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ANSYS simulation for Ag/HEG Hybrid Nanofluid in Turbulent Circular Pipe

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Abstract – *A CFD simulation analysis about enhancement of turbulent flow heat transfer in a horizontal circular pipe by convenient software where FLUENT was used to predict the heat transfer coefficient and Nusselt number for forced convection heat transfer of Ag/HEG+water nanofluid. The range of Reynolds number selected were 20 000 and 40 000 in a horizontal straight tube of diameter 0.01m with heat flux of 1000 W/m2. The volume fraction of nanoparticle considered were 0.1%, 0.2%, 0.3%, 0.5%, 0.7% and 0.9%. This problem also considered 100x30 meshing in order for Y+ to approach 1 to get more accurate results. The results show that the heat transfer coefficient and Nusselt number were decreasing with increasing of volume fraction. Finally, the results were compared with the theoretical values obtained from Dittus-Boelter Equation by using tool of package from ANSYS-FLUENT which show similar results.*

Keywords: volume fraction, hybrid nanofluid, mesh, Nusselt number

1.0 INTRODUCTION

Heat is a form of energy passes from higher temperature to lower temperature. There are three fundamental modes of heat transfer which are conduction, convection and radiation. In this research, convection was selected. The heat transfer coefficients in forced convection are governed by thermal conductivity of the fluid as well as factors representing both turbulence and the operating condition. These fluids, including oil, water, and ethylene glycol mixture are rather poor heat transfer media. Their thermal conductivity plays an important role in the heat transfer between the working fluid and the heated surface. An innovative way to improve the thermal conductivity of a fluid is to suspend nanosized particles with high thermal conductivity in the base fluid with low thermal conductivity. Generally, the thermal conductivity of the particles, metallic or non-metallic are typically an order of magnitude higher than that of the base fluids even at low concentrations resulting in significant increases in heat transfer. As the modern technology grows, there are demands on development in various engineering equipment mainly on the effectiveness of regulating heat content such as heat exchangers, transformers, electronic devices, auto mobile engines and diesel generators. The main restriction of devices that make use of convectional heat transfer fluid are low thermal conductivity [1]. Numerous of researches had been conducted to increase thermal carrying capacity of conventional heat transfer fluid to overcome the stated restriction. The wiser choice is to disperse nanosize particles into base fluid [2].

The term of nanofluids was introduced by [3] in 1995. Nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal

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suspensions of nanoparticles in a base fluid. Nanofluids have few properties to be referred. First, the particle size will make the nanofluids stable. Dense nanoparticles can be suspended in liquids due to the property of the particles that have an extremely high ratio of surface area to volume. In addition, nanoparticles are charged and thus particle-particle interactions are not allowed. Second, size matters in making nanofluids with novel properties. The very small particle size can affect transport mechanisms at the nanoscale. Finally, particle size matters in making nanofluids useful. The nanofluids can be used in biomedical applications such as drug delivery and nanofluids-based control of biological functions because of the size of nanoparticles is similar to that of biomolecules studied by [4]. The nanofluid effective viscosity increases with increasing particle concentration. For example, for the 47 nm alumina–water, the relative viscosity has increased from ≈ 1.12 to ≈ 1.6, ≈ 3.0 and then to ≈ 5.3 as for particle fraction, the increment is from 1% to 4%, 9% and then to 12% related to [5]. Increment in the relative thermal conductivity of the nanofluids with temperature is subjected by [6]. The increase in the thermal conductivity with decreasing particle size cannot be explained if the particles are well dispersed. The probability of aggregation increases with increasing temperature and decreasing particle size stated by [7]. The mechanism for increase in the thermal conductivity of water is partly responsible for the thermal conductivity increase in nanofluids. Conversely, it is reasonable to expect a decrease in the nanofluid thermal conductivity for a base fluid that has a negative change in conductivity with increasing temperature according to [8].

Hybrid nanofluid refers to the composition of two variant types of dispersed nanoparticles in a base fluid. The combination of two materials can be advantages as the positive features of each component can be enhance and overcome the disadvantages of nanofluid that only consist of one material. For example, alumina, a type of a ceramic material has many beneficial properties such as chemical inertness and a great deal of stability. Al2O3, also known as aluminium oxides exhibits lower thermal conductivity with respect to the metallic nanoparticles. However, the use of metallic nanoparticles for nanofluid applications is limited due to their stability and reactivity.

Graphene is a two-dimensional (2D) material, formed of a lattice of hexagonally arranged carbon atoms [9]. The term graphene is typically applied to a single layer of graphite. This material comprises a monolayer of hexagonal arranged sp2 hybridized carbon atoms [10]. Based on Geim and Noveselev [11], due to graphene's good traits such as high thermal conductivity, high electrical conductivity, high mechanical strength high mobility of charge carriers, extremely large surface area and so on [12], graphene has been widely used as nanomaterial. The application of the synthesis of graphene includes micromechanical cleavage [12], chemical vapour deposition [13] and exfoliation of graphite oxide [14]. This material is chosen due to easy to synthesize and cheaper in cost compared to other nanomaterials [1]. Some researchers realised that the method of preparation and different number of layer of graphene will slightly affect the property of graphene.

