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Turbulent Force Convective Heat Transfer of Hybrid Nano Fluid in a Circular Channel with Constant Heat Flux

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Abstract – *In this paper, silver/graphene (Ag/HEG) nano-fluid and copper oxide/graphene (Cuo/HEG) nano-fluid, where numerically studied in a circular tube subjected to constant heat flux. The hybrid nano-fluids where simulated over the range of Reynolds number of 10,000 to 120,000 with volume fraction of 0.4% to 1%. In this study, a remarkable improvement was observed in using the hybrid nano fluid due to synergistic effect. At 1% volume fraction of Ag/HEG 34.34% and 38.72% enhancement was recorded at Reynolds number of 60,000 and 40,000 respectively. 35.95% and 43.96% were obtained for CuO/HEG at the same volume fraction and Reynolds number respectively. The friction factor slightly increases with increase in volume fraction.* ***Copyright © 2016 Penerbit Akademia Baru - All rights reserved.***

Keywords: Hybrid Nano Fluid, Reynolds Number, Volume Fraction

1.0 INTRODUCTION

With the development of modern technology, there is high need to develop efficient way of regulating heat content in many engineering equipment such as heat exchangers, transformers, electronic devices, auto mobile engines and diesel generators. Low thermal conductivity of convectional heat transfer fluid is a primary limitation in efficient heat dissipation of devices that utilize these fluids as working fluids. To overcome the limitations stated above, a lot of research has been conducted to increase the thermal carrying capacity of convectional heat transfer fluid and one of the ideal ways is to disperse nano-size particles in to the base fluid [1].

Nano-fluids are engineered colloids prepared by dispersing solid particles of 10 – 100nm in a base fluid with the aim of impoving the thermal characteristics of the base fluid [2]. In extension a hybrid nano-fluid is a new type of nano-fluid that is believed to give better heat transfer performance as compared to conventional heat transfer fluid and nano-fluid containing single nano-particle. Hybrid nano fluids are stable colloidal suspension of nano-sized solid particles prepared by dispersing composite nano-powder in a base fluid such as water, oil and ethylene glycol with or without surfactant.

Maxwell suggested that thermal conductivity of fluids could be improved by dispersing solid particles with a high thermal conductivity [3]. Metal particles where observed to possess high thermal conductivity as a result of small inter-atomic space which helps easy conduction. The

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important parameters which attracts researcher in to nano-fluids are high thermal conductivity and heat transfer coefficient. These characteristics depends on a number of factors such as nano-particles type, nano-particles size, stability, base fluid type etc. [4]. Previous experiments have shown that nano-fluids have high conductive and convective heat transfer capability in comparison to the base fluids and the secret behind these characteristics are the stability of the fluid and its high thermal conductivity [5]. Choi [6], Eastman [7], Xuan and li [8]conducted experimental study on different type of nano-fluid and obtain a remarkable improvement in thermal conductivity. Li et al. [9], Park et al. [10], Kang et al. [11] have reported a good thermal conductivity of nano-fluid containing silver nano-particles. In Jha and Ramaprabhu [12] a better thermal conductivity was reported by decorating silver nano-particles with multi-walled carbon nano-tube.

Graphene discovered by Geim and Noveselev [13], is the most widely used nano-material as a result of its excellent properties such as high thermal conductivity, high electrical conductivity, high mechanical strength, high mobility of charge carriers, extremely large surface area, etc. [14]. It's easy to synthesize, and the cost of synthesis is cheaper compared to other nano-materials. Researcher have observed that the property of graphene slightly vary due to method of preparation and number of graphene sheet present. Some of the methods used in the synthesis of graphene include but not limited to micromechanical cleavage [14], chemical vapor deposition [15], exfoliation of graphite oxide [16].

In this study the effect of using silver/graphene (Ag/HEG) and copper oxide/graphene (Cuo/HEG) nano-fluid in a circular tube subjected to constant heat flux under turbulence regime is investigated. The thermo physical properties of the hybrid nano-fluid were obtained using correlation. The Reynolds number of 10,000 to 120,000 where used whereas the hybrid nano fluids volume fractions are 0.4% to 1%.

