them.
ii. The flow is assumed to be two-dimensional stationary and in turbulent regime.
iii. The nanofluid is considered to be Newtonian and incompressible.
iv. The effective thermophysical properties are assumed to be constant without depending on temperature except for the density which varies according to the Boussinesq approximation [19-20]:

$$\rho = \rho_0\big(1 - \beta(T - T_0)\big) \tag{7}$$

v. Pressure dissipation is not taken into account. The cylindrical configuration is axisymmetric.

Given to the aforementioned assumptions the governing equations are as follows [21]:

Continuity equation:

$$\nabla\big(\rho_{nf} U\big) = 0 \tag{8}$$

Momentum equation:

$$\nabla\left(\rho_{nf} U U\right) = -\nabla P + \nabla(\tau + \tau^{t}) \tag{9}$$

Energy equation:

$$\nabla\left(\rho_{nf} C_{p,nf} \overline{T}\,\overline{U}\right) = \nabla\left(\mathrm{k_{nf}}(\nabla \overline{T})\right) - \overline{\grave{U}\grave{T}} \tag{10}$$

Where U, P, T, $\grave{T}$, $\overline{T}$, $\grave{U}$ and $\overline{U}$ are respectively the velocity vector, the pressure, the temperature, fluctuating part of temperature, mean temperature, fluctuating part of velocity and Mean velocity.

In the present study, the shear stress transport (SST) k-ω turbulence model is used for the purpose to resolve the flow all the way near the wall. The main feature of the SST model is its ability to take into account the viscous sublayer by applying the k-ω model near the wall and to use the standard k-ε model in the turbulent core [22].

The SST model includes two transport equations:

Turbulence kinetic energy:

$$u_i \frac{\partial(k)}{\partial x_i} = P_k - \beta^* \omega k + \frac{\partial}{\partial x_i}\left[(\nu + \sigma_k \nu_t)\frac{\partial k}{\partial x_i}\right] \tag{11}$$

Specific dissipation rate :

$$u_i \frac{\partial \omega}{\partial x_i} = \alpha S^2 - \beta \omega^2 + \frac{\partial}{\partial x_i}\left[(\nu + \sigma_\omega \nu_t)\frac{\partial \omega}{\partial x_i}\right] + 2(1 - F_1)\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} \tag{12}$$

Where F_1 is the Blending Function (F_1 = 1 inside the boundary layer and 0 in the free stream) defined as follows:

$$F_1 = tanh\left\{\left\{min\left[max\left(\frac{\sqrt{k}}{\beta^* \omega y}, \frac{500\nu}{y^2 \omega}\right), \frac{4\sigma_{\omega 2} k}{CD_{k\omega} y^2}\right]\right\}^4\right\} \tag{13}$$

$$CD_{k\omega} = max\left(2\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}, 10^{-10}\right) \tag{14}$$

ν_t is the Kinematic eddy viscosity determined as follows:

$$\nu_t = \frac{a_1 k}{max(a_1 \omega, S F_2)} \tag{15}$$

F_2 is second Blending Function determined as follows:

$$F_2 = tanh\left[\left[max\left(\frac{2\sqrt{k}}{\beta^* \omega y}, \frac{500\nu}{y^2 \omega}\right)\right]^2\right] \tag{16}$$

P_k is the production limiter defined by:

$$P_k = min\left(\tau_{ij}\frac{\partial u_i}{x_j}, 10\beta^* k\omega\right) \tag{17}$$

$$\Phi = F_1\Phi_1 + (1 - F_1)\Phi_2 \quad (18)$$

In those equations, S is an invariant scale of the strain rate. The constants of the model have the following values [22]: β_1=0.075, β_2=0.0828, β^*=0.09, σ_{k1}=0.85, σ_{k2}=1, $\sigma_{\omega 1}$=0.5, $\sigma_{\omega 2}$=0.856, ϕ_1=5/9, ϕ_2=0.44.

4. Geometric Configuration and Boundary Conditions

In this simulation, a horizontally circular tube with 4x10^{-2} m in diameter and 1.2 m in length is kept at constant temperature, and the nanofluid, which flows through it, is considered to be a monophasic system consisting of water and Al_2O_3 particles as illustrated in Figure 1.

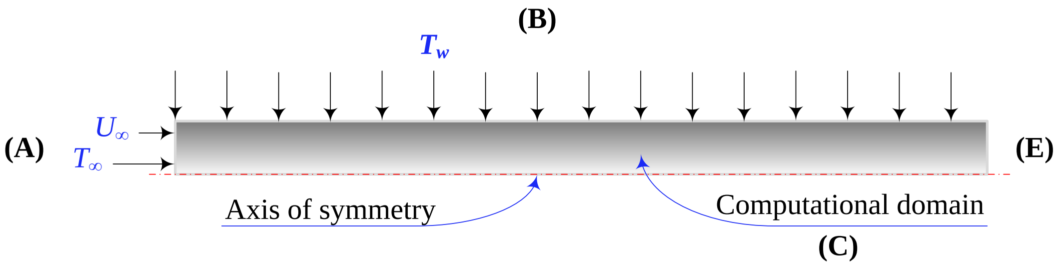


Fig. 1. Diagram of calculation domain and boundary conditions

The velocity and temperature of nanofluid at the inlet are uniform and the flow is fully developed in the computational domain. The boundary conditions used in the simulation are shown in Table 2.

Table 2
The Boundary Conditions

	U	V	T
Entry (A)	U_∞	0	T_∞
wall (B)	0	0	T_w
Symmetry (C)	$\frac{\partial U}{\partial r} = 0$	0	$\frac{\partial T}{\partial r} = 0$
Exit (E)	$\frac{\partial U}{\partial x} = 0$	$\frac{\partial V}{\partial x} = 0$	$\frac{\partial T}{\partial x} = 0$

5. Heat Transfer and Hydrodynamic Parameters

The heat transfer coefficient of the nanofluid is expressed as follows:

$$Nu_{aveg} = \frac{h_{nf}D}{K_{nf}} \quad (19)$$

Where D and K_{nf} represent the tube diameter as well as the effective thermal conductivity nanofluid. h_{nf} is the convective heat transfer coefficient given by the following expression:

$$h_{nf} = \int_0^l h(x)dx \quad (20)$$

h(x) is the local heat transfer coefficient calculated using following expression:

$$h(x) = \frac{-K_{nf}\frac{\partial T}{\partial x}\Big|_{wall}}{T_w - T_b} \tag{21}$$

T_w et T_b are respectively the wall temperature and the average temperature of nanofluid.

The friction factor is expressed as follows:

$$f_{nf} = \frac{0.316}{Re^{(0.25)}} \tag{22}$$

$$Re = \frac{\rho_{nf} U D}{\mu_{nf}} \tag{23}$$

The pressure drop is expressed as follows:

$$\Delta P = \frac{f_{nf} l \rho_{nf} U^2}{2D} \tag{24}$$

6. Numerical Method and Validation

As it has been mentioned previously, a monophasic approach is adopted in this study to simulate numerically the convective heat transfer of nanofluid flowing through a tube using a COMSOL software. In this simulation, the temperature of nanofluid at the inlet T_∞ is constant and its axial velocity U_∞ is uniform. A 2D axisymmetric option is chosen and the constant temperature T_w as a boundary condition is applied to the wall. The set of coupled nonlinear differential equations is solved with (SST) k-ω turbulence model using the finite element method. The second-order upwind scheme is used for the discretization of convective and diffusive terms. The SIMPLE algorithm is used for the coupling of velocity and pressure fields together. The convergence criterion is based on the residual value of the calculated variables such as mass, velocity components, turbulent kinetic energy (*k*), and dissipation energy rate (ω). Furthermore, a non-uniform structured mesh is used to solve the computational domain, and it is refined near the wall where the temperature and velocity gradients are significant.