The nanofluids can be applied in many aspects. The capability of nanofluids in heat transfer enhancement has encouraged researchers to develop concepts and technologies advocated by manufacturers of ultra-compact, miniaturized and intrinsic electronic chips. The uplifting demand for higher speed, multiple functioning, more powerful and smaller sized boards has almost doubled number of transistors on electronic chips [15]. According to the [16], observed reversible tunable thermal property of nanofluid with advantage of 300% increase in thermal conductivity of the based fluid. Besides that, nanofluids can be used to cool automobile engines and welding equipment and to cool high heat-flux devices such as high power microwave tubes and high-power laser diode arrays. A nanofluid coolant could flow through tiny passages in MEMS to improve its efficiency. The measurement of nanofluids critical heat flux (CHF) in a forced convection loop is useful for nuclear applications. Nanofluids also found potential to use in deep drilling application conducted by [17]. Moreover, [18] have studied dispersed CuO and Al2O3 nanoparticles into engine transmission oil.

In this paper, the effect of using hybrid nanofluid, silver/graphene (Ag/HEG) in horizontal circular pipe of 0.01m diameter with constant heat flux, 1000W/m2 is investigated. Reynolds number of 20 000 and 40 000 were implemented with six volume fractions nanoparticles which are 0.1%, 0.2%, 0.3%, 0.5%, 0.7% and 0.9%. CFD simulation analysis of enhancement of turbulent flow heat transfer in a horizontal circular pipe by convenient software as Ansys-Fluent was used to predict the heat transfer coefficient and Nusselt number for forced convection heat transfer of Ag/HEG+water nanofluid.

2.0 METHODOLODY

The fluid flow and heat transfer into the heat pipe is a complex process. In consequence, the efficiency of a thermal CFD simulation depends on many factors. Creation of the model geometry and its integration in a physical domain, grid generation and choice of a suitable numerical computing scheme are significant factors that can determine the level of success of the simulation process. The main steps of the performed studies are briefly described in the following paragraphs.

2.1 CAD model

A cylindrical tube in a horizontal position with dimensions of 0.01m diameter and 0.8m length is considered in the current study. A constant heat flux is applied to the tube wall. The two-dimensional (2D) axisymmetric geometry has been assumed. As the result, a rectangular domain with dimensions of 0.005m x 0.8m is created. For further progressions, a small portion from the pipe was analysed in a rectangular shape. As mentioned above, problem happened to be axisymmetric flow and can be further simplified by focusing only on the radius of the shape. A typical pipe with given parameters is shown in Figure 1.

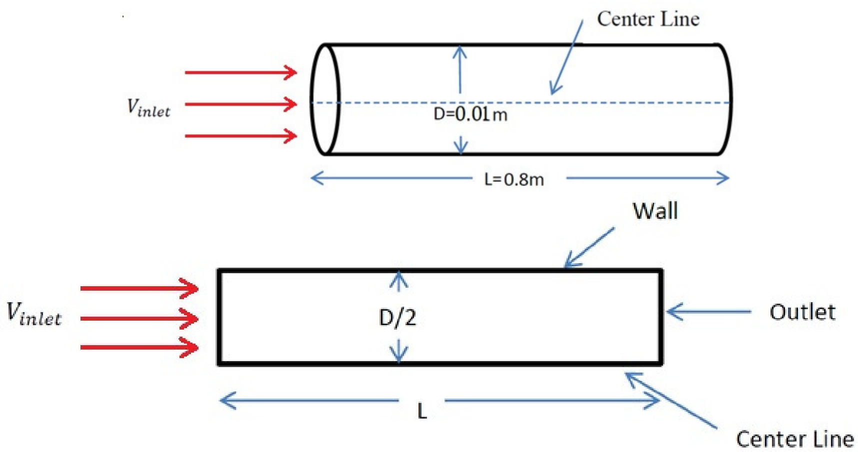

Figure 1: Characteristic geometry, dimensions and boundary of the heat pipe

2.2 Mathematical modelling

CFD model by FLUENT software was used to solve governing equations of turbulent forced convection heat transfer in horizontal tube with constant heat flux. The description of problem was graphed by ANSYS model and the meshing section was test with size of 100×30, 0.8m length of pipe and 0.005m radius as shown in Figure 1. The governing equations (continuity, momentum and energy) are written [19] as:

$$\left(\frac{1}{r}\right)\frac{\partial}{\partial r}(\rho_{nf}u) = 0 \tag{1}$$

$$\left(\frac{1}{r}\right)\frac{\partial}{\partial r}(\rho_{nf}uu) = -\frac{1}{r}\frac{\partial P}{\partial x} + \frac{1}{r^2}\frac{\partial}{\partial x}(\tau) = 0 \tag{2}$$

$$\left(\frac{1}{r}\right)\frac{\partial}{\partial r}(\rho uT) = \frac{1}{r^2}\frac{\partial}{\partial x}\left\{\frac{k_{nf}}{C_p}\frac{\partial T}{\partial x}\right\} = 0 \tag{3}$$