2.0 MATHEMATICAL FORMULATION

2.1 Statement of Problem

In this paper, the geometry is 2D circular channel with length and hydraulic diameter of 0.8 m and 0.01 m, respectively as shown in Figure 1. A constant heat flux 1000W/m^2 was applied to the top wall whereas axisymmetic is set at the bottom wall. Ag/HEG and Cuo/HEG nano-fluids with volume fraction of 0.4% to 1% were used as the working fluids. Reynolds numbers are ranging from 10,000 to 120,000. In this study, the hybrid nano fluid is assumed to be, single phase fluid, incompressible and Newtonian fluid with constant thermo physical properties.

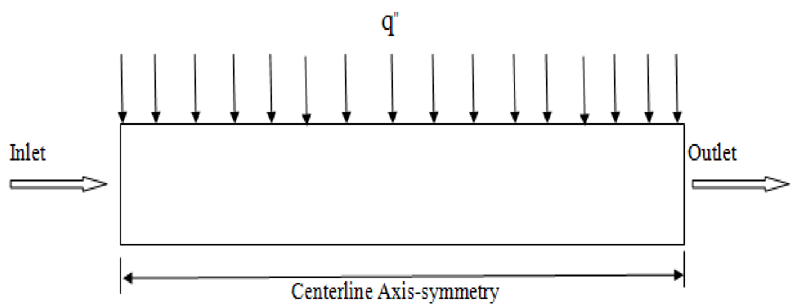

Figure 1: Geometry of a the model

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2.2 Governing Equations

Continuity:

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

Momentum:

$$\frac{\partial}{\partial xj}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u'_i u'_j}\right) \tag{2}$$

Energy:

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

$$\Gamma = \frac{\mu}{\Pr}, \qquad \Gamma_t = \frac{\mu_t}{\Pr_t}$$

Where Γ and Γ_t are molecular viscosity and eddy viscosity.

2.3 Thermo-Physical Properties of Hybrid Nano-Fluids

The working fluids used in this simulation are Ag/HEG and CuO/HEG nano-fluid with volume fraction of 0.4% to 1%. It is assumed that the hybrid nano-fluid is in thermal equilibrium with zero relative velocity. The thermo physical properties of hybrid nano-fluid are calculated using the relations below:
Density:

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

Specific heat capacity:

$$(c_p)_{hnf} = \frac{(1-\phi)(\rho c_p)_{bf} + \phi(\rho c_p)_{hnp}}{\rho_{nf}} \tag{5}$$

Thermal Conductivity:

$$k_{hnf} = k_{bf}\left[\frac{k_{np} + 2k_{bf} - 2\phi(k_{bf} - k_{np})}{k_{np} + 2k_{bf} + \phi(k_{bf} - k_{np})}\right] \tag{6}$$

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Dynamic Viscosity:

$$\mu_{hnf} = \left(1 + 2.5\phi + 6.17\phi^2\right) \tag{6}$$

2.4 Turbulence Model

Realizable k-ε model was chosen in this simulation as a result of the model differs from the standard k-ε model in two important ways. Firstly, it contains a new formulation for the turbulent viscosity and secondly a new transport equation for the dissipation rate, ε, that has been derived from an exact equation for the transport of the mean-square vorticity fluctuation. The model satisfies certain mathematical constraints on the Reynolds stresses, which are consistent with the physics of turbulent flows [17].

