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Simulation of Turbulent Heat Transfer Augmentation with Hybrid Nanofluid

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Abstract

Study of heat transfer augmentation with hybrid nanofluid represents a new class of heat transfer augmentation. The CFD model by using commercial software depending on finite volume technique and adopting SIMPLE algorithm is performed. Mixture of Aluminum Nitride (AlN) and alumina (Al_2O_3) nanoparticles into water as a basefluid is classified as a new class of hybrid nanofluids that can augment heat transfer. The nanofluid volume fraction and Reynolds number are in the range of (1% to 4%) and (5000 to 17000) respectively. The size diameter of nanoparticles and heat flux around a horizontal straight tube are fixed at 30 nm and 5000 w/m^2 respectively. The numerical solution has been successfully validated by using an experimental data available in the literature. Results show that combination of AlN - Al_2O_3 nanoparticles into water basefluid tends to augment significant heat transfer performance.

Keywords: Nanofluid; Hybrid; Turbulent; CFD; ANSYS, Heat transfer.
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Nomenclature

C specific heat capacity
D diameter
E enhancement
f friction factor
h convection heat transfer coefficient
k thermal conductivity
Nu Nusselt Number
P Pressure
Pr Prandtle Number
Re Renolds Number
u Velocity
μ Viscosity
ρ Density
φ Volume concentration
η efficiency

Subscripts

f liquid phases
p solid particle
eff effective nanofluid

1.Introduction

The fluids heat transfer using conventional fluids (water, oil and ethylene glycol) were mainly applied in mechanical equipment with a large variety of devices. By growing the industrial processes, electronic and transportation needed to remove the heat generation rate, many investigators and designers have focused to the heat transfer augmentation last decades. The benefit of thermal fluid properties plays an important role to improve the equipment heat transfer performance [1].

Nanofluids are a new class of working fluids with the capability of enhancing conductivity of liquids for various industrial applications. Experimental studies of heat transfer enhancement using different types of nanofluids such as Cu, CuO, Fe_2O_3, Al_2O_3, CNT, SiO_2, TiO_2, SiC, Ag, and zirconia through a tube have been conducted by many researchers [1, 2, 3, 4, 5 & 6]. Recent interesting topics were focused to nanocomposite materials to find a new hybrid nanofluids giving the highest heat transfer rates. Cu-Al_2O_3/water hybrid nanofluids have been synthesized using two-step method adopting the hydrogen reduction technique by [7]. The hybrid nanofluids volume fraction from (0.1 – 2%) were prepared by dispersing the synthesized nanocomposites powder in deionized water. It was showed that both viscosity and thermal conductivity of new nanofluids increase with the volume fraction increases. It was found that the increasing of viscosity is higher than the increasing of thermal conductivity of hybrid nanofluids. A fully developed laminar convective heat transfer and the pressure drop characteristics through a uniformly heated circular tube using Cu-Al_2O_3/water hybrid nanofluid has been carried out by [8]. Results showed Nusselt number enhances by 13.56% at a Reynolds number of 1730 as compared with Nusselt number of water. The regression equations between the input and output parameters were in good agreement with the experimental data. The hybrid nanofluid heat transfer enhancement flow in the double pipe heat exchanger was experimentally performed by [9]. The nanofluid was synthesis by suspending the titanium/copper nanoparticles in water with 0.1% to 1.0% volume fraction. Results illustrated that the Nusselt number

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values were increasing by 48.4% up to 0.7% volume fraction of hybrid nanofluid. The effect of functionalization method on the stability and the thermal conductivity of CNT- Alumina hybrids nanofluid have been investigated by [10].