Which solved iteratively using finite volume method (FVM) and SIMPLE scheme was adopted for the treatment of pressure. The Reynolds number studied in this work is high as the turbulent viscous such as k-ε model has been employed. In this work, converged solutions were considered for residuals lower than 10–6 for all the governing equations [20]. The results of simulation for nanofluid were compared with the theoretical data available for the conventional water. The theoretical data of water were simulated in FLUENT software too. Data was compared with Dittos-Boelter correlation [21] for heat transfer (Nu) as shown [22].

$$f = \frac{\partial}{\partial r}(\rho_{nf}u) \tag{4}$$

$$Nu = \frac{h_f}{k_f}D = 0.023Re^{0.8}Pr^{0.4} \tag{5}$$

The Nusselt number and heat flux coefficient were calculated by the given equations below. Nusselt numbers based on the present study were calculated as follow:

$$\bar{Nu} = \frac{\bar{h}D}{k} \tag{6}$$

Average heat transfer coefficient (hx) is defined as:

$$\bar{h}_x = \frac{q''}{(\bar{T}_w(x) - \bar{T}_b(x))} \tag{7}$$

Based on the result obtained from Fluent report, the average of both temperatures of wall and bulk can be found from Ansys-Fluent simulation.

2.2.1 Thermal properties of nanofluid

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The thermophysical properties of the nanofluids, namely viscosity μ_{nf}, density ρ_{nf}, thermal conductivity k_{nf}, and heat capacitance, $(\rho C_p)_{nf}$ are proposed by Brinkman [23]. Eventually, the Brinkman model is presented in the volume fraction as following form.

$$\rho_{nf} = (1-\emptyset)\rho_f + \emptyset\rho_s \quad (8)$$

$$(\rho C_p)_{nf} = (1-\emptyset)(\rho C_p)_f + \emptyset(\rho C_p)_s \quad (9)$$

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\emptyset(k_f - k_s)}{(k_s + 2k_f) + \emptyset(k_f - k_s)} \quad (10)$$

$$\mu_{nf} = \frac{\mu_f}{(1-\emptyset)^{2.5}} \quad (11)$$

2.3 Synthesis of nanofluid

Based on the nanofluid model, those equations were used to estimate the effective viscosity, density, thermal conductivity and heat capacitance of nanofluid with influence temperature by simply substituting the base fluid viscosity at a particular temperature. The thermophysical properties of pure water at 293K are shown in Table 1.

Table 1: Thermophysical properties of pure water at 293K

Thermophysical properties	Water
Density, (ρ) m3/kg	998.21
Specific heat, (Cp) j/kg.k	4182
Thermal conductivity, k w/m.k	0.6024
Dynamic viscosity, (μ) pa.s	0.001003

The thermophysical properties of the Ag/HEG nanoparticle and water-based known as hybrid nanofluid are presented at temperature 293K in Table 2.

Table 2: Thermophysical properties of Ag/HEG+water different volume fraction at T0=293K

Thermophysical properties	Ag/HEG+Water Volume fraction						
	∅=0.0%	**∅=0.1%**	**∅=0.2%**	**∅=0.3%**	**∅=0.5%**	**∅=0.7%**	**∅=0.9%**
Density, (ρ) m3/kg	998.21	1003.581	1008.963	1014.345	1025.109	1035.872	1046.636
Specific heat, (Cp) j/kg.k	4182	4156.65	4134.201	4111.752	4066.854	4022.4225	3969.545
Thermal conductivity, (k) w/m.k	0.6024	0.600608	0.601201	0.601795	0.602982	0.604166	0.605346
Dynamic viscosity, (μ) pa.s	0.001003	0.001006	0.001008	0.001011	0.001016	0.001021	0.001026

The determination of nanofluids thermophysical properties is an increasingly important area in nanofluid applications. A considerable amount of literature has been accumulated on the basic nanofluid thermophysical properties over the past few years but in the present, there is no

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agreement within the nanofluid community about description of thermophysical properties [24-25].

The available experimental data were rather controversial and no systematic study on thermophysical properties of nanofluids. The single-phase approach was chosen to calculate the thermophysical properties of nanofluids as it is widely used in the literature [26–28]. In this model, the homogenous mixture was assumed prior to solve the governing equations of continuity, momentum and energy for the single phase fluid flow that the presence of nanoparticles was realized by modifying physical properties of the mixture fluid. It is assumed that there is no velocity difference between fluids and the particles and the fluids and particles were in thermal equilibrium [29–31]. This assumption implies that all the convective heat transfer correlations available in the literature for single-phase flows can be extended to nanoparticle suspensions, providing that the thermophysical properties appearing in them were the nanofluids effective properties calculated at the reference temperature [32].