To ensure that the results are independent from the number of mesh elements, grid independent test was carried out. Several numbers of elements were used to compute the average Nusselt number for pure water as shown in Figure 2. The mesh employed in this simulation consists of 367624 elements which is the best in terms of saving time and accuracy.

The results obtained from the simulation seem to be almost consistent (more than 98.5 %) with both the correlation of Nusselt number proposed by Dittus and Boelter [23] and the data of the pressure drop measured experimentally by Osman *et al.,* [24] for Al_2O_3-water nanofluid under similar conditions, as shown in Figure 3 and Figure 4 respectively. This comparison validates our numerical model.

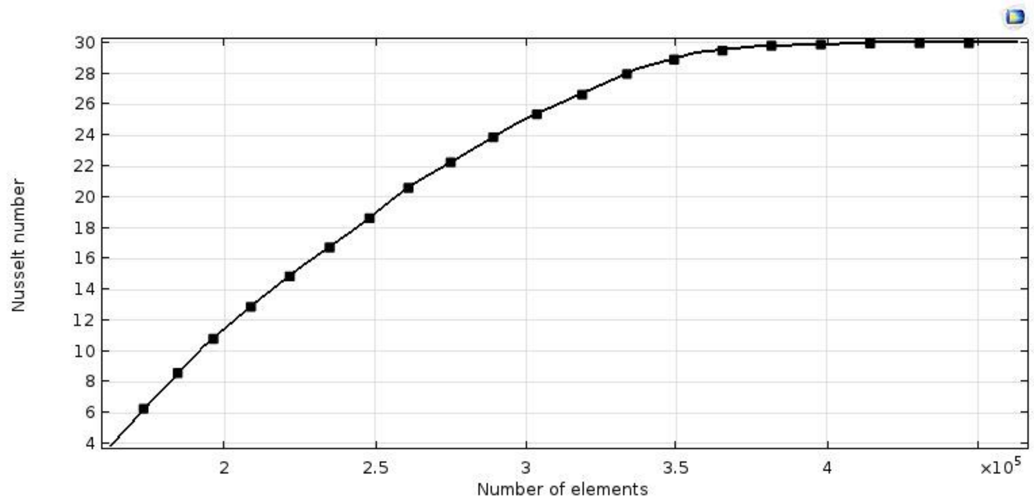


Fig. 2. Gird independence test based on the average Nusselt number

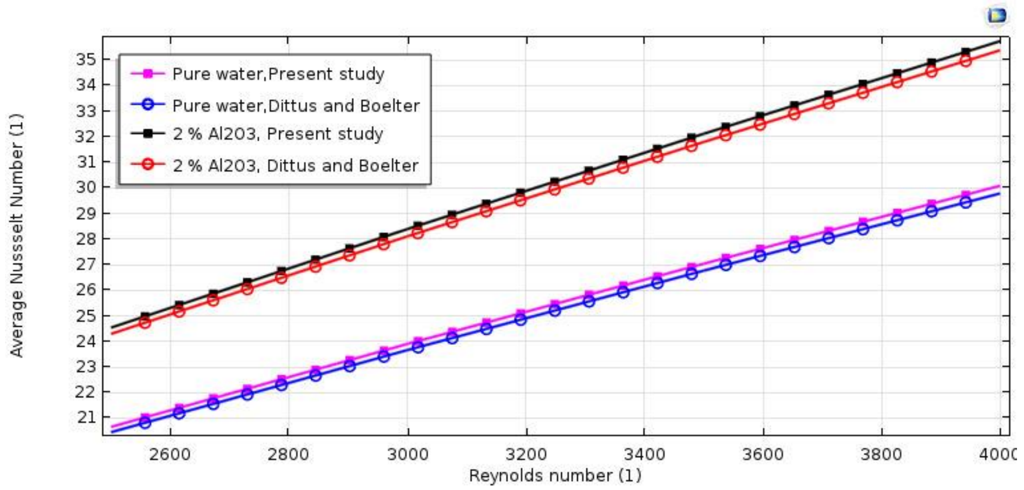


Fig. 3. Average Nusselt number compared to Dittus and Boelter correlation for pure water and Al_2O_3-water nanofluid [23]

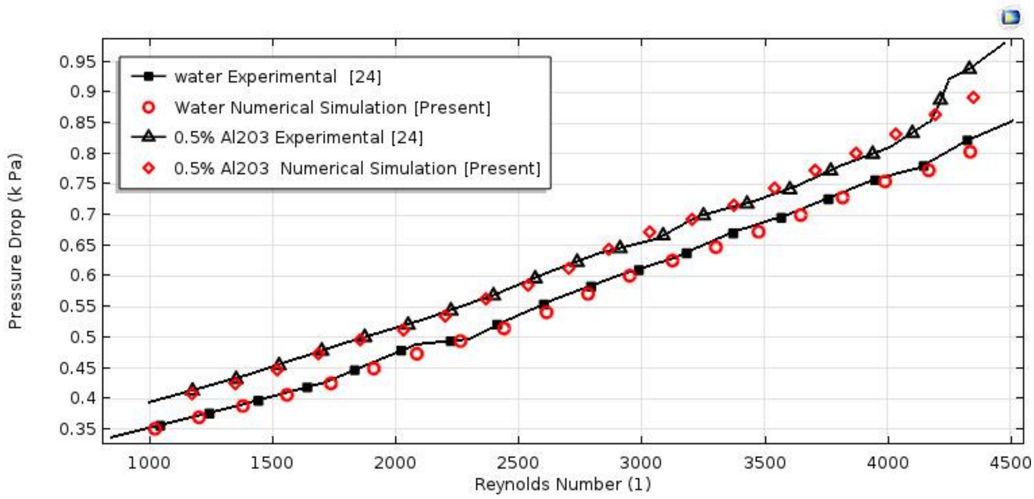


Fig. 4. Pressure drop compared to experimental study of Osman *et al.,* [24] for pure water and Al_2O_3-water nanofluid

Figure 5 illustrates the nanofluid velocity field (dispersed with 2% Al_2O_3 nanoparticles) flowing through the pipe. This figure delineates the velocity field of nanofluid inside the tube. It can be noticed the appearance of the boundary layer that manifests itself along the pipe's wall.

