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TURBULENT CONVECTIVE HEAT TRANSFER OF GRAPHENE OXIDE NANOFLUID THROUGH HORIZONTAL TUBE

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ABSTRACT

The aim of this paper is to study experimentally the forced convective heat transfer behaviour of Graphene oxide nanofluids inside a horizontal circular tube subject to a constant and uniform heat flux at the pipe wall. Graphene oxide (GO) nanoparticles were synthesized by the modified Hummers method. GO particles dispersed in pure water are used as the working fluid. Consideration is given to the effect of the inclusion of nanoparticles on heat transfer enhancement, thermal conductivity and viscosity in the turbulent flow. Four volume fractions of 0.05%, 0.10%, 0.15% and 0.20% are tested for GO/water nanofluids. The heat transfer within the flowing nanofluids were measured and compared with the corresponding data for base fluid (pure water). The Reynolds number is ranged from 3000 to 10000. It is found from the study that (i) heat transfer enhancement is caused by suspending nanoparticles and becomes more pronounced with an increase in the particle volume fraction, (ii) the nanofluids have substantially higher value of Nusselt number than the same liquids without nanoparticles and the Nusselt number of nanofluids increase in accordance with an increase of the Reynolds number, (iii) heat transfer coefficient of nanofluid increase with Reynolds number, (iv) the viscosity, thermal conductivity, and electrical conductivity of Graphene oxide (GO) nanofluid increase in accordance with an increase of the volume fraction.

KEYWORDS: Nanofluid, Volume Fraction, Heat Transfer, Graphene oxide

INTRODUCTION

Conventional fluids such as deionized water (DI), ethylene glycol (EG) and transformer oil used as heat transfer fluids for most industries (power generation, automobiles, air conditioning, microelectronics and cooling system). Fluid including nanoparticles is referred to as nanofluid, which is a term proposed by Choi [1]. The term ‘nanofluid’ refers to a two-phase mixture with its continuous phase being generally a liquid and the dispersed phase constituted of ‘nanoparticles’ i.e., extremely fine metallic particles of size below 100 nm. Heat transfer through fluid is mainