Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 | Vol. 24, No. 1. Pages 1-11, 2016

Numerical Study on Turbulent Force Convective Heat Transfer of Hybrid Nanofluid, Ag/HEG in a Circular Channel with Constant Heat Flux

C. K. Sinz, H. E. Woei, M. N. Khalis and S. I. Ali Abbas*

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia.
**chenkingsing@yahoo.com*

Abstract – *This paper presents a two dimensional numerical analysis of a horizontal circular tube to study the turbulent force convective heat transfer characteristics of hybrid nanofluid flows through the circular tube under specific heat flux of 1000 W/m^2. Silver Ag and graphene HEG nanoparticles dispersed in water with volume concentration of 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 vol. % were used as working fluids for the convective heat transfer simulation. The hybrid nanofluid was studied with Reynolds number of 60,000 and 80,000 as well as inlet temperature of 293 K. Effects of nanoparticles volume concentration and Reynolds number on the Nusselt number have been presented and discussed in details. It is clear from the obtained results that the Nusselt number increases as the Reynolds number increases but decreasing trend was observed when nanoparticle volume fraction increases.*

Keywords: Hybrid nanofluid, Reynolds number, Volume fraction

1.0 INTRODUCTION

Forced convection heat transfer is an essential and concerned problem in engineering. The continuing interest is due to its important in industrial or domestic application, such as cooling of electronic packages, thermal spreaders, cooling or heating of food items, heat exchangers as well as diesel engine fuel heater. Over the years, heat transfer enhancement are always the concerns of researchers, where most of the methods are on structure variation, namely increment of heat surface area, fins, vibration of heated surface and etcetera. These enhancing methods hardly applied in high compactness device [1]. Subsequently, improvement of the thermal properties of energy transmission fluids appears as another option in improvement of convective heat transfer performance.

Nanotechnology has attracted interests of researchers to be one of the important research fields that lead to the next major industrial revolution in future. A massive research effort has been done to investigate the thermal transport properties of colloidal suspensions of nano-sized solid particles that known as nanofluids. Traditional working fluids have inherently low thermal conductivity relative to solid particles. Recent works found that the nanoparticles existence in the fluids increases the thermal conductivity of the fluid which result in enhancing the heat transfer properties. With their special features, nanofluids emerge as a new generation of working fluids in heat exchanging applications.

Extensive studies have been conducted experimentally and numerically to investigate the influential factors of the thermal conductivity and heat transfer coefficient of nanofluids. Several factors have been verified, namely types of nanoparticles and base fluids, nanoparticle volume concentration, nanoparticle size and etcetera [2]. Previous researches have shown that introduction of nanoparticles into base fluid significantly increases the convective heat transfer performance in comparison with pure base fluids [3-6]. Based on the earlier investigation on nanofluid regarding thermo-physical properties and heat transfer coefficient on single type of nanoparticles, graphene based nanofluids provided remarkable heat transfer coefficient. Baby and Sundara [7] prepared hybrid CuO-HEG nanofluid and obtained 28% enhancement in thermal conductivity for 0.05% volume concentration. Besides, there are few studies conducted show silver nanoparticles in nanofluids enhance the convective heat transfer. Li et al. [8] and Park et al. [9] found that a good thermal conductivity of nanofluids containing silver nanoparticles.

Nevertheless, there is no single agreement on the effects of nanoparticle volume concentration to the heat transfer performance of nanofluids. The increasing trend in convective heat transfer of nanofluids with increase of nanoparticle volume concentration has been widely expressed in most experimental and numerical researches [1, 4, 10]. Nor Azwadi and Adamu [10] found that the Nusselt number of the hybrid nanofluids increases with increment of volume concentration for both Ag/HEG and CuO/HEG nanofluids while Farajollahi et al. [4] observed that increasing of nanoparticles to the base fluid enhancing the heat transfer performance. In contrast, Pakravan and Yaghoubi [11] noticed the decreasing behavior of Nusselt number with increment of nanoparticles volume fraction while Haddad et al. [12] showed that increasing volume concentration has an adverse effect on heat transfer.

In present study, the heat transfer performance of a turbulent force convective heat transfer of hybrid nanofluid, silver graphene (Ag/HEG) flows through the circular tube under constant heat flux of 1000 W/m^2 was investigated numerically. The hybrid nanofluid was studied with Reynolds number of 60,000 and 80,000 whereas the volume concentrations are 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 %. The effects of volume concentration and Reynold number on the Nusselt number of Ag/HEG in circular tube were concerned.