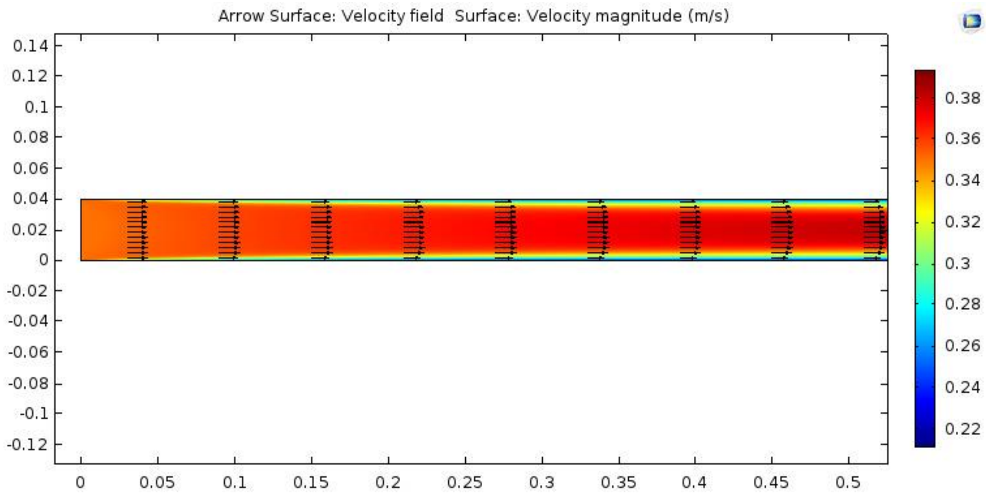


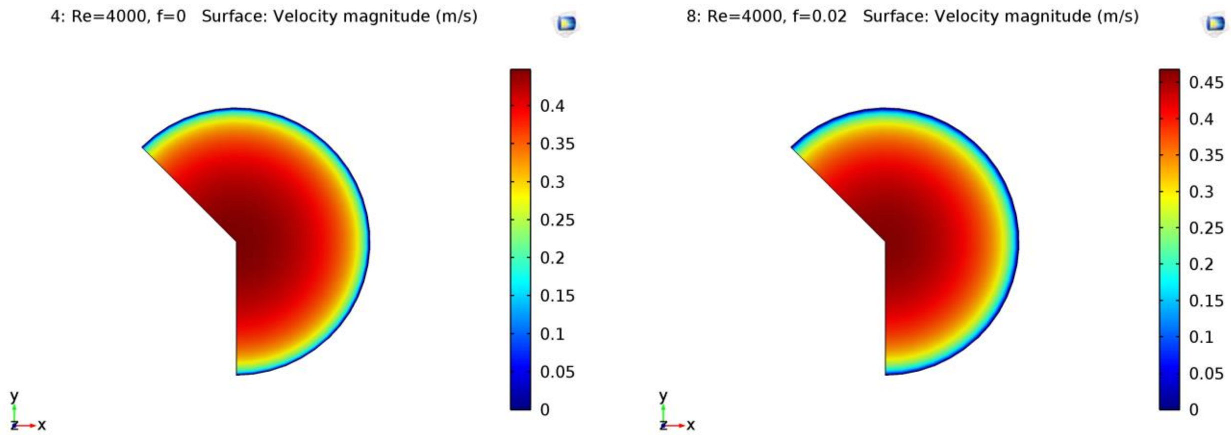
Fig. 5. Velocity field of nanofluid within the pipe

7. Results and Interpretations

The effect of Reynolds number (2500-4000) and volume fraction (0-6 %) of the nanoparticles on the thermal and hydrodynamic parameters are both examined in this study.

7.1 Velocity Field

Figure 6 shows the velocity contours at the outlet when Re = 4000 in different volume fractions. It is worth noting that in the center, the velocity contours decrease when the volume fractions increase. Furthermore, there is an increase in the velocity gradient near the wall and consequently an improvement in the hydrodynamic boundary layer thickness is obtained. The presence of nanoparticles results in a certain homogeneity due to the molecular diffusion which serves to enhance heat transfer throughout the radial direction.



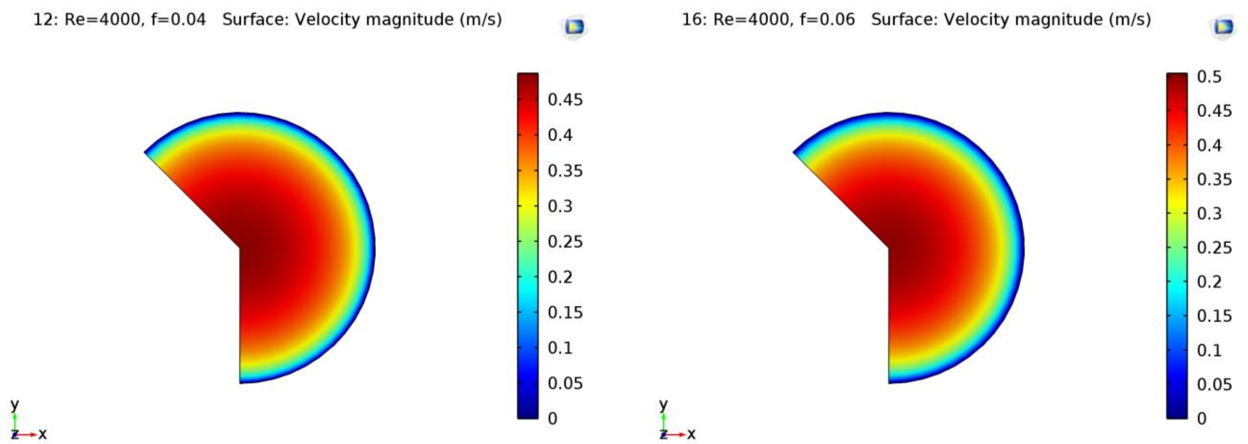
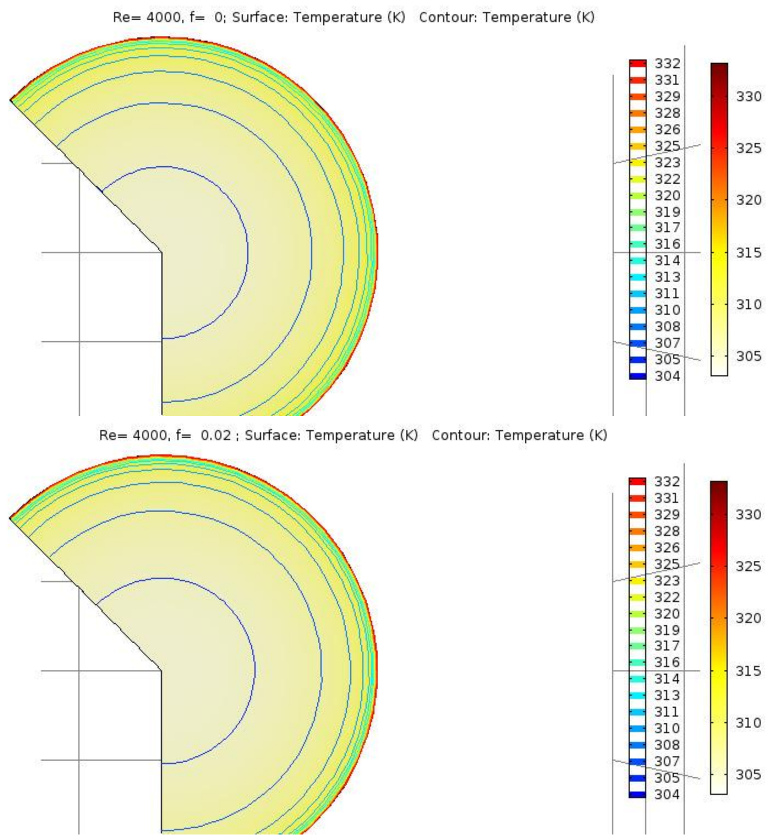


Fig. 6. Radial velocity distribution of nanofluid for different values of (ϕ), Re = 4000

7.2 Temperature Field

With regard to the temperature field, the effect of nanoparticles volume fraction modifies significantly the thermal behavior of nanofluid as shown in Figure 7. Indeed, the thermal conductivity of particles contributes to a quicker absorption of thermal energy which enhance the wall-fluid heat exchange resulting in the increase of the nanofluid temperature in the central regions of the tube leading to the uniformity of temperature in the radial direction. Furthermore, the Brownian motion ameliorates the heat transfer through the heat diffusion that is associated with nanoparticles.