Realizable $k\!-\!\varepsilon$ model:

Transport Equations

The modelled equation of the steady turbulent kinetic energy (TKE) k, is written as [18]

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon + S_k \tag{7}$$

Similarly the steady dissipation rate of turbulent kinetic energy (TKE), ε is given as follows [18]:

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho\varepsilon \upsilon_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho c_1 s\varepsilon - \rho c_2 \frac{\varepsilon^2}{k + \sqrt{v\varepsilon}} + s\varepsilon \tag{8}$$

$$C_1 = \max\left[0.43, \frac{\eta}{\eta + 5}\right], \quad \eta = S\frac{k}{\varepsilon}, \quad S = \sqrt{2S_{ij}S_{ij}}$$

In these equations, G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, and it is calculated as;

$$G_k = -\rho\overline{u_i' u_j'}\frac{\partial u_j}{\partial x_i} \tag{9}$$

To evaluate G_k in a manner consistent with the Boussinesq hypothesis,

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

Where S is the modulus of the mean rate-of-strain tensor, defined as:

$$S = \sqrt{2S_{ij}S_{ij}} \tag{11}$$

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The eddy viscosity μ_t and C_μ are computed from

$$C_\mu = \frac{1}{A_0 + A_s \frac{kU^*}{\varepsilon}} \qquad (12)$$

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

The model constants are

$C_{1\varepsilon} = 1.44$, $C_2 = 1.9$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.2$

3.0 RESULTS AND DISCUSSION

3.1 Grid Independent

The grid generation process consists of subdividing the domain into small cells. In this simulation, non-uniform grid size was chosen. The cell size was made finer near the tube wall in order to capture small fluctuation of flow variable near the tube wall. Number of cell size tested where in the range of 4920 to 120150. The cell size of 104130 was chosen in order to save computational time.

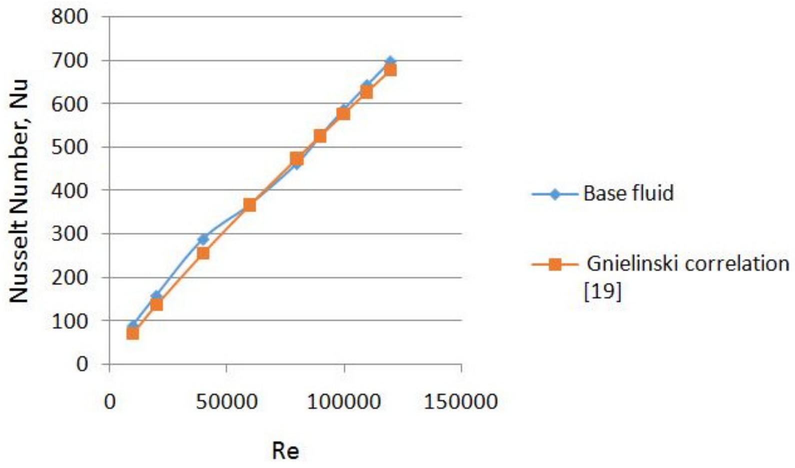

Figure 2: Comparison of Nusselt for the present result and Gnielinski [19].

3.2 Validation

The validation of the numerical setup was done by firstly circulating the base fluid into the test section. The average Nusselt number and friction factor obtained for this study is compared with Gnielinski [19] and Blausius [20] correlation. The percentage deviation between this simulation and Gnielinski correlation is 3% whereas for friction factor 2.8% was obtained in comparison with the Blausius correlation. This result indicates that the model is well designed and consequently, it can be used to estimate the heat transfer coefficient for the hybrid nano-fluids over wide range of volume concentrations.