2.0 MATHEMATICAL FORMULATION

2.1 Physical Description

A numerical simulation of forced convective heat transfer in a circular channel is considered in 2-dimensional where the geometry is illustrated as Figure 1. The simulation setup via ANSYS Fluent involves a circular channel with length of 0.8 m and diameter of 0.01m whereas the channel wall exhibiting constant heat flux of 1000 W/m^2. The initial and boundary condition of the simulation, temperature of Ag/HEG nanofluid will be set at an initial value of 293 K at the inlet. The investigated parameters varied with each simulation adopting a Reynolds number of 60,000 and 80,000 totalling up to 12 simulations with each 6 of the simulations conducted using 60,000 Re and 80,000 Re coupled with varying volume fraction of 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 %. In this study, simulated Ag/HEG nano-fluids are assumed to be incompressible, single phase, exhibiting steady and turbulent flow with constant thermo-physical properties.

Penerbit Akademia Baru
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 I Vol. 24, No. 1. Pages 1-11, 2016

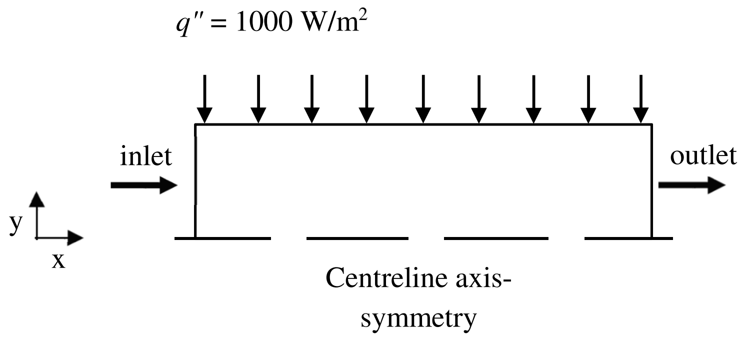

Figure 1: Geometry of the test model

2.2 The Governing Equations

The governing equations of the velocity distribution are continuity equation and momentum equation, in the meantime, the governing equation of the temperature distribution is energy equation, where the governing equations are listed as below:

2.2.1 Continuity Equation

The continuity equation is essentially the mathematical equation for the conservation of mass and given as

$$\frac{\partial}{\partial \mathrm{x}_i}(\rho u_i) \tag{1}$$

2.2.2 Momentum Equation

The momentum equation is an equation derived from Newton's second law of motion and stated as

$$\frac{\partial}{\partial \mathrm{xj}}(\rho u_i u_j) = -\frac{\partial p}{\partial \mathrm{x}_i} + \left[\mu\left(\frac{\partial u_i}{\partial \mathrm{x}_j} + \frac{\partial u_j}{\partial \mathrm{x}_i}\right)\right]\frac{\partial p}{\partial \mathrm{x}_j} + (-\rho\bar{u_i}\bar{u_j})\frac{\partial}{\partial \mathrm{x}_j} \tag{2}$$

2.2.3 Energy Equation

The energy equation is the equation for the conservation of energy, which is written as

$$\frac{\partial}{\partial x_i}(\rho u_i T) = -\frac{\partial p}{\partial x_i}(\Gamma + \Gamma_t)\frac{\partial T}{\partial x_j} \tag{3}$$

where Γ and Γ_t are the molecular viscosity and eddy viscosity respectively.

2.3 Thermo-physical Properties

The working fluid considered is Ag/HEG hybrid nanofluid with the investigated volume fraction of 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 %. The main assumption taken into account in the simulations is that thermal equilibrium is achieved on behalf of the simulated fluid at the

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 | Vol. 24, No. 1. Pages 1-11, 2016

channel wall exhibiting no slip condition with constant thermo-physical properties. The thermo-physical properties of the hybrid nanofluid can be calculated according to the prominence relations evident in many previous researches [13,14] and can be calculated as below:

2.3.1 Effective Density

The effective density can be determined as

$$\rho_{hnf} = (1 - \phi)\rho_{bf} + \phi\rho_{np} \tag{4}$$

where the volumetric concentration is expressed as:

$$\phi = \frac{\rho_{bf}\phi_m}{\rho_{bf}\phi_m + \rho_p(1 - \phi_m)} \tag{5}$$

2.3.2 Heat Capacity

The heat capacity of hybrid nanofluids is given as

$$(C_P)_{hnf} = \frac{(1 - \phi)(\rho c_P)_{bf} + \phi(\rho c_P)_{hnp}}{\rho_{nf}} \tag{6}$$

2.3.3 Thermal Conductivity

The thermal conductivity can be expressed as

$$k_{eff} = k_{bf} + 3\,\phi.\frac{k_p - k_{bf}}{2k_{bf} + k_p - \phi(k_p - k_{bf})}k_{bf} \tag{7}$$

where k_{eff}, k_p and k_{bf} denote the effective, nanoparticle, base fluid thermal conductivity respectively.