The hybrid nanofluids thermal conductivities were measured by using a modified transient hot wire method. Results indicated that the correlation equations had a significant effect on the hybrid nanofluid thermal conductivity. The thermal conductivity improved up to 20.68% at a 0.1% volume concentration of hybrid nanofluid. Mosayebidorcheh *et al.*, [11] was studied the turbulent nanofluid heat transfer in the presence of a magnetic field. Results illustrated that Nusselt number increases linearly with Reynolds number, nanoparticle volume fraction and turbulent Eckert number while it was inversely proportional on the Hartmann number and the turbulent parameter. Labib et al. [12] was selected two-phase mixture model of hybrid nanofluid convective heat transfer. They were employed two different basefluids individually for studying the influence of liquids on heat transfer mixing Alumina nanoparticles. Results indicated that the using of ethylene glycol as basefluid has given better heat transfer augmentation than that of water. The comparison of the computational model for CNTs/water nanofluid was conducted to be validated with the available data in the literature. Sundar *et al.* [13] was studied the turbulent heat transfer of hybrid nanofluids flowing through a circular tube. The Fe_3O_4/MWCNT nanocomposites were prepared by in-situ method that included the dispersion of carboxylated carbon nanotubes in distilled water and mixing of ferrous chloride and ferric chloride. The results showed that the heat transfer enhancement by 31.10% with a penalty of 1.18-times increase of pumping power for the particle loading of 0.3% at a Reynolds number of 22,000 as compared to base fluid data. The correlations equations were proposed for the input and output parameters and there were good agreements with the experimental data. Baby and Ramaprabhu [14] were prepared Fe_3O_4/MWNTs and Fe_3O_4-SiO_2/MWNTs by a simple chemical reduction technique and dispersed ultrasonically in water. It was observed for Fe_3O_4/MWNTs with surfactant and Fe_3O_4-SiO_2/MWNTs without surfactant with 0.03% volume concentrations of a magnetic field give an improving of thermal conductivity by 20% and 24.5% respectively.

The present article studies the heat transfer and pressure drop characteristics of hybrid nanofluids under the turbulent flow condition in the circular tube. This article proves the heat transfer enhancement and pressure drop with hybrid nanofluid using the CFD analysis by commercial software. The two nanocomposite used in this work are AlN - Al_2O_3 from 1% to 4% volume fractions dispersed in water as a basefluid.

2.Thermal Properties

The hybrid mixture of AlN - Al_2O_3 nanopowders suspended in water nanofluids under taken are considered as a single-phase flow, incompressible, Newtonian fluid and an isotropic. The effective thermal properties Density (ρ_{nf}), Specific heat capacity (C_{nf})thermal conductivity (k_{nf}) and viscosity (μ_{nf}) of hybrid nanofluids have been evaluating by using classical formulas developed [15].

$$\rho_{nf} = \left(\frac{\phi}{100}\right)\rho_p + \left(1 - \frac{\phi}{100}\right)\rho_f$$

$$C_{nf} = \frac{\frac{\phi}{100}(\rho C)_p + \left(1 - \frac{\phi}{100}\right)(\rho C)_f}{\rho_{nf}}$$

$$\frac{k_{nf}}{k_w} = 1.2035\left[\left(0.001 + \frac{\varphi}{100}\right)^{0.0098}\left(0.01 + \frac{T_{nf}}{90}\right)^{0.1331}\left(0.001 + \frac{d_p}{170}\right)^{-0.0001}\left(0.01 + \frac{\alpha_p}{\alpha_w}\right)^{0.0153}\right]$$

$$\frac{\mu_{nf}}{\mu_w} = 0.3659 \times C_1 \times \exp\left[\left(\frac{T_{nf}}{90}\right)^{-0.0239}\left(1 + \frac{\varphi}{100}\right)^{10.83}\left(1 + \frac{d_p}{170}\right)^{-0.1609}\right]$$

Where φ is the volume fraction of hybrid nanofluid and subscript *p*, *f* and *nf* are referred to solid nanocomposite particles, fluid and hybrid nanofluid part, respectively.

All properties of water as a basefluid have taken from ASHRAE (2005) [16]. Thermal properties of AlN and Al_2O_3 nanopowders and hybrid nanofluids have been shown in a Table 1 and Table 2 respectively.

Table 1 Thermal properties of nanoparticles and basefluid.

Properties	Water	Al_2O_3	AlN
ρ (kg/m^3)	998	3880	3260
c_p (J/kg.K)	4180	773	735
k (W/m.K)	0.6067	40	180
μ (kg/m.s)	0.0014	-	-

Table 2 Thermal properties of hybrid nanofluid.

ϕ	ρ kg/m^3	Cp J/kg.K	k W/m.K	μ kg/m.s
0.01	1100	4150	0.652	0.0081
0.02	1125	4115	0.764	0.0085
0.03	1144	4094	0.812	0.0091
0.04	1156	4082	0.893	0.0096

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3. Numerical Analysis

3.1 Mathematical Modeling

The forced convection under turbulent condition of a hybrid nanofluids consisting of water and AlN - Al_2O_3 nanopowders 30 nm size diameter through a straight horizontal tube with 5000 W/m^2 uniform heat flux around tube wall is employed. The schematic of the physical model shown in Figure 1(a) represents a two-dimensional nanofluid flow through a circular horizontal tube with a length of 2000 mm. In this study, rectangular cells were used as the meshing surfaces of the tube wall as shown in Figure 1(b).