2.4 Boundary conditions

Volume fraction of nanofluids (0.1%, 0.2%, 0.3%, 0.5%, 0.7%, 0.9% and 1%) at 293K (25oC) was used for Ag/HEG+water as input fluids. For comparison purposes, water was also employed as working fluid. Simulation study has been carried out with uniform velocity profile at the inlet of the horizontal tube. Turbulent intensity (I) was specified for an initial guess of turbulent quantities (k and ε). The turbulent intensity was estimated for each case based on the formula I = 0.16Re-1/8. Outflow boundary condition has been used at the outlet boundary. The wall of the tube was assumed to be perfectly smooth with constant wall heat flux was used at the wall boundary.

The fluid entered with uniform temperature at 293K and velocity profiled at the pipe inlet. Different inlet uniform velocities were applied which are listed in Table 3. In order to validate the CFD model, Reynolds (Re) and thermal boundary condition were chosen to match Re of the available correlations [21]. At the outlet of the computational model, a relative average pressure equal to zero was defined. The surfaces of the walls were assumed to be hydraulically smooth. A constant heat flux 1000W/m2 is specified for the wall (rod surface). A similar approach with [33–34] has been chosen to calculate the Re based on thermophysical properties of Ag/HEG+water nanofluid at different volume fractions of 0.1% till 0.9%. Sequence of steps involved in ANSYS-FLUENT and analysed. Determination of mean velocity (u) of working fluid (hybrid nanofluid) by using Reynolds Number considered from the following equation (10). For present study, the given Reynolds number were 20 000 and 40 000 which were turbulence flow. From these values, the velocity pass can be found through the internal of pipe.

$$Re = \frac{\rho u D}{\mu} \tag{10}$$

As given Re=20 000 and volume fraction=0.1%, the velocity flow can be determined by calculating the inlet velocity:

$$20000 = \frac{1003.581 \cdot u_1 \cdot 0.01}{0.001006}$$

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$$u_1 = \frac{20000 \cdot 0.001006}{1003.581 \cdot 0.01}$$

$$u_1 = 2.003824$$

The calculated inlet velocity for all volume fractions is tabulated in Table 3.

Table 3: Inlet velocities and Reynolds (Re) number

Re	Water	Ø=0.1%	Ø=0.2%	Ø=0.3%	Ø=0.5%	Ø=0.7%	Ø=0.9%
20 × 103	2.009597	2.003824	1.998091	1.992419	1.981253	1.970320	1.960567
40 × 103	4.019194	4.007649	3.996182	3.984838	3.962505	3.940639	3.921134

The boundary conditions and reference values were shown in table below.

Table 4: Inlet, outlet and wall boundary conditions

Location	Inlet	Outlet	Wall
Speed	Refer Table 3	-	-
Medium intensity	5%	-	-
Static temperature	293 K	-	-
Relative pressure	-	1 Pa	-
Heat flux	-	-	1000 w/m2k
Option	-	-	No slip wall

2.5 Mesh Generation

The accuracy of finite volume method is directly related to the quality of the discretization used. In this study, structured hexahedral meshes were used which were known to provide higher accuracy and reduce the CFD computational effort (Figure 2). A comprehensive mesh sensitivity study was done to check on the influence of the mesh resolution on the results and to minimize numerical influences introduced by the size of meshes and their distributions.

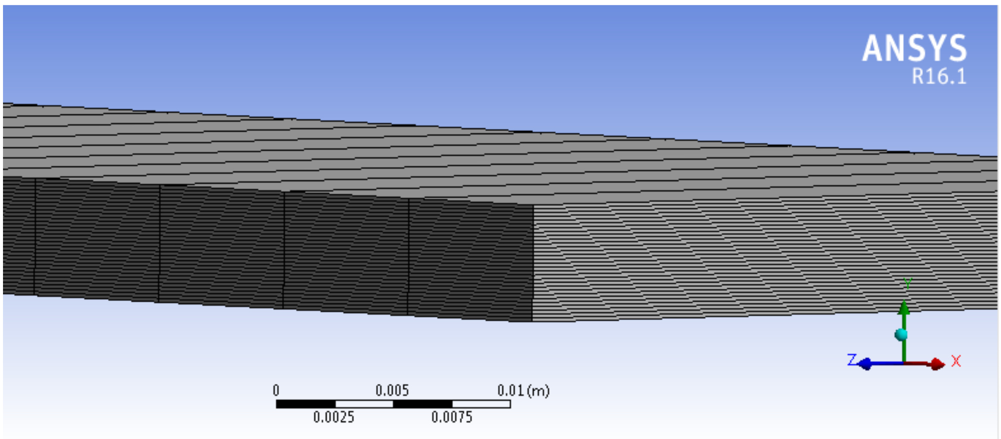

Figure 2: Mesh generated by ANSYS ICEM CFD

The computational grid was generated using multi-blocks scheme with wedges and hexahedral elements nearest to surface of the heat pipe in order to solve the flow accurately and heat

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transfer in the proximity around the fluid flow and surface at the wall in the pipe. In this sense, the side length of the elements on the surface of the heat pipe was 0.05 m (Fig. 2). Thus, the dimensions of the computational grid were:

- global number of grid points: 3131;
- global number of elements: 3000.