2.3.4 Thermo-physical Properties of Ag/HEG Nanofluid

The thermo-physcial properties of Ag/HEG nanofluid are tabulated in Table 1.

Table 1: Thermo-physical properties of Ag/HEG Nanofluid

Volume Fraction, Ø (%)	k (W/m.K)	μ (N.s/m^2)	c_p (J/kg.K)	ρ (kg/m^3)
0.1	0.6006	0.001006	4156.65	1003.58
0.2	0.6012	0.001008	4134.20	1008.96
0.3	0.6018	0.001011	4111.75	1014.35
0.5	0.6030	0.001016	4066.85	1025.11
0.7	0.6042	0.001021	4022.42	1035.87
0.9	0.6053	0.001026	3969.55	1046.64

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 | Vol. 24, No. 1. Pages 1-11, 2016

2.4 Turbulence Model

The turbulence model selected in the simulations is the Realizable k-ε turbulence model with its associated near wall enhanced wall function activated with the operating simulation software.

The Realizable k-ε turbulence model differs with that of standard k-ε model in two distinct formulation manners regarding the turbulent viscosity and dissipation rate ε transport equation. In the aforementioned aspects, Realizable k-ε turbulence model introduced a new formulation for turbulent viscosity and new derivation of dissipation rate ε from an exact equation governing the transport equation of mean-square value of vorticity perturbations. The model agrees within certain mathematical context of Reynold stresses computation and can be considered conforming to the physics of turbulence fluid flow [15].

2.4.1 Transport Equations

As for the model equation of Steady Turbulent Kinetic Energy is expressed as per equation below:

$$\frac{\partial}{\partial \mathrm{x}_j}(\rho k u_j) + \frac{\partial}{\partial \mathrm{t}}(\rho k) = \frac{\partial \mathrm{k}}{\partial \mathrm{x}_j}\left(\mu + \frac{\mu_t}{\sigma_k}\right) + G_k + S_k - \rho\varepsilon \tag{8}$$

where G_k is the generation of turbulence kinetic energy due to mean velocity gradients and it is expressed as

$$G_k = (-\rho \bar{u}_i \bar{u}_j)\frac{\partial \mathrm{u}_j}{\partial \mathrm{x}_i} \tag{9}$$

and based on Boussines hypothesis, G_k is defined as

$$G_k = \mu_t s^2 \tag{10}$$

Dissipation rate of turbulent kinetic energy ε is defined as below:

$$\frac{\partial}{\partial \mathrm{t}}(\rho\varepsilon) + \frac{\partial}{\partial \mathrm{xj}}(\rho\varepsilon\upsilon_j) = \frac{\partial\varepsilon}{\partial \mathrm{xj}}\left[\frac{\partial}{\partial \mathrm{xj}}\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\right] + \rho(c_1 s\varepsilon - c_2\frac{\varepsilon^2}{k + \sqrt{\nu\varepsilon}}) + s\varepsilon \tag{11}$$

where,

$C_{1\varepsilon} = 1.44\,, C_2 = 1.9\ \sigma_\varepsilon = 1.2$

$C_1 = \max(0.43, \frac{\eta}{\eta+5})$

$\eta = S\frac{k}{\varepsilon}$

$S = \sqrt{2(s_{ij})^2}$

$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$

$$C_\mu = \frac{1}{A_0 + A_s \frac{ku^*}{\varepsilon}} \tag{12}$$

3.0 RESULTS AND DISCUSSION

3.1 Grid Independent Test

In present study, non-uniform grid size was chosen where the grid size near the tube wall was constructed finer with a bias factor of 5 in order to capture the flow detail of boundary layer near the wall. A grid independence test was performed to evaluate the effects of grid sizes on the Nusselt number along the tube as shown in Figure 2. Four sets of mesh size were generated with nodes number of 42671, 60701, 90751 and 144981 respectively. It was noticed that the Nusselt number of 90751 nodes was closed with the Nusselt number of 144981 nodes, where the former nodes number was selected to save computing time.