The inner tube diameter is 19 mm and the outer diameter of the tube is 21mm. It is similar the geometry of numerical work that used by the authors [2] which investigated numerically the pressure drop and convective heat transfer under turbulent condition of nanofluid inside a circular tube. The model has assumed that the flow is steady, turbulent and symmetrical with respect to the horizontal plane passing through the circular tube. For all these assumptions, the dimensional conservation equations are the continuity, momentum and energy equations [17]:

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \qquad (5a)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\upsilon\frac{\partial^2 u}{\partial x^2} \qquad (5b)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial x^2} \qquad (5c)$$

A high Reynolds number supposed as an input parameter and the pressure treatment adopted using the SIMPLE scheme and a turbulent viscous *k*-ε model used.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+S_k \qquad (6)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(P_k+C_{3\varepsilon})-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \qquad (7)$$

Where the turbulent viscosity model as: $\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}$, $P_k=-\rho u_i u_j\frac{\partial u_j}{\partial x_i}$

The solutions are considered converged at the residuals lower than 10^{-6}. The simulation results are compared to the equations for the friction factor Equatiom 8 and Nusselt number Equation 9 correlated by Blasius and Dittus-Boelter respectively [17]:

$$f=\frac{0.316}{Re^{0.25}} \qquad (8)$$

$$Nu=\frac{h}{k}D_h=0.023\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3} \qquad (9)$$

The percentage of heat transfer enhancement and the efficiency depending on the nanofluid and basefluid used can be evaluated as [17]:

$$Enhancement\%=\frac{Nu_{nf}-Nu_f}{Nu_{nf}}\times 100 \qquad (10)$$

$$\eta=\frac{Nu_{nf}/Nu_f}{(f_{nf}/f_f)^{1/3}} \qquad (11)$$

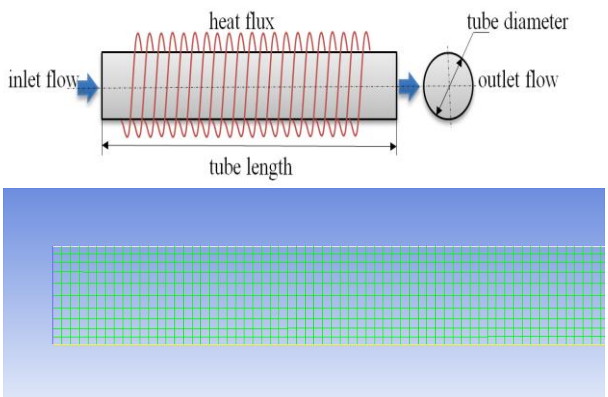

Figure 1: Geometry and grid computational model

3.2 Boundary conditions

The volume fractions of AlN - Al_2O_3 / water hybrid nanofluid used as the input fluids are 1, 2, 3 and 4% with the inlet temperature of 30°C. Water used as the working fluid for comparison purposes and CFD analysis performed with a uniform velocity profile at the inlet and a pressure outlet condition at the outlet regions. The perfectly smooth walls of the tube assumed and Reynolds number was varied from 5000 to 17000 at each iteration step as input data.

3.3 Grid independence test

Grids independence are performed using the ANSYS software and it was found the 20000 cells (2000x10) is the best size of mesh, which adopted as an optimum meshing size. Four different meshing sizes are considered 10000 cells (1000x10), 20000 cells (2000x10), 30000

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cells (1000x30) and 40000 cells (2000x20) for water to check the grid sizing. It can be seen that all of meshing sizes chosen could have used while the meshing size of 20000 cells is considered as an optimum meshing size due to the best accuracy. As shown in Figure 2, the computation of Nusselt number for all four meshing size with Dittus-Boelter Equation 9 was in a good agreement with maximum deviation not more than 5%.