2.6 Numerical Method

The modelled cases were solved using ANSYS FLUENT software version 12.1 [35]. A segregated, implicit solver option was used to solve the governing equations. It first involves creating a system of algebraic equations through the process of discretising the governing equations for mass, momentum, and scalar transport. The finite volume method was a particular finite differencing numerical technique and is the most common method of flow calculations in CFD codes. This section described the basic procedures involved in finite volume calculations. To account for flow fluctuations due to turbulence in this project, the RANS equations were discretised instead when the cases were ran using the k-epsilon turbulence model. When the equations had been discretised using the appropriate differencing scheme for expressing the differential expressions in the integral equation of upwind or other higher-order differencing schemes which discrimination scheme was employed for the terms in energy, momentum and turbulence parameters that resulting algebraic equations were solved at each node of each cell. The value of the scalar properties of interest such as temperature at a particular location in the computational domain depends on the flow's direction and velocity, which must also be solved in the calculation process. The solutions sequential algorithm (called the segregated solver) used in the numerical computation requires less memory that the coupled solver. In this project SIMPLE algorithm was used in calculation process. A standard pressure interpolation scheme and SIMPLE pressure velocity coupling were implemented. A residual root-mean-square (RMS) target value of 10−6 (10−6 for energy equation) was defined for the CFD simulations.

3.0 RESULTS AND DISCUSSION

By utilizing the results simulated from ANSYS, the values obtained for the convective heat transfer coefficient (h) and the Nusselt number (Nu) for different volume fractions (vol.%) of Ag/HEG hybrid nanofluid using 20 000 and 40 000 Reynolds numbers (Re), respectively under a constant heat flux were recorded in Table 5. The effect of nanofluid volume fraction on Nusselt number is shown in Figure 3. Simulation results were made reliable by comparing them with available correlation in the literature. Nusselt number for the hybrid nanofluids' results were validated by comparing the obtained ANSYS FLUENT results against Dittus-Boelter equation (5) as shown in Table 6. Nusselt number from simulation is in very good agreement with that of the correlation values. That means Nusselt number from Dittos-Boelter equation has same behavior of simulation data which increasing when Re of nanofluid are increased as shown in Fig. 5.

Table 5: Variations of convective heat transfer coefficient and Nusselt number versus Reynolds numbers for different volume fractions of Ag/HEG hybrid nanofluid

Volume fraction	Re=20 000		Re=40 000	
	h	Nu	h	Nu
0.1%	8331.330610	138.714946	14918.949935	248.152447
0.2%	8325.994716	138.489369	14906.120109	247.939044
0.3%	8318.003679	138.356451	14897.579143	247.796979
0.5%	8297.430988	138.014258	14859.265609	247.159695
0.7%	8278.277481	137.695671	14840.182648	246.842282
0.9%	8259.868160	137.389461	14791.637036	246.034804

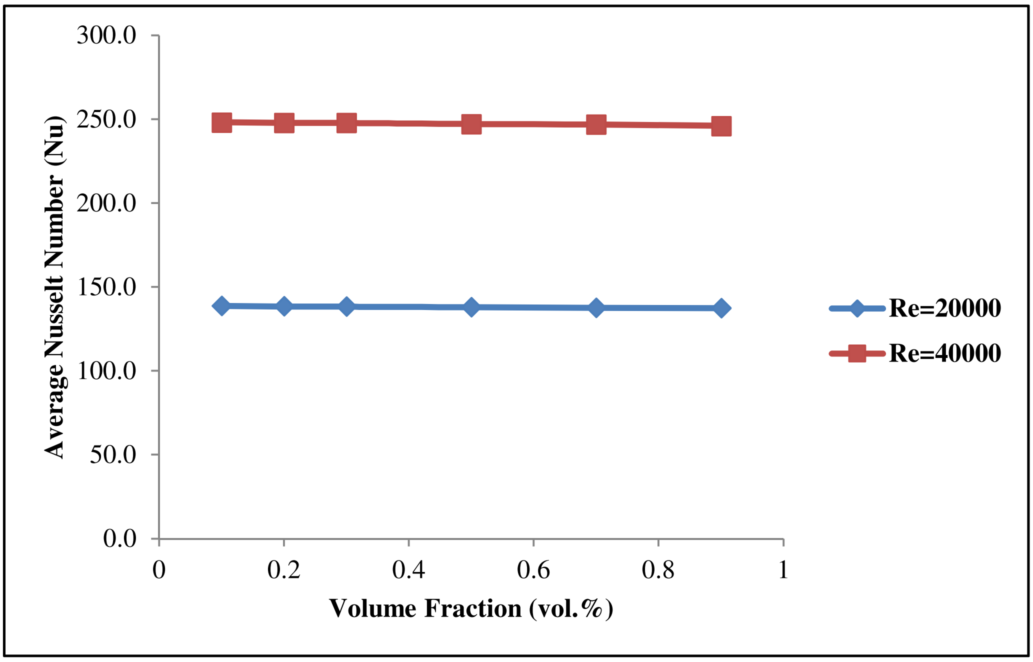

Figure 3: Nusselt number coefficient against volume fraction for different Reynolds numbers.