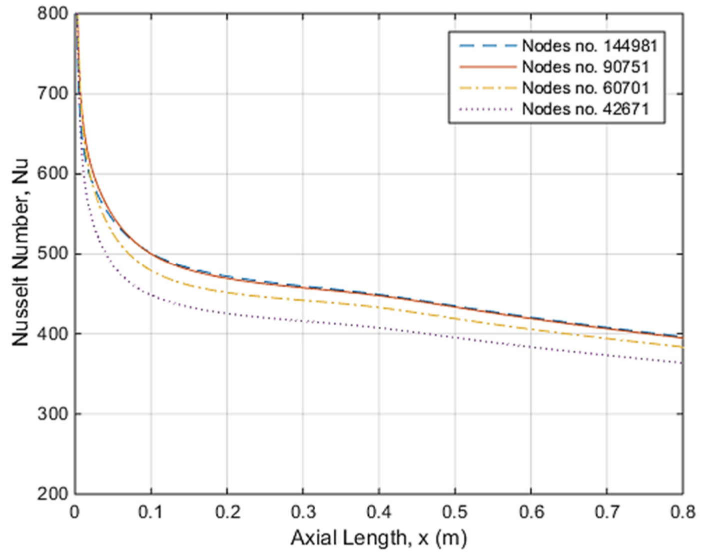

Figure 2: Grid independent test

3.2 Validation of Result

The 2-dimensioanl physical model used in this study was validated by comparing the simulated result with Gnielinski [16] correlation where the Nusselt number for Reynolds number of 60,000 with varying nanoparticle volume fraction of 0.1, 0.2, 0.3, 0.5, 0.7 and 0.9 % was compared as shown in Figure 3. The percentage of deviation between the simulated Nusselt number and Gnielinski correlation is about 1.67 %, where the model was well designed and able to be utilized to predict the heat transfer performance of the hybrid nanofluids.

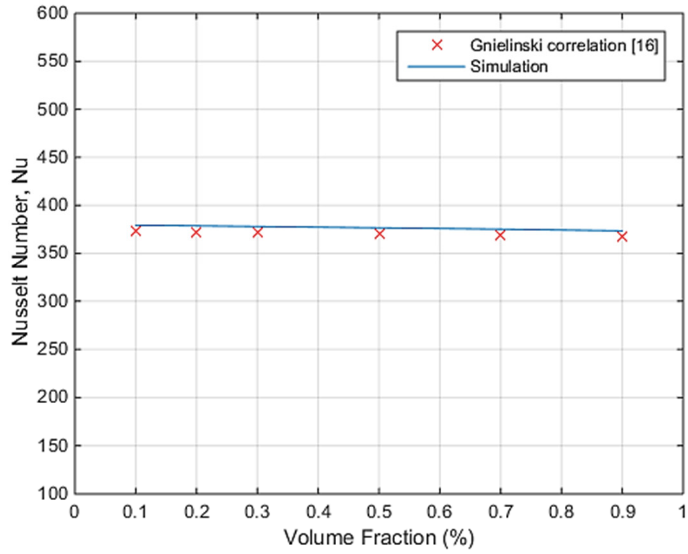

Figure 3: Comparison of simulated Nusselt number with Gnielinski correlation [16].

3.3 Effects of Volume Concentration on the Nusselt Number

Figure 4 shows the Ag/HEG nanofluid corresponding Nusselt number with Reynold number of 60000 and 80000, in which Nusselt number increases with increment of Reynold number. Besides, the Nusselt number was found slightly decreases with increasing volume fraction and this trend can be applied to both sets of simulations utilizing Reynolds number of 60000