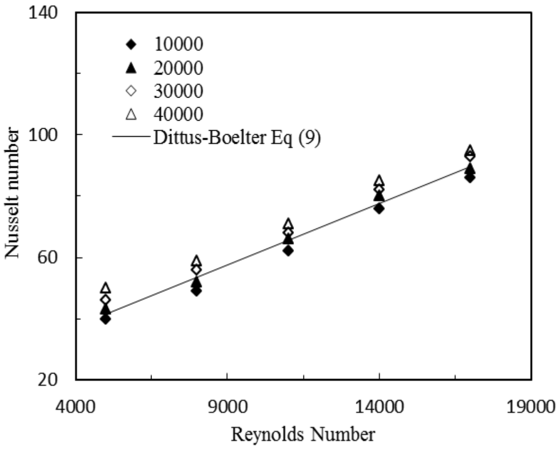


Figure 2: Grid independent test

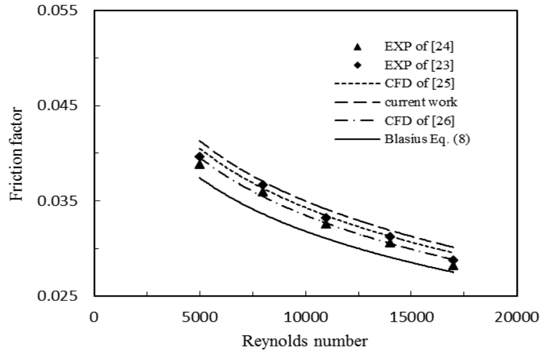
3.4 CFD analysis

CFD simulations are performed using ANSYS software with the solver strategy. The single-phase governing equations were solved by the approach of control volume. The simulation results are compared to the predicted results of [11 & 12]. The simulation study consists of the problem geometry that constructed as a circular tube and the meshing then creating the physical model and choosing the boundary conditions and finally setup and solving step. The velocity components values were evaluated at the control volume center where the schemes of grid are used intensively. The residuals were appeared throughout the iterative process. Finally, the results are obtained when the solution converged which was defined by a set of convergence criteria. The Nusselt number and pressure drop inside the circular tube could then be determined throughout the computational domain in the post-process stage.

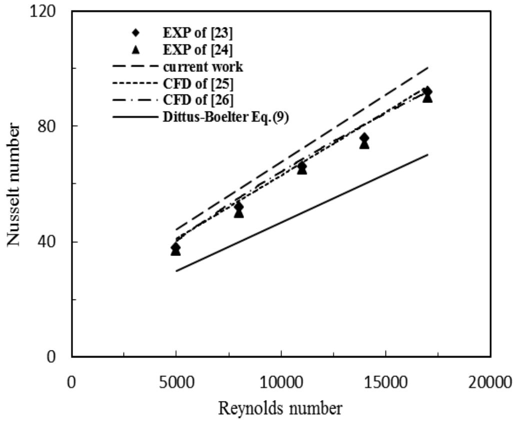
4. Results and Discussion

4.1 Validation

The CFD analysis was compared to experimental data reported by [(17-22)] for Al_2O_3/water under turbulent flow condition to be validated as shown in Figure 3. Likewise, the CFD results were compared to the numerical data of [23 & 26] under turbulent flow for Al_2O_3/water nanofluid through circular tube. It can be seen that the maximum deviations between the experimental and numerical results of the friction factor and Nusselt number are not exceed than 8%.



(a) Friction factor



(b) Nusselt number

Figure 3: Friction factor and Nusselt number validation

4.2 Velocity profile

Figure 4 shows the radial velocity profile at the mid-plane along the length of the circular tube. The radial velocity profile obtained from the optimum mesh (20000). It can be seen that the values of hybrid nanofluids velocity has gone to fix at constant value (5 m/s) and (5.2 m/s) for 1% and 4% hybrid volume fraction respectively. It seems that the radial velocity decreases with increasing of volume fractions of hybrid nanofluids because thermophysical hybrid nanofluids properties improve due to increase of the volume fraction [12].

The nanofluids viscosity and density are increasing due to increase of volume fraction during same Reynolds number condition. It was observed that significant deformation of the velocity profile that obvious the hybrid nanofluids as compared to the nanofluid. The hydro-dynamically developing region is clearly of the velocity profile of hybrid nanofluids as compared to the alumina nanofluid in the hydro-dynamically fully developed region.

Figure 5 shows the velocity vector contour along the tube at Re=17000 and heat flux = 5000W/m^2. The maximum velocity value at the center of tube is 6.0 m/s.