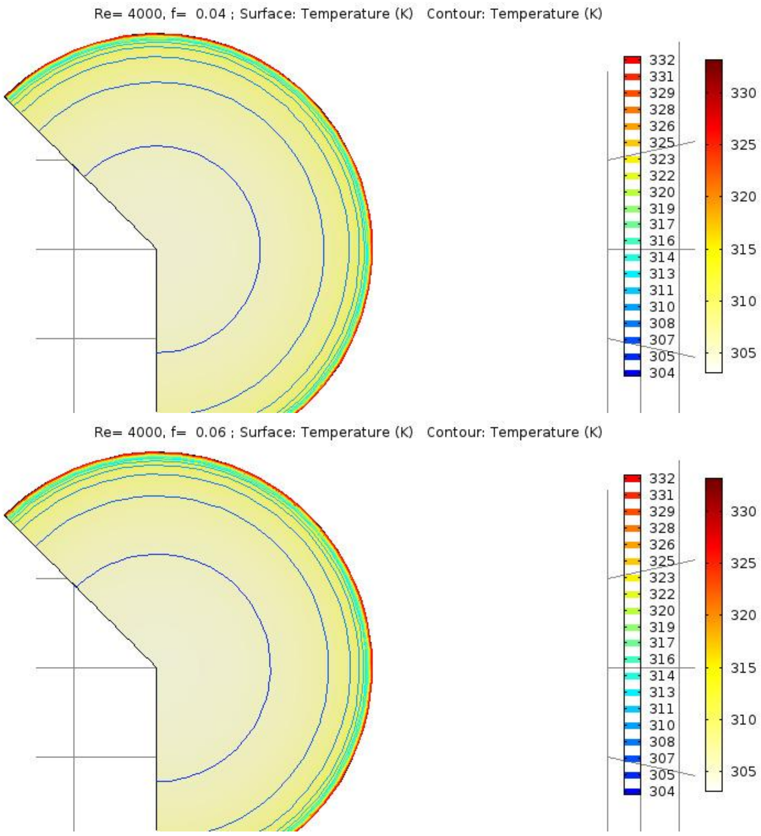


Fig. 7. Temperature contours for different values of φ, Re = 4000

7.3 Thermal Behavior of Nanofluid

The obtained results from the simulation show a remarkable increase in the thermal conductivity of nanofluid K_{nf} as a result of adding nanoparticles (Figure 8). Several mechanisms bring about this augmentation, such as the intermolecular and intramolecular (fluid-wall) interactions and the Brownian motion of nanoparticles, which give rise to an increase in the heat transfer through convection and conduction. The obtained results are in good agreement with literatures [25-28].

Figures 9 (a) and 9 (b) illustrate how an increase in the volume fraction of nanoparticles and Reynolds number can lead to an augmentation in the average Nusselt number. Indeed, the random motion of the nanoparticles (Brownian motion) enhances the convective heat exchange. In addition, the turbulent flow provides the nanoparticles with a good molecular diffusion which improves the thermal exchange nanoparticles-fluid and nanoparticles-walls which both contribute to the enhancement of the overall heat transfer rate. For instance: at Re = 4000, a 48.68 % increase in the number of Nusselt is reached when the volume fraction is 6 %.

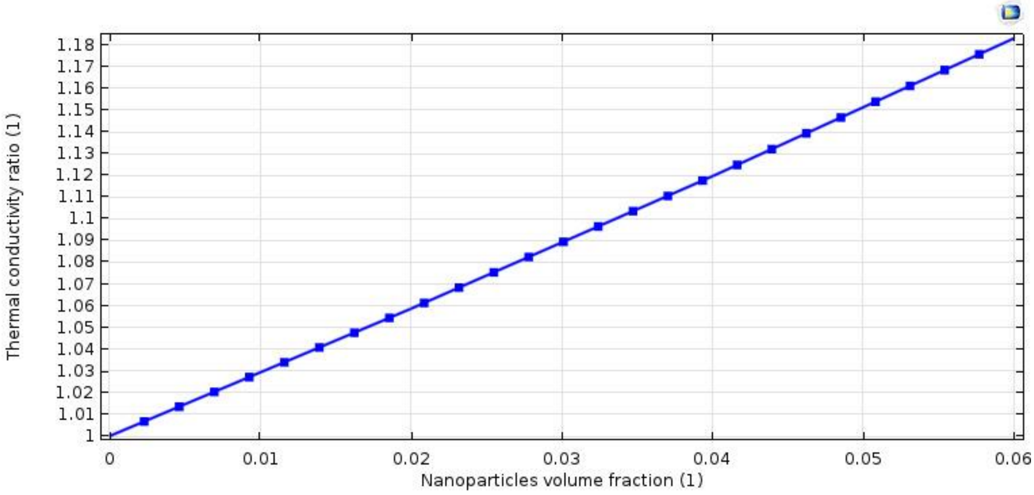
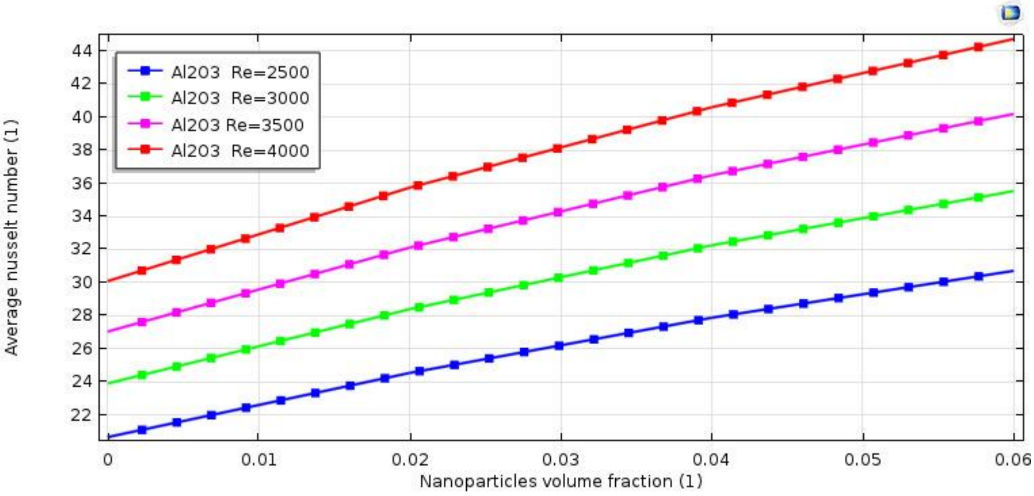
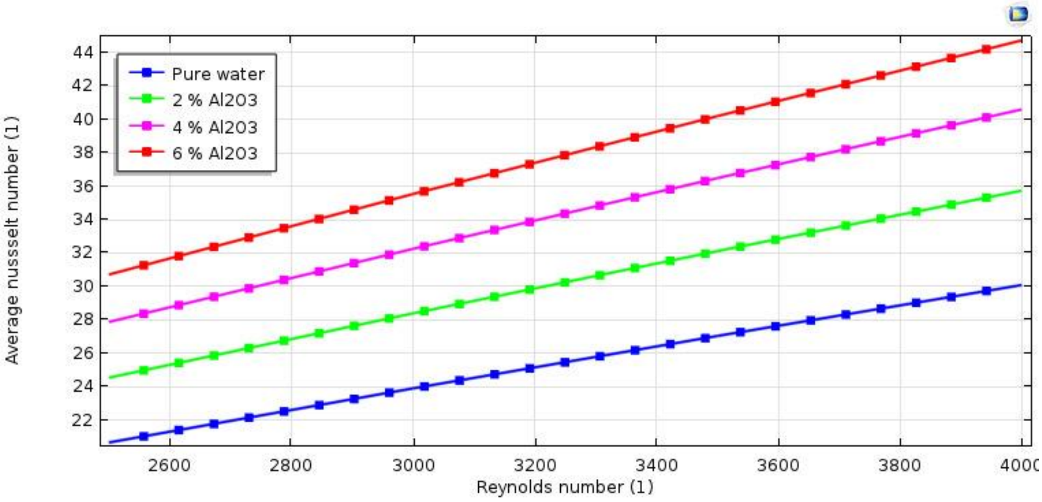