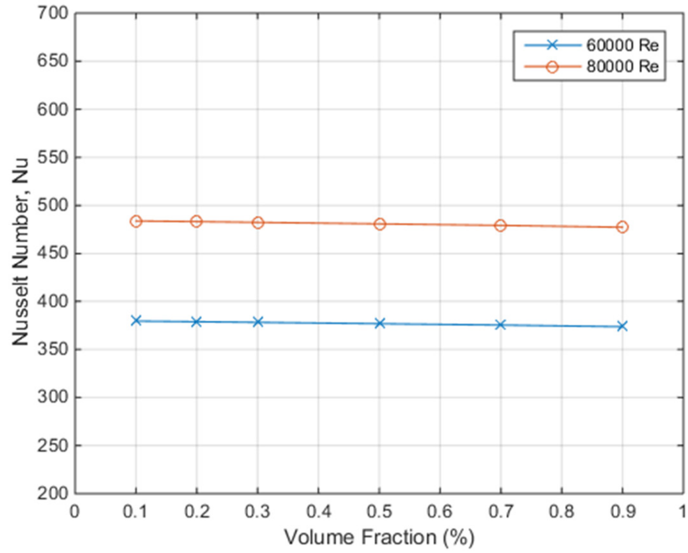

Figure 4: Graph of Nusselt number for Ag/HEG against volume fraction for Reynolds number of 60000 and 80000.

and 80000 as shown in Figure 4. The results obtained agreed well with previous study by Pakravan and Yaghoubi [11] which also indicate decreasing Nusselt number with increasing volume concentration. The results shown in Figure 4 contradicts the supposed increasing Nusselt number theory due to the increment of convective heat transfer coefficient as

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 | Vol. 24, No. 1. Pages 1-11, 2016

demonstrated by collective researches [17-19]. It should be noted that density and dynamic viscosity are varied with increasing volume fraction of nanofluid. With larger nanoparticle volume fraction, the pressure drop is remarkably affected and this in turn limits the application of heat transfer under restricted pumping power condition deducted from the operation of the entire thermal system. Nevertheless, selection of improper correlation in calculating dynamic viscosity can also lead to the aforementioned trend of nano-fluid according to Abouali and Falahatpisheh [20]. Nusselt number of the Ag/HEG nanofluid along the circular tube for Reynolds number of 80000 and 0.1 % volume fraction is illustrated as Figure 5. It was noted that the Nusselt number has highest value at the entrance of the tube and decreases rapidly until it reaches 0.1 m of the tube length and decreases gradually until the outlet.

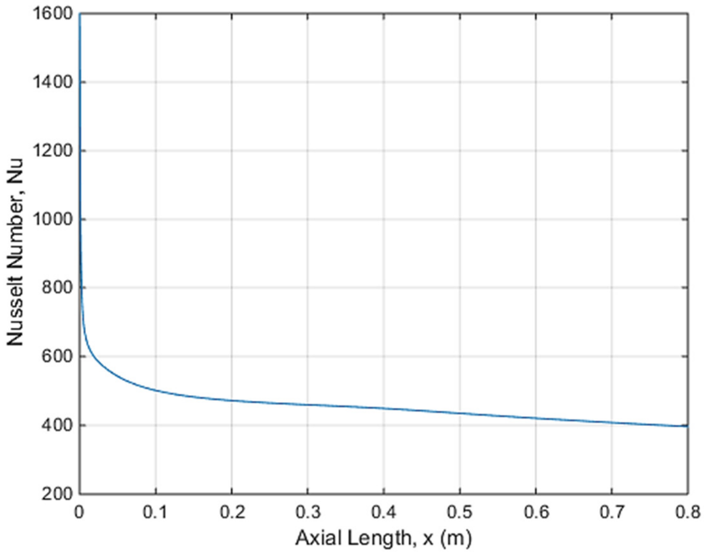

Figure 5: Nusselt number along circular tube for 80000 Reynold number and 0.1 % volume fraction.

3.4 Velocity profile of the turbulent hybrid nano-fluid.

The velocity profile was expressed in terms of axial velocity profile as shown in Figure 6 and 7, which is representative of the velocity profile generated with all the simulation parameters considered. Figure 6 and 7 were generated using the 80000 Reynolds number and 0.1 volume fraction. It can be shown that in Figure 6, axial velocity varies in magnitude with different y-section but eventually reaches a fully developed flow at x of 0.7 m. Hence, it can be summarized that the greatest velocity fluctuations can be observed from the section of inlet to x about 0.6 m or in fluid physics the turbulence properties of the hybrid nanofuid decreases along x-section irrespective of the y-section. Less velocity fluctuation will stabilize heat transfer in thermal system as the frequency of fluid particles coming in contact with the thermal wall becomes constant or with slight changes. Axial velocity decreases when moves closer to tube wall, where zero value of axial velocity found at the wall. Turbulent velocity profile was observed from Figure 7, which has a flattened tip shape compared with laminar velocity profile.