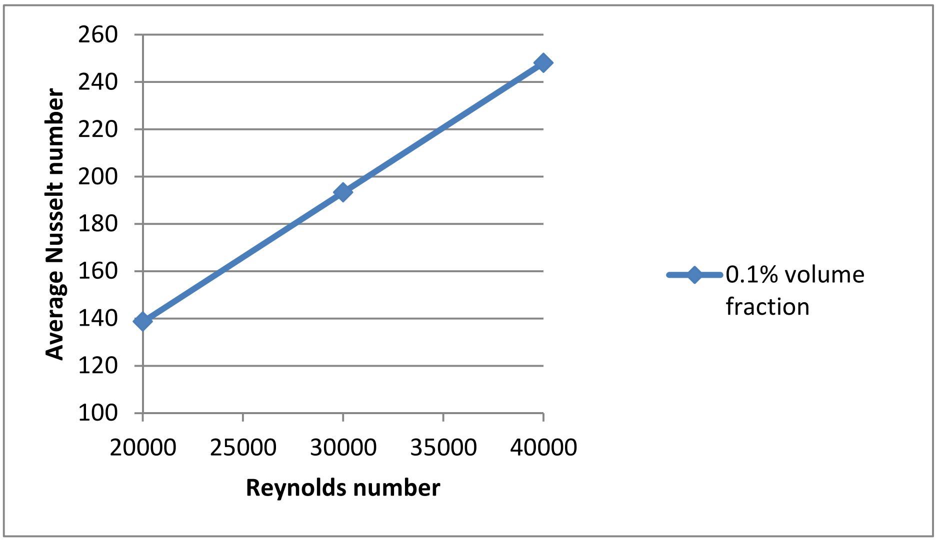

Figure 4: Nusselt number coefficient against volume fraction for Reynolds numbers 20 000 at 0.1% volume fraction.

According to Table 5, the values of the convective heat transfer coefficient and the Nusselt number for various volume concentrations of Ag/HEG hybrid nanofluid increased with respect

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to the Reynolds number. This can be seen in Figure 4 that at 0.1% of volume fraction, the increment of Nusselt number obviously influenced by Reynolds number. It was clearly shown in Figure 4 that there was a huge gap between the results obtained using 20 000 and 40 000 Reynolds number. This is because the higher value of Reynolds number will cause turbulence due to the greater velocity of nanoparticles which in turn leads to the enhancement of the heat transfer. Consequently, the Nusselt number increased with the increment of convective heat transfer coefficient.

However, at constant Reynolds number, both convective heat transfer coefficients and Nusselt number decreased gradually as the volume fractions of Ag/HEG hybrid nanofluid increased from 0.1% to 0.9%. This result contradicted to several researches that had been done on hybrid nanofluids where some researchers obtained an increment value for the convective heat transfer coefficient as well as the Nusselt number as the volume fraction increased. One of the reasons may due to different types of nanoparticle used in hybrid nanofluid to improve the heat transfer. Recently, there is no reliable information about the effects of using different hybrid nanoparticles on the enhancement of heat transfer of the base fluid. Therefore, more researches need to be done because the combinations and volume fraction of different materials of nanoparticles can affect the performance characteristics of various heat transfer equipment, especially the heat pipes.

3.1 Analysis of Problem in Ansys-Fluent

3.1.1 Validation

Comparison between theoretical calculations of Dittus-Boelter results compare to ANSYS-FLUENT calculations of Nusselt number coefficient for Reynolds numbers 20 000 and 40 000, respectively were tabulated below:

Table 6: Comparison Dittus-Boelter and Ansys-Fluent calculations

Volume fraction	DITTUS-BOELTER		ANSYS-FLUENT	
	Re=20 000	Re=40 000	Re=20 000	Re=40 000
0.1%	137.9004696	240.0986629	138.714946	248.152447
0.2%	137.6844211	239.7225006	138.489369	247.939044
0.3%	137.466805	239.3436091	138.356451	247.796979
0.5%	137.0268396	238.5775847	138.014258	247.159695
0.7%	136.5870728	237.8119063	137.695671	246.842282
0.9%	136.0522541	236.8807328	137.389461	246.034804

3.1.2 Mesh/Grid independent test

The grid independent test for the physical model performed to determine the most suitable size of the mesh faces. In this study, rectangular cells were used to mesh the surfaces of the wall and the surfaces of the gap as Figure 2. Grid independence was checked using different grid systems and two mesh faces were considered, 100×10 and 100×30. Two different mesh sizes with rectangular elements are applied in the grid test, to use wall Y+ as the appropriate near-wall treatment (wall functions modelling as k-ε model is used). This was achieved by refining the mesh, with particular attention to the near-wall region so as to achieve the desired wall Y+, i.e. the distance from the wall to the centroid of the wall-adjacent cells. It was observed that a

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grid of (100×30) has good agreement with the theoretical results and hence this model was considered as the optimum grid for carrying out all the analysis shown in Figure 5 as below.