Fig. 8. Thermal conductivity ratio versus (φ)



(a)



(b)

Fig. 9. Variation of the average Nusselt number with: (a) (φ) for different values of Re, (b) Re for different values of (φ)

7.4 Hydrodynamic Behavior of the Nanofluid

The dynamic viscosity of nanofluid shows a significant increase in comparison with the base fluid as shown in Figure 10, because the interactions between the nanoparticles result in augmenting the viscous friction forces. For example, a 1% of nanoparticles leads to a 50% augmentation in the dynamic viscosity.

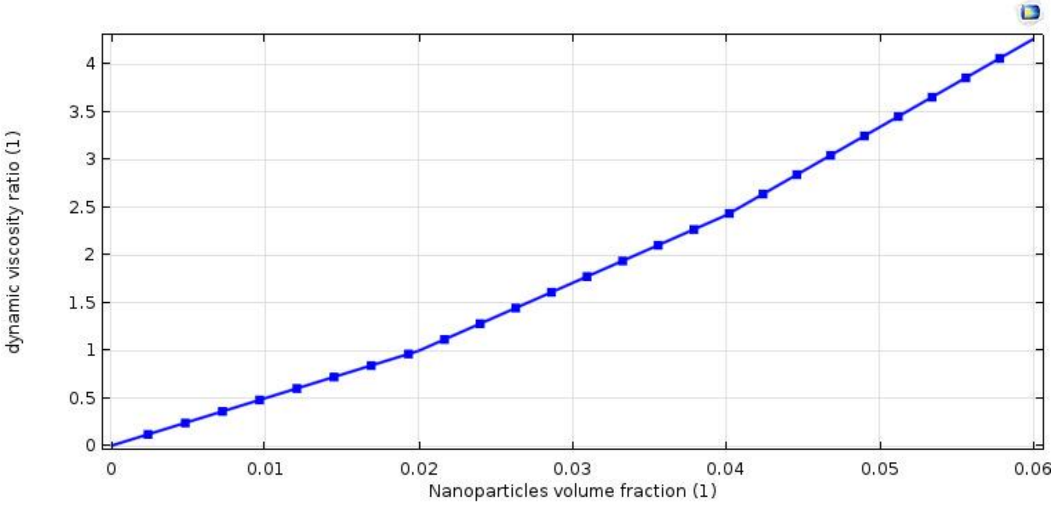
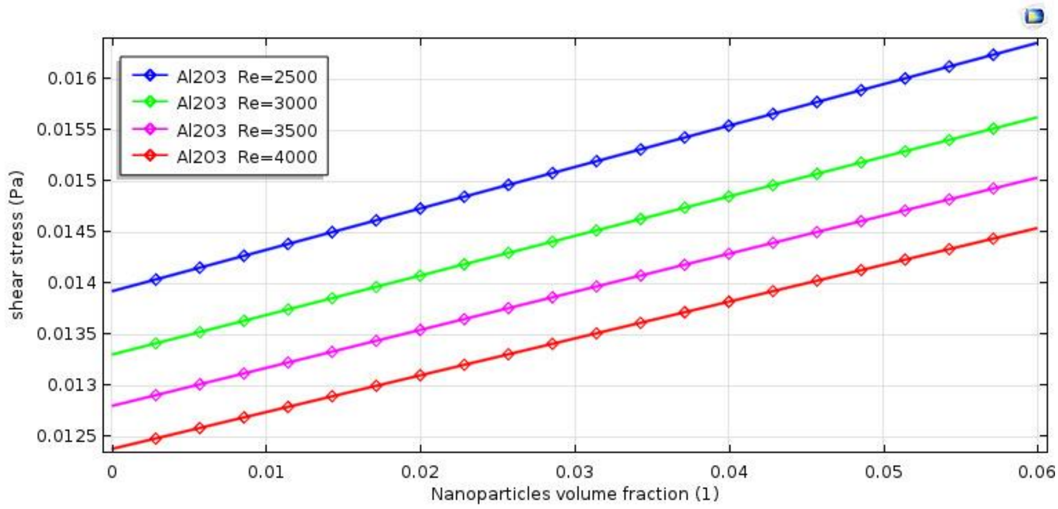
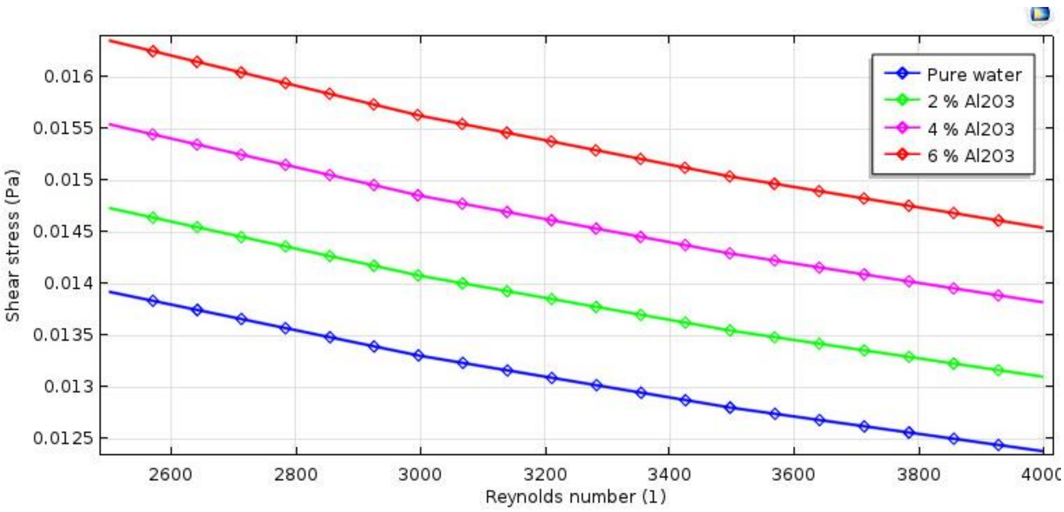