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 I Vol. 24, No. 1. Pages 1-11, 2016

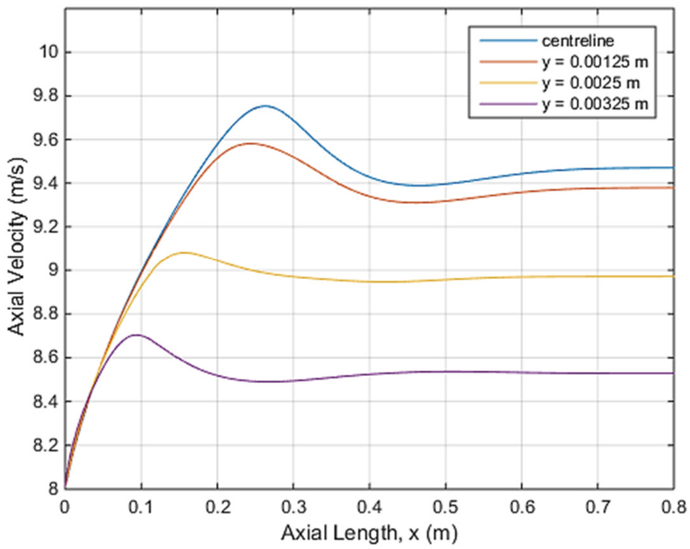

Figure 6: Axial velocity of Ag/HEG along the tube length at different distance from centreline.

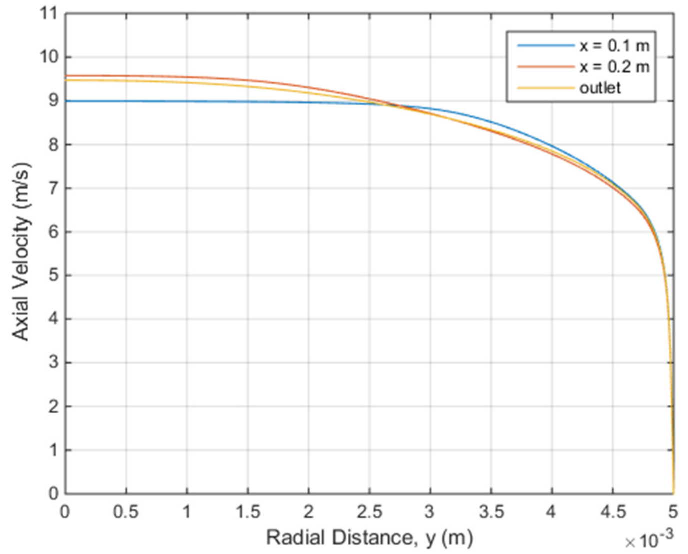

Figure 7: Axial velocity of Ag/HEG along the tube diameter at different distance from tube inlet.

4.0 CONCLUSION

From the previous discussion, a single-phase model is used to solve the governing equations and SIMPLEC algorithms were used for discretization. The uniform heat flux at the tube wall was considered. The result of the study indicates that the Nusselt number of the nanoparticle increases when the Reynold number increases as observed from 60000 Re and 80000 Re. However, Nusselt number decreases with the increase of nanoparticle volume fraction, as observed from volume fraction of 0.1 % to 0.9 %. Nevertheless, Ag/HEG enhances the heat transfer performance as a working fluid with the highest Nusselt number of 483.96 at Reynolds number of 80000 and 0.1 % volume fraction among the Reynolds number and volume concentration investigated.

As a conclusion, the increase Reynold number, increases the kinetic energy and therefore the velocity and turbulences in the fluid. In engineering world, the increase amount of Reynold Number brings a lot of good prospect especially in the development of modern engines. It is because by increasing Reynold number, the convective heat transfers coefficient and shear stress increase but the volume friction decreases. In this case, the dispersion of nanoparticles into the engine oil helps enhancing and reduce friction.

REFERENCES

[1] Heris, S. Zeinali, M. Nasr Esfahany, and S. Gh Etemad. "Experimental investigation of convective heat transfer of Al 2 O 3/water nanofluid in circular tube." International Journal of Heat and Fluid Flow 28, no. 2 (2007): 203-210.

[2] Vanaki, Sh M., P. Ganesan, and H. A. Mohammed. "Numerical study of convective heat transfer of nanofluids: A review." Renewable and Sustainable Energy Reviews 54 (2016): 1212-1239.