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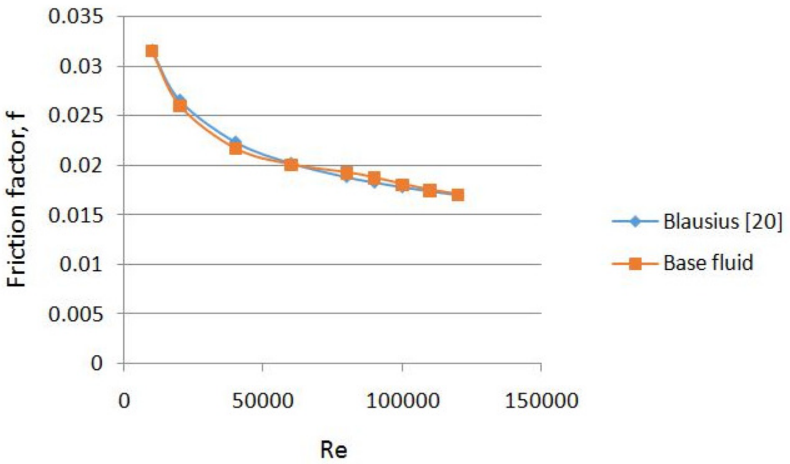
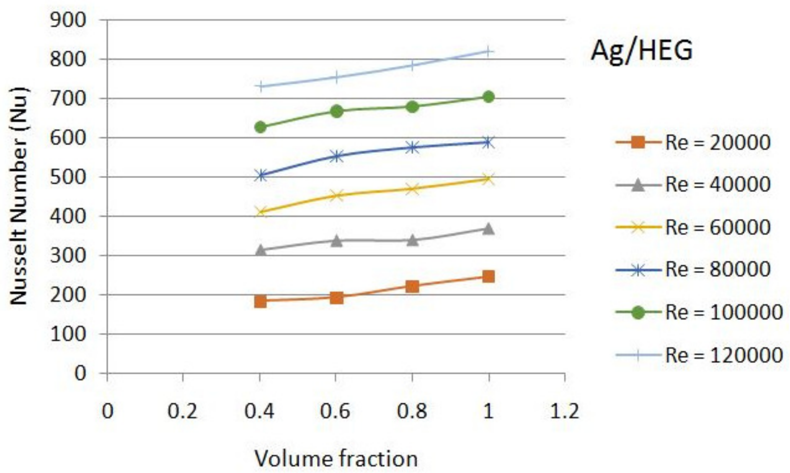


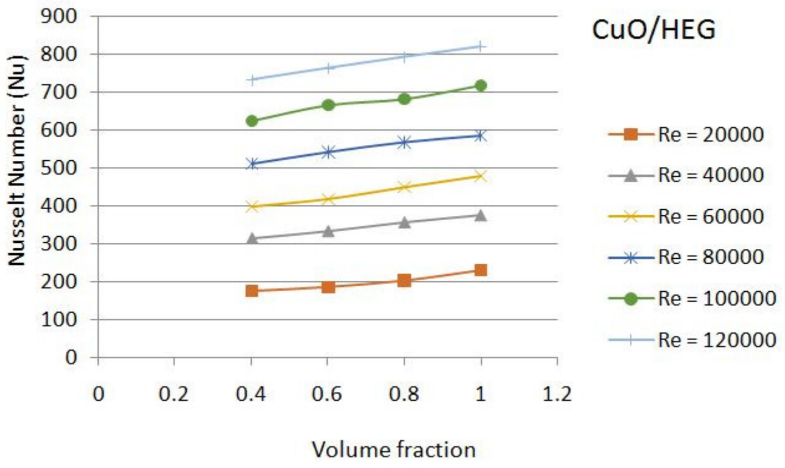
Figure 3: Comparison of friction factor for the present result and Blausius correlation [20]

3.3 Effect of Hybrid Nano-Fluids Volume Concentrations on Nusselt Number

The Nusselt number of Ag/HEG and CuO/HEG hybrid nano-fluids was observed to increase with increase in volume fraction. At 0.4% volume fraction, the improvement in Nusselt number for both the hybrid nano-fluids is slightly greater than that of the base fluid. 34.34% and 38.72% enhancement was obtained at ϕ =1% volume fraction of Ag/HEG at Re 60,000 and 40,000. 35.95% and 43.96% enhancement was obtained for the CuO/HEG at the same volume fraction and Reynolds number respectively. The enhancement was due to chaotic movement of the nano-particles in the mixture and with increase in volume fraction the frequency of lattice vibration increases, more particles take part in heat transport thereby enhancing the heat transfer process. Furthermore clustering of nano-particles in the base fluid with increase in volume fraction facilitates the heat transfer process.