Fig. 10. Dynamic viscosity ratio versus (φ)

The rheological behavior of nanofluid is totally modified by adding nanoparticles. The shear stress depends largely on the volume fraction of the nanoparticles and Reynolds number. The shear stress level goes up when there is an increase in the volume fraction (Figure 11 (a)). Whereas, it goes down when there is an increase in the Reynolds number (Figure 11 (b)). Indeed, the addition of nanoparticles contributes to an increase in the viscosity of nanofluid which has an effect on the shear stress. However, the increase in the Reynolds number could result in making the particles move more freely leading to a reduction in any friction between them.



(a)



(b)

Fig. 11. Shear stress versus (a) φ for different values of Re (b) Re for different values of φ

To study the influence of geometry on the dispersion and molecular diffusion of nanoparticles during the flow, Figure 12 represents the friction velocity based on the pipe geometry (length/diameter ratio, z/D) for different volume fractions of nanoparticles. The results show that when the ratio z/D is over 20, the friction velocity becomes constant reaching a low-value regardless of the volume fractions value. For this geometrical condition the hydrodynamic effect of adding nanoparticles may not represent a great impact while the thermal behavior of nanofluid is dominantly significant.

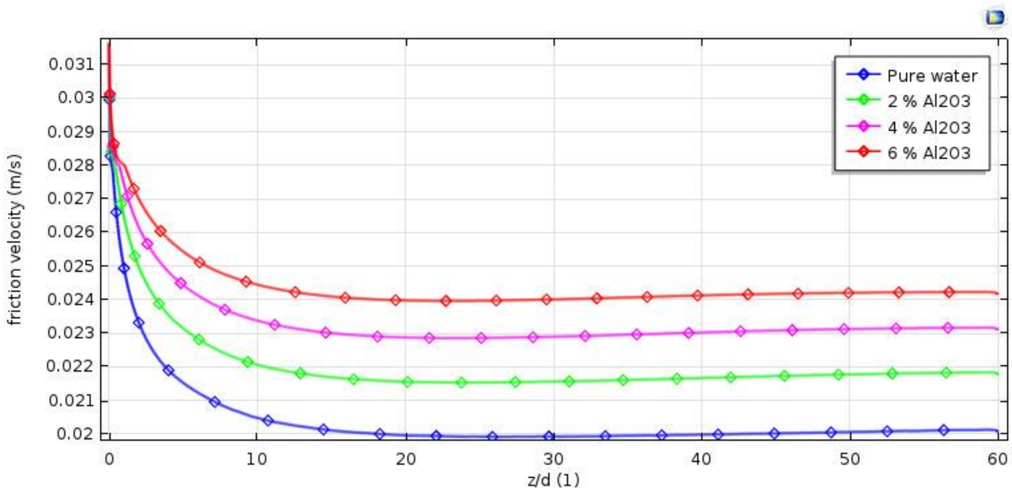


Fig. 12. Friction velocity versus z/D for different values of φ

In order to understand better the impact of the type of nanoparticles on the thermal efficiency and the hydrodynamic behaviour of nanofluids a comparative study is conducted when using another nanoparticle known for its high thermal conductivity, which is CuO, instead of using Al_2O_3 particles under similar conditions. From thermal perspective there is a slight improvement of heat transfer when CuO particles is dispersed in the base fluid, as shown in Figures 13 (a) and (b), despite that the thermal conductivity of CuO is higher than the Al_2O_3. For instance, when the volume fraction is 6 % and Re = 4000 the Nusselt number is increased by 2.12 % with CuO instead of using Al_2O_3 (Figure 13 (b). It is worth noting that at low volume fraction the effect of the type of nanoparticles on the heat transfer is negligible.

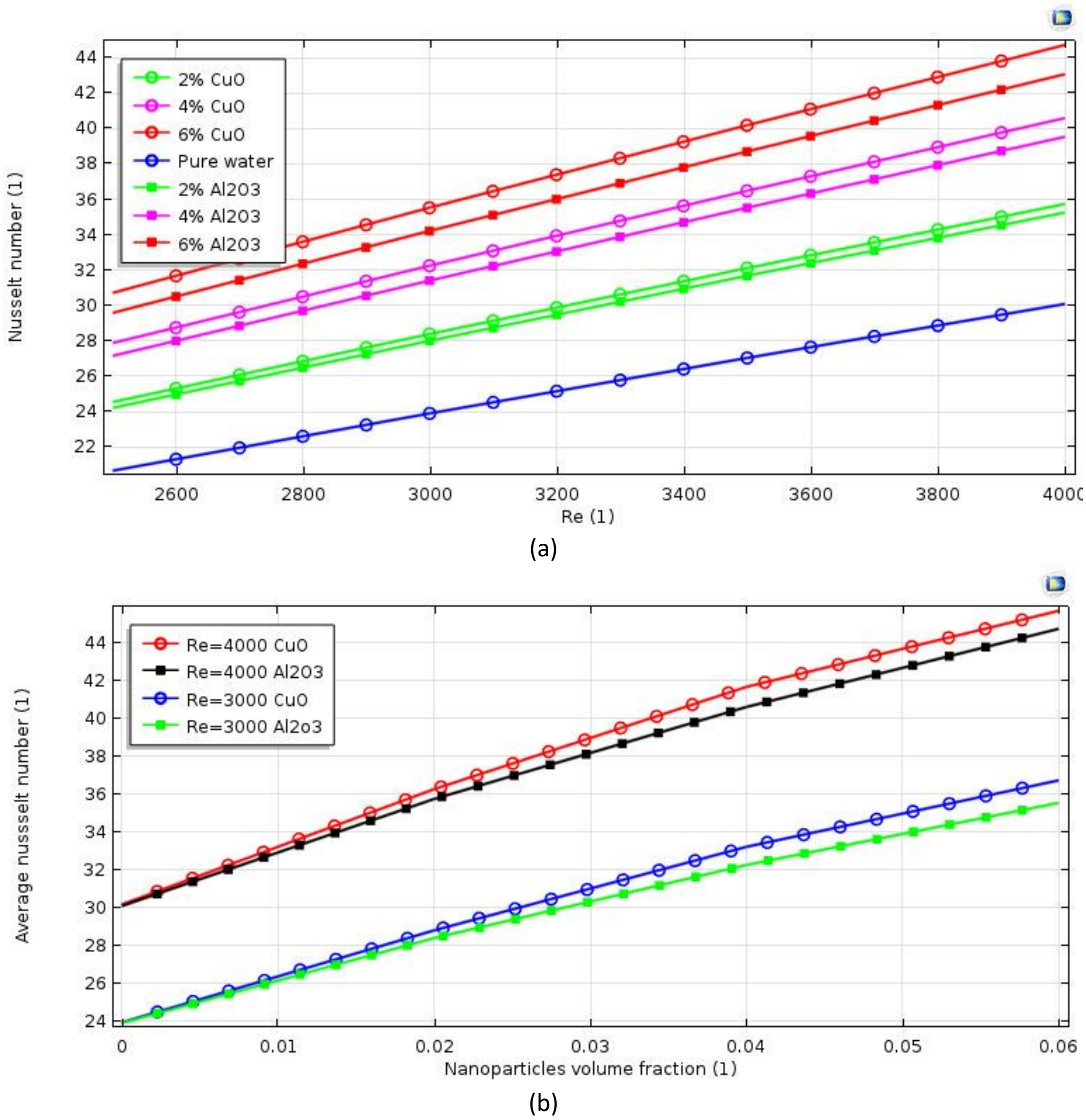
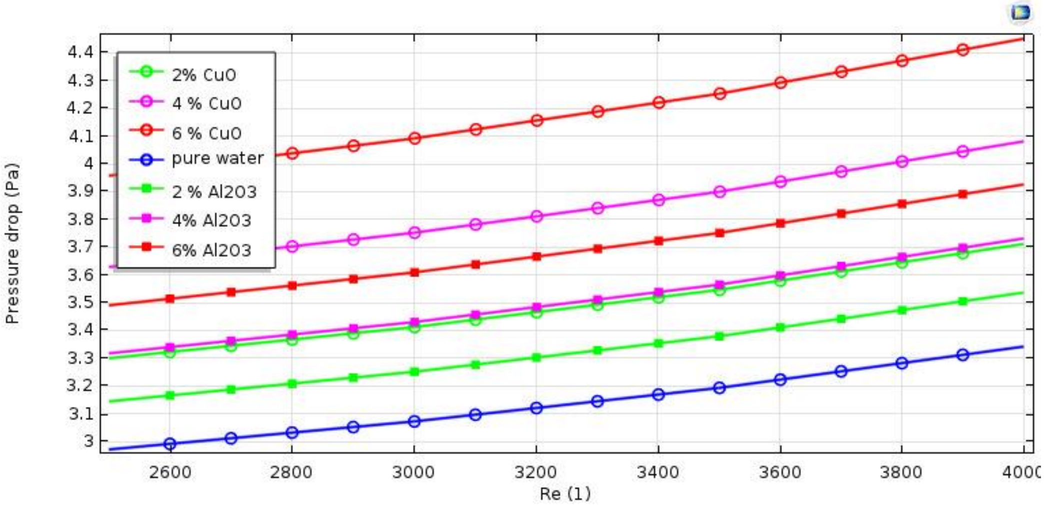