[3] Duangthongsuk, Weerapun, and Somchai Wongwises. "An experimental study on the heat transfer performance and pressure drop of TiO 2-water nanofluids flowing under a turbulent flow regime." International Journal of Heat and Mass Transfer 53, no. 1 (2010): 334-344.

[4] Farajollahi, B., S. Gh Etemad, and M. Hojjat. "Heat transfer of nanofluids in a shell and tube heat exchanger." International Journal of Heat and Mass Transfer 53, no. 1 (2010): 12-17.

[5] Vajjha, Ravikanth S., Debendra K. Das, and Praveen K. Namburu. "Numerical study of fluid dynamic and heat transfer performance of Al 2 O 3 and CuO nanofluids in the flat tubes of a radiator." International Journal of Heat and fluid flow 31, no. 4 (2010): 613-621.

[6] Peyghambarzadeh, S. M., S. H. Hashemabadi, M. Seifi Jamnani, and S. M. Hoseini. "Improving the cooling performance of automobile radiator with Al 2 O 3/water nanofluid." applied thermal engineering 31, no. 10 (2011): 1833-1838.

[7] Baby, Tessy Theres, and Ramaprabhu Sundara. "Synthesis and transport properties of metal oxide decorated graphene dispersed nanofluids." The Journal of Physical Chemistry C 115, no. 17 (2011): 8527-8533.

[8] Li, Dan, Biyuan Hong, Wenjun Fang, Yongsheng Guo, and Ruisen Lin. "Preparation of well-dispersed silver nanoparticles for oil-based nanofluids."Industrial & Engineering Chemistry Research 49, no. 4 (2010): 1697-1702.

[9] Park, Sung Dae, Seung Won Lee, Sarah Kang, In Cheol Bang, Ji Hyun Kim, Hyeon Suk Shin, Dong Wook Lee, and Dong Won Lee. "Effects of nanofluids containing graphene/graphene-oxide nanosheets on critical heat flux."Applied Physics Letters 97, no. 2 (2010): 023103.

[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." J. Adv. Res. Fluid Mech. Therm. Sci 19 (2016): 1-9.

[11] Pakravan, Hossein Ali, and Mahmood Yaghoubi. "Analysis of nanoparticles migration on natural convective heat transfer of nanofluids." International Journal of Thermal Sciences 68 (2013): 79-93.

[12] Haddad, Zoubida, Eiyad Abu-Nada, Hakan F. Oztop, and Amina Mataoui. "Natural convection in nanofluids: Are the thermophoresis and Brownian motion effects significant in nanofluid heat transfer enhancement?."International Journal of Thermal Sciences 57 (2012): 152-162.

[13] Chaupis, Joseph Edher Ramírez, Guilherme Azevedo Oliveira, and Enio Pedone Bandarra Filho. "Numerical analysis of nanofluids flowing in a straight pipe." (2011).

[14] Zamanian, A., M. Haghshenas Fard, S. Gh Etemada, and F. Mircharkhchian. "Numerical Investigation of Free Convection Heat Transfer of Al_2O_3/water Nanofluid Under Constant Wall Temperature Condition."

[15] Shih, Tsan-Hsing, William W. Liou, Aamir Shabbir, Zhigang Yang, and Jiang Zhu. "A new k-ϵ eddy viscosity model for high reynolds number turbulent flows." Computers & Fluids 24, no. 3 (1995): 227-238.

[16] Gnielinski, Volker. "New equations for heat and mass transfer in the turbulent flow in pipes and channels." NASA STI/recon technical report A 75 (1975): 22028.

[17] Godson, Lazarus, B. Raja, D. Mohan Lal, and S. Wongwises. "Enhancement of heat transfer using nanofluids—an overview." Renewable and sustainable energy reviews 14, no. 2 (2010): 629-641.

[18] Xuan, Yimin, and Qiang Li. "Heat transfer enhancement of nanofluids." International Journal of heat and fluid flow 21, no. 1 (2000): 58-64.

[19] Trisaksri, Visinee, and Somchai Wongwises. "Critical review of heat transfer characteristics of nanofluids." Renewable and Sustainable Energy Reviews11, no. 3 (2007): 512-523.

[20] Abouali, Omid, and Ahmad Falahatpisheh. "Numerical investigation of natural convection of Al2O3 nanofluid in vertical annuli." Heat and mass transfer 46, no. 1 (2009): 15-23.