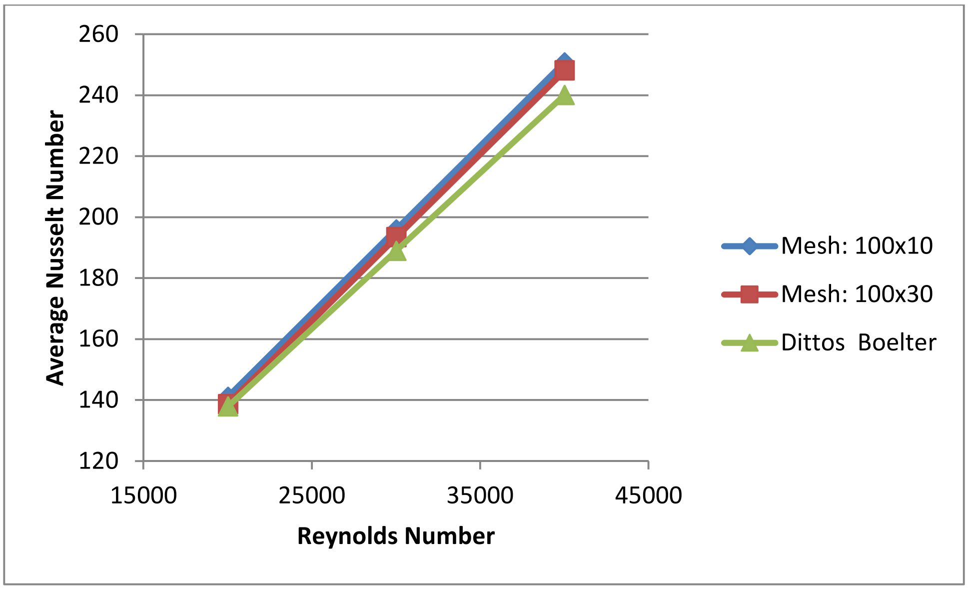

Figure 5: Optimum mesh grid size for Nusselt Number with Reynolds Number for Ag/HEG+water at 293K

XY plots will be performed for the Y+ values, centerline velocity in the axial direction and the fully developed velocity profile in the radial direction. Figure 8 represents the Y+ values comparison for the k-epsilon model for the two created meshes. Since Y+ was a dimensionless quantity there is no need to manipulate the column any further. However, the x-axis values were computed by dividing each value in the column for the axial pipe distance by the total length of the pipe in our case 0.8m. It can be seen that as the mesh is refined the Y+ values are getting closer to 1 signalling the 100×30 is the better mesh choice.