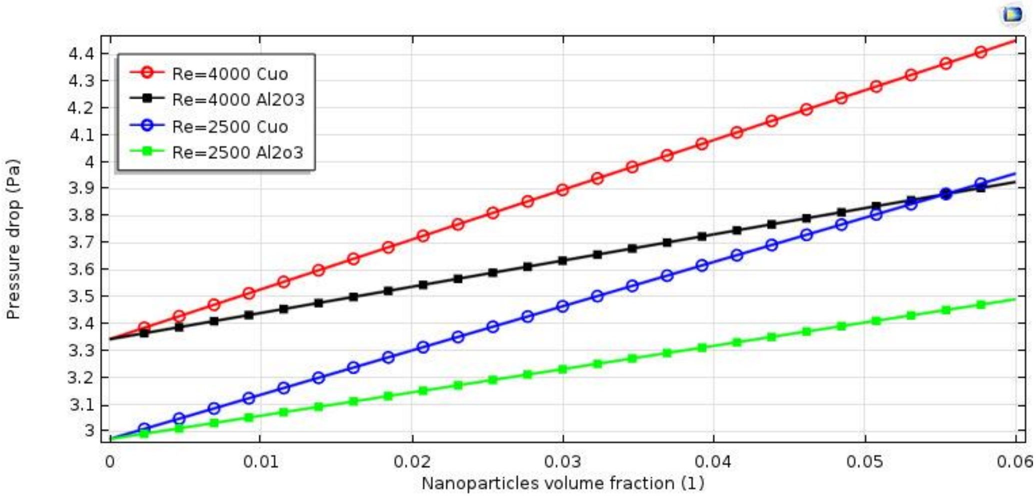
Fig. 13. Variation of the average Nusselt number of Al_2O_3/water and CuO/water nanofluids versus: (a) Re, (b) φ

However, the impact of the type of nanoparticles on the pressure drop is significant as illustrated in Figures 14 (a) and (b). The difference between CuO and Al_2O_3 on the pressure drop is noticeable even at low volume fraction and became important as the volume fraction increases.

For example, when CuO particles is dispersed in water under Re = 4000 the pressure drops increase by 2.94 % with volume fraction of 1% whereas it is about 15.39 % with volume fraction of 6% compared when using Al_2O_3 dispersed in water under similar conditions. The obtained results are in good agreement with [29-30].



(a)



(b)

Fig. 14. Pressure drop of Al_2O_3/water and CuO/water nanofluids versus: (a) Re, (b) (φ)

8. Conclusions

In this work, a complete study of thermal and hydrodynamic behavior of nanofluid consisting of Al_2O_3 and water flowing through a circular pipe while maintaining constant temperature in turbulent flow regime is investigated numerically with a CFD program by adopting the (SST) k-ω model. The results show how the temperature and velocity distribution of nanofluid are affected by adding nanoparticles resulting in an increase in the heat transfer due to the intermolecular and intramolecular interactions. The obtained results show that the heat transfer coefficient rate represented by the Nusselt number increases when both the volume fraction of nanoparticles and Reynolds number go up. However, the nanoparticle could trigger a substantial friction due to an increase in viscosity leading to increases the pressure drop. The outcome of this investigation shows clearly that the impact of the type of nanoparticles on the thermal side is not important when using CuO or Al_2O_3 dispersed in water but the pressure drop is more effected when using CuO compared to Al_2O_3 under similar conditions. Thus, after a careful investigation it is preferable to use Al_2O_3-water nanofluid instead of CuO-water nanofluid for the purpose of enhancing the rate of heat transfer and the drop of pressure when using Al_2O_3-water nanofluid can easily be solved in a technical way by installing a suitable pump system.

References

[1] Choi, Stephen US, and Jeffrey A. Eastman. *Enhancing thermal conductivity of fluids with nanoparticles*. No. ANL/MSD/CP-84938; CONF-951135-29. Argonne National Lab., IL (United States), 1995.

[2] Garg, J., Bed Poudel, M. Chiesa, J. B. Gordon, J. J. Ma, J. B. Wang, Z. F. Ren, Y. T. Kang, H. Ohtani, J. Nanda, and G. H. McKinley. "Enhanced thermal conductivity and viscosity of copper nanoparticles in ethylene glycol nanofluid." *Journal of Applied Physics* 103, no. 7 (2008): 074301.