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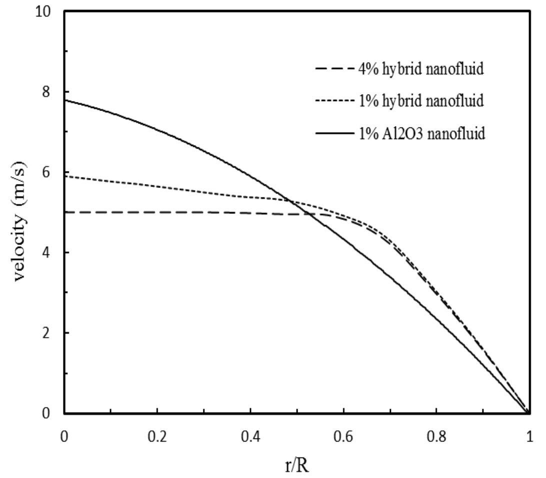


Figure 4: Velocity profile at the mid-plane of tube length

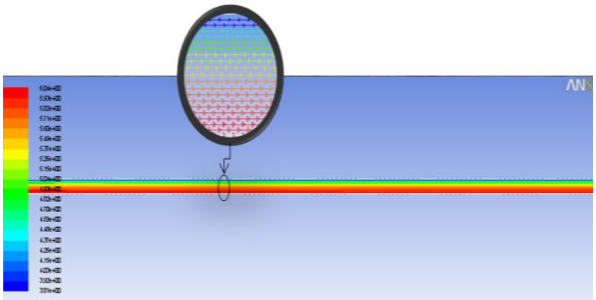
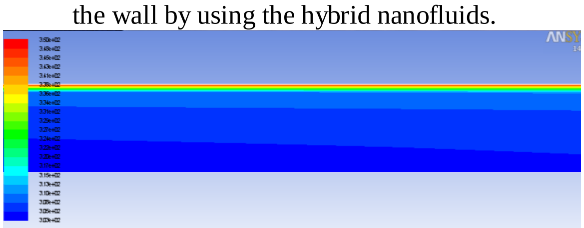


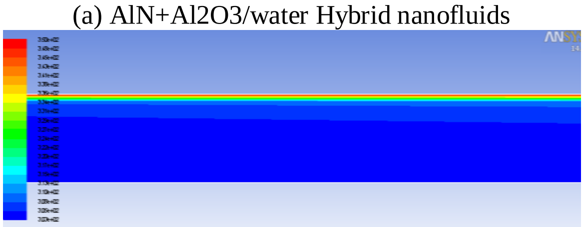
Figure 5: Velocity vector along the tube

4.3 Isothermal contours

Figure 6 shows the isothermal contours of the temperature through the hybrid nanofluids along the tube length at Re = 17000. The cold area at the center of tube with temperature value is 303K whereas; the hot area near the wall with temperature value is 350K. The fluid mixing has been promoted from the center to the wall by using the hybrid nanofluids.



(a) AlN+Al2O3/water Hybrid nanofluids



(b) Al2O3/water nanofluid

Figure 6: Isothermal contour along the tube

4.4 Pressure drop

The pressure drop should be investigated with Nusselt number inherently to understand the industrial applications of hybrid nanofluids. The CFD data of pressure drop against Reynolds number are illustrated in Figure 7. The pressure drop is increased due to increase of Reynolds number by 13% due to increase of the tube velocity.

Likewise, the increasing of pressure drop by 14% with increasing of the hybrid nanofluid volume fractions due to increase in the viscosity of the hybrid nanofluid. The numerical data of pressure drop in the study undertaken are in a good agreement with the literature [17 & 25].

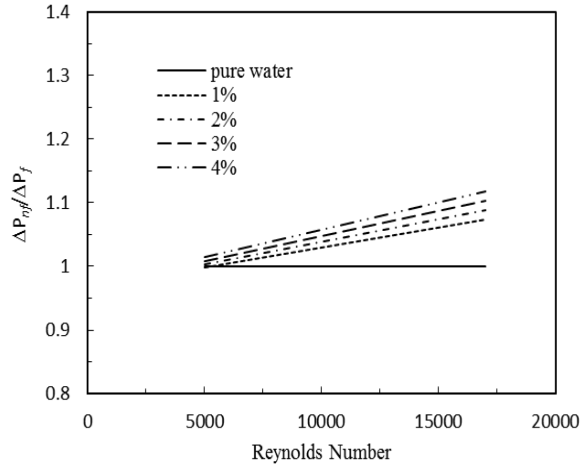


Figure 7: The pressure drop ratio at different Reynolds number

4.5 Nusselt number

Figure 8 shows the ratio of convection heat transfer of hybrid to that of basefluid at different Reynolds numbers. It was observed significant increasing of the convection heat transfer with increasing of Reynolds number. In this CFD analysis, the maximum enhancement of heat transfer is about 1.5 for 3% volume fraction of hybrid nanopowders in water at Reynolds number of 17000. The Nusselt number values for the hybrid nanofluid are up to 50% higher than the values gained for water flows in the circular tube. Similarly the Nusselt number enhancement of Al_2O_3/water nanofluid at different volume fraction observed by [17 & 25].