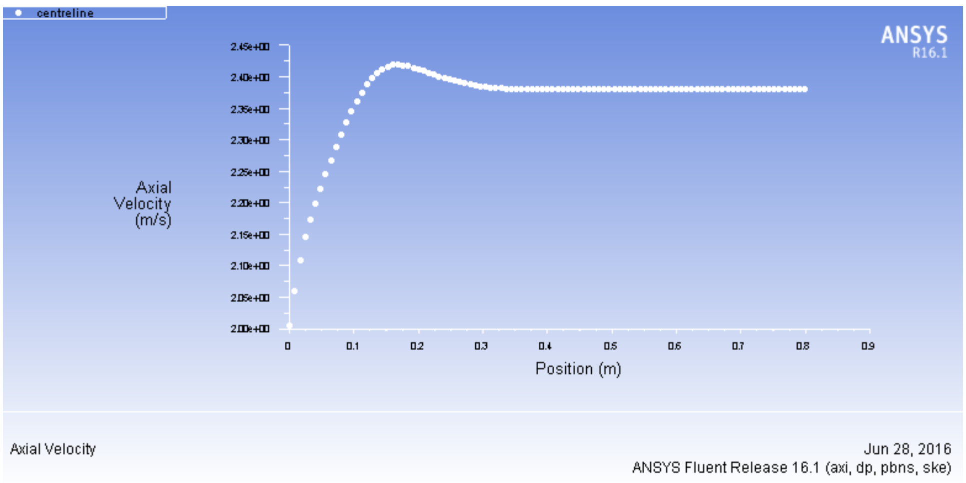

Figure 6: Velocity distribution along centreline of pipe for Ag/HEG hybrid fluid

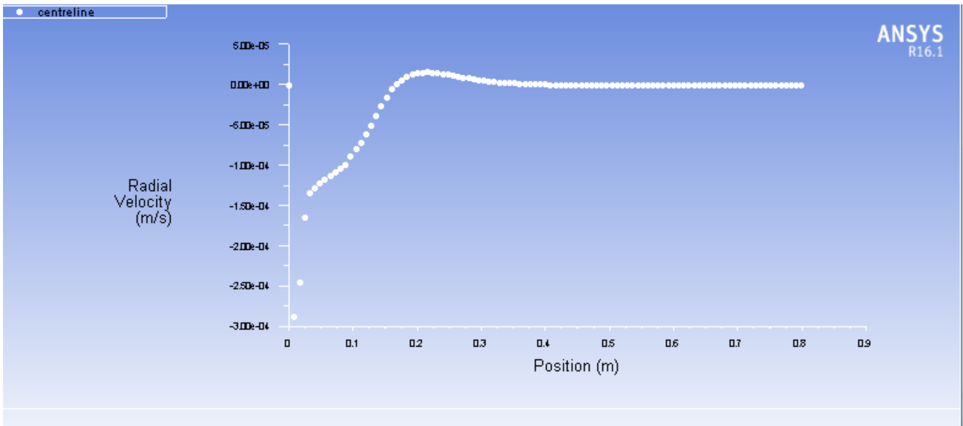

Figure 7: Fully developed velocity profile in the radial direction

4.0 CONCLUSION

In the present work, the modified original properties of pure water with combination of two types of nanoparticles (Ag and HEG) have increased their thermophysical properties totally. The enhancements of density, specific heat, thermal conductivity and viscosity depend on the volumetric concentration. CFD simulations were carried out for that problem by using commercial CFD software ANSYS 16.0. CFD analysis of enhancement heat transfer of different volume fractions for improving heat transfer in horizontal tube has been carried out with boundary conditions such as inlet velocity and temperature and pressure outlet defined with constant heat flux. Then, heat transfer analysis for hybrid nanofluids flowing through a circular pipe was done by calculation of convective heat transfer coefficient and Nusselt number at the specified conditions were studied. From numerical simulation results, convective heat transfer coefficient (h) and Nusselt number (Nu) for the straight pipe was found to be varied from 8260 to 14919 and 137 to 248 at the Reynolds number 20 000 and 40 000, respectively. Meanwhile, results revealed by carrying out CFD simulation and theoretical calculation were validated using Dittus-Boelter correlation.

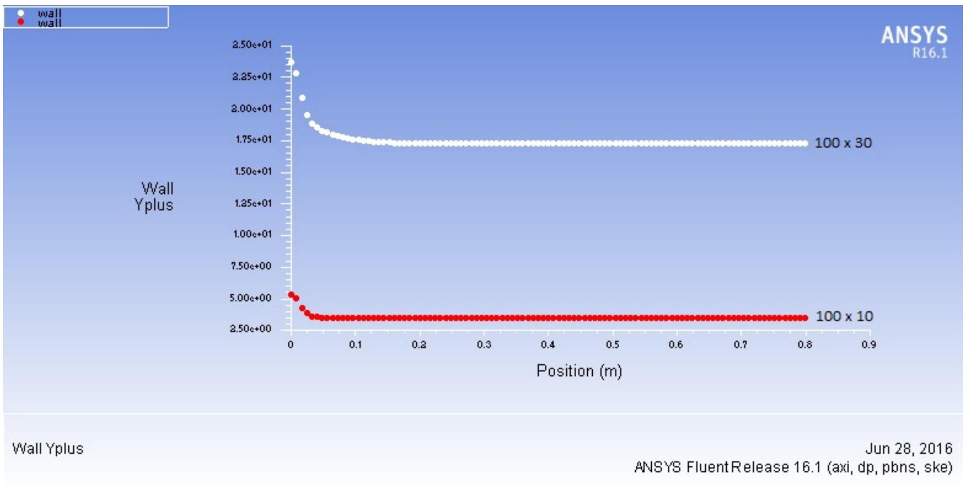

Figure 8: Y+ values comparison for the k-epsilon model of mesh 100×10 and 100×30

It can be concluded that these correlations give an error well within the range 0.6%. There are many reasons which contribute to the errors. The heat loss does account for errors but the value of heat loss is negligible as compared to total heat flux. Another reason is correlation results must be adequate but in this current study, it is insufficient because this has been taking the property of hybrid nanofluids at mean temperature of inlet and outlet considered zero temperature. However, at constant Reynolds number both convective heat transfer coefficients and Nusselt number decreased as the volume fractions of Ag/HEG hybrid nanofluid increased from 0.1% to 0.9%. On the other hand, [36] found experimentally that the presence of nanoparticles (Al2O3 and CuO) in water based nanofluids inside a horizontal cylinder decreased natural convective heat transfer coefficient with an increase in the volume fraction of nanoparticles, particle density as well as the aspect ratio of the cylinder. [37] have also reported experimentally that natural convective heat transfer coefficient decreases systematically with an increase in nanoparticle concentration, and the deterioration was partially attributed to the higher viscosity of nanofluids. [38] performed natural convection experiments with Al2O3 microparticle (~250 nm) aqueous suspensions in thin enclosures. Their results seem to indicate that the particles have a negligible effect on the Nusselt number values for a vertical enclosure. However, for horizontal enclosure, there was a decrease in Nusselt number compared to presence of pure water at lower Rayleigh numbers and higher particle concentrations. The authors attributed this anomalous behavior to sedimentation. As a result of the review of the nanoparticles impact, it is also found that the presence of nanoparticles is a key factor which is capable of changing the flow and heat transfer capability of the base fluids.

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