[3] Sekhar, Y. Raja, and K. V. Sharma. "Study of viscosity and specific heat capacity characteristics of water-based Al2O3 nanofluids at low particle concentrations." *Journal of experimental Nanoscience* 10, no. 2 (2015): 86-102.

[4] Kulkarni, Devdatta P., Ravikanth S. Vajjha, Debendra K. Das, and Daniel Oliva. "Application of aluminum oxide nanofluids in diesel electric generator as jacket water coolant." *Applied Thermal Engineering* 28, no. 14-15 (2008): 1774-1781.

[5] Nnanna, AG Agwu, William Rutherford, Wessam Elomar, and Brian Sankowski. "Assessment of thermoelectric module with nanofluid heat exchanger." *Applied Thermal Engineering* 29, no. 2-3 (2009): 491-500.

[6] Japar, Wan Mohd Arif Aziz, Nor Azwadi Che Sidik, Siti Rahmah Aid, Yutaka Asako, and Tan Lit Ken. "A Comprehensive Review on Numerical and Experimental Study of Nanofluid Performance in Microchannel Heatsink (MCHS)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 45, no. 1 (2018): 165-176.

[7] Moraveji, Mostafa Keshavarz, Mehdi Darabi, Seyyed Mohammad Hossein Haddad, and Reza Davarnejad. "Modeling of convective heat transfer of a nanofluid in the developing region of tube flow with computational fluid dynamics." *International communications in heat and mass transfer* 38, no. 9 (2011): 1291-1295.

[8] Demir, H., A. S. Dalkilic, N. A. Kürekci, W. Duangthongsuk, and S. Wongwises. "Numerical investigation on the single phase forced convection heat transfer characteristics of TiO2 nanofluids in a double-tube counter flow heat exchanger." *International Communications in Heat and Mass Transfer* 38, no. 2 (2011): 218-228.

[9] Jehad, D. G., and G. A. Hashim. "Numerical prediction of forced convective heat transfer and friction factor of turbulent nanofluid flow through straight channels." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 8, no. 1 (2015): 1-10.

[10] Azwadi, CS Nor, and I. M. Adamu. "Turbulent force convective heat transfer of hybrid nano fluid in a circular channel with constant heat flux." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 19, no. 1 (2016): 1-9.

[11] Velagapudi, Vasu, Rama Krishna Konijeti, and Chandra Sekhara Kumar Aduru. "Empirical correlations to predict thermophysical and heat transfer characteristics of nanofluids." *Thermal Scirnce* 12, no. 2 (2008): 27-37.

[12] Shedid, Mohamed H. "Computational heat transfer for nanofluids through an annular tube." In *Proceedings of the International Conference on Heat Transfer and Fluid Flow. Prague, Czech Republic, Paper*, no. 206. 2014.

[13] Abu-Nada, Eiyad. "Application of nanofluids for heat transfer enhancement of separated flows encountered in a backward facing step." *International Journal of Heat and Fluid Flow* 29, no. 1 (2008): 242-249.

[14] Khanafer, Khalil, Kambiz Vafai, and Marilyn Lightstone. "Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids." *International journal of heat and mass transfer* 46, no. 19 (2003): 3639-3653.

[15] Pak, Bock Choon, and Young I. Cho. "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles." *Experimental Heat Transfer an International Journal* 11, no. 2 (1998): 151-170.

[16] Wang, Xiang-Qi, and Arun S. Mujumdar. "A review on nanofluids-part I: theoretical and numerical investigations." *Brazilian Journal of Chemical Engineering* 25, no. 4 (2008): 613-630.

[17] Hamilton, R. L[illegible], and O. K. Crosser. "Thermal conductivity of heterogeneous two-component systems." *Industrial & Engineering chemistry fundamentals* 1, no. 3 (1962): 187-191.

[18] Sekrani, Ghofrane, and Sébastien Poncet. "Further investigation on laminar forced convection of nanofluid flows in a uniformly heated pipe using direct numerical simulations." *Applied Sciences* 6, no. 11 (2016): 332.

[19] Kashani, S., A. A. Ranjbar, M. Mastiani, and H. Mirzaei. "Entropy generation and natural convection of nanoparticle-water mixture (nanofluid) near water density inversion in an enclosure with various patterns of vertical wavy walls." *Applied Mathematics and Computation* 226 (2014): 180-193.

[20] Malik, Sumit, and A. K. Nayak. "Buoyancy driven heat transfer in nanofluids due to wall mounted heat source." *Alexandria Engineering Journal* 55, no. 2 (2016): 797-810.

[21] Yarmand, Hooman, Samira Gharehkhani, Salim Newaz Kazi, Emad Sadeghinezhad, and Mohammad Reza Safaei. "Numerical investigation of heat transfer enhancement in a rectangular heated pipe for turbulent nanofluid." *The Scientific World Journal* 2014 (2014): 1-9.

[22] Yuan, G.Fang, X.Zhang, Y.Tang, Z. Wan, and S. Zhang."Heat Transfer and Friction Characteristics of Turbulent Flow through a Circular Tube with Ball Turbulators". *Applied sciences* 8, no. 5 (2018):776 (1-13).

[23] Dittus, F. W., and L. M. K. Boelter. "Heat transfer in automobile radiators of the tubular type." *International Communications in Heat and Mass Transfer* 12, no. 1 (1985): 3-22.
[24] Osman, Sohaib, Mohsen Sharifpur, and Josua P. Meyer. "Experimental investigation of convection heat transfer in the transition flow regime of aluminium oxide-water nanofluids in a rectangular channel." *International Journal of Heat and Mass Transfer* 133 (2019): 895-902.
[25] Yu, Wenhua, David M. France, Jules L. Routbort, and Stephen US Choi. "Review and comparison of nanofluid thermal conductivity and heat transfer enhancements." *Heat transfer engineering* 29, no. 5 (2008): 432-460.
[26] Krishna, V. Murali. "Experimental investigation of heat transfer enhancement by using al2o3water nanofluid in a concentric tube heat exchanger." *International Journal of Mechanical Engineering and Technology (IJMET) Volume* 7 (2016): 449-458.
[27] Demir, H., A. S. Dalkilic, N. A. Kürekci, W. Duangthongsuk, and S. Wongwises. "Numerical investigation on the single phase forced convection heat transfer characteristics of TiO2 nanofluids in a double-tube counter flow heat exchanger." *International Communications in Heat and Mass Transfer* 38, no. 2 (2011): 218-228.
[28] Sridhara, Veeranna, and Lakshmi Narayan Satapathy. "Al2 O3-based nanofluids: a review." *Nanoscale research letters* 6, no. 1 (2011): 456.
[29] Khairul, Mohammad A., Mohammad A. Alim, Islam M. Mahbubul, Rahman Saidur, Arif Hepbasli, and Altab Hossain. "Heat transfer performance and exergy analyses of a corrugated plate heat exchanger using metal oxide nanofluids." *International Communications in Heat and Mass Transfer* 50 (2014): 8-14.
[30] Aghaei, Alireza, Ganbar Ali Sheikhzadeh, Majid Dastmalchi, and Hamed Forozande. "Numerical investigation of turbulent forced-convective heat transfer of Al2O3–water nanofluid with variable properties in tube." *Ain Shams Engineering Journal* 6, no. 2 (2015): 577-585.