It can be said the Nusselt number value increased with the volume fraction of hybrid nanofluid are agreed with the literature results [17, 25]. The numerical study by [2] was reported that the increasing of Nusselt number was 13.6% for TiO_2/water using in the same geometry, meanwhile, the benefit of using of AlN - Al_2O_3 hybrid nanofluids is significant clearly as compared with titanium nanofluid flow in the circular tube.

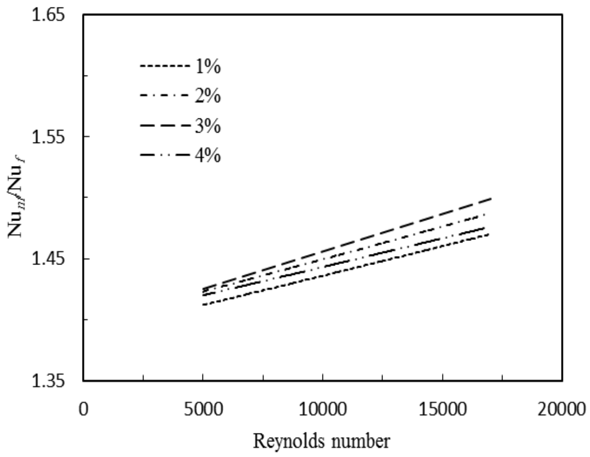


Figure 8: Nusselt number ratio at different Reynolds number

4.6 Heat transfer enhancement

Figure 9 shows the improving of Nusselt number against volume fractions of nanofluid. It can be seen that the Nusselt number enhancement obtained from 28% to 50% at the hybrid nanoparticles volume fractions from 1% to 3% respectively; whereas, 33% of the heat transfer enhancement observed at 4% hybrid nanofluid volume fractions. The CFD analysis of the heat transfer enhancement appears slightly closer results to the experimental data [17 & 25] for Al_2O_3/water nanoparticle volume fractions under turbulent flow condition inside circular tube.

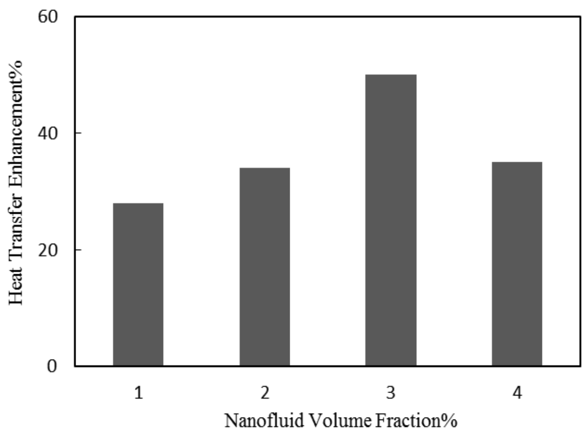


Figure 9: The heat transfer enhancement at different hybrid nan fluids volume fractions

5. Conclusions

In this study, a CFD analysis conducted to investigate the effect of AlN - Al_2O_3 hybrid nanopowders on pressure drop and heat transfer inside a horizontal tube:

1. Grids independence test is performed using the ANSYS/FLUENT software and the best size of mesh 20000 cells (2000x10) adopted as an optimum meshing size.
2. The CFD analysis is successfully validated with experimental and numerical results that reported in the literature [17, 25].
3. The pressure drop has grown as Reynolds number and nanofluid volume fractions increased.
4. It was observed that the maximum values of Nusselt numbers ratio for the 3% of hybrid nanofluids that are up to 50% higher than the values gained for water flows through the circular tube whereas, the low values of Nusselt number observed at 4% hybrid nanofluids volume fractions.
5. The heat transfer enhancement obtained from 28% to 50% at the AlN - Al_2O_3 nanoparticles volume fractions from 1% to 3% respectively, whereas, 33% of the heat transfer enhancement observed at 4% hybrid nanofluid volume fractions.
6. It was found that significant using of 1% to 3% AlN - Al_2O_3 hybrid nanofluids with respect to the efficiency while, insignificant added more than 3% volume fractions due to obtain less than one efficiency.

Acknowledgements

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