(a)

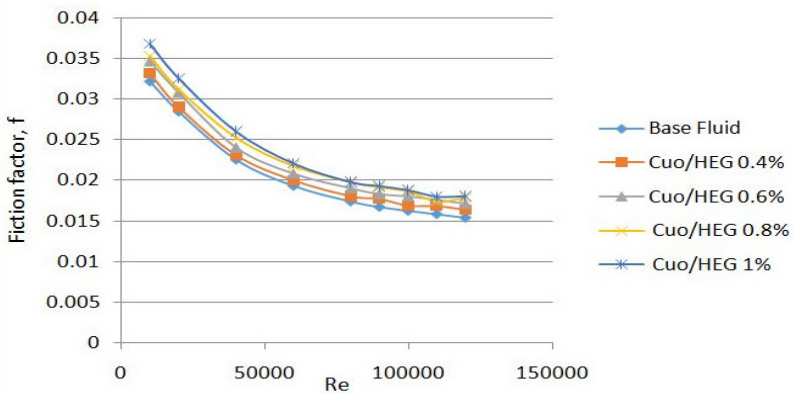


(b)

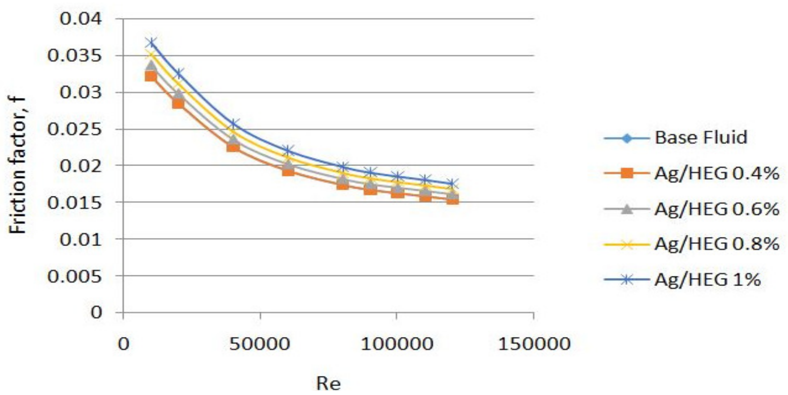
Figure 4: Nusselt number against volume fraction for different Reynolds numbers; (a) Ag/HEG; (b) CuO/HEG nano-fluid.

3.4 Effect of Hybrid Nano-Fluid Volume Concentration on the Friction Factor

The friction factor of Ag/HEG and CuO/HEG nano-fluid were found to be slightly greater than that of the base fluid at volume fraction of 0.4%. It was observed that, with increase in volume fraction, the friction factor increases. This is due to an increase in fluid viscosity. At 0.4% volume fraction, the value fluctuates between 1.9 and 3.6 while at 1%, a maximum value of 17.4 and 14.4 was recorded for CuO/HEG and Ag/HEG nano-fluid respectively.



(a)



(b)

Figure 5: Friction factor against Reynolds number (a) Cuo/HEG (b) Ag/HEG nano-fluid.

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4.0 CONCLUSION

In conclusion, Ag/HEG and CuO/HEG nano-fluid have shown a remarkable enhancement in heat transfer performance. The Nusselt number of the hybrid nano-fluids increases with increase in Reynolds number and volume fraction. At 0.4% volume fraction the Nusselt number is slightly greater than that of the distilled water. At 1% volume fraction of Ag/HEG 34.34% and 38.72% enhancement was obtained at Reynolds number of 60,000 and 40,000 respectively. 35.95% and 43.96% was obtained for CuO/HEG at the same volume fraction and Reynolds number respectively. Friction factor was found to increase with an increase in volume fraction. At low volume fraction, it fluctuates between 1.9 and 3.6. At higher volume fraction, the fluctuation increases with a maximum value of 14.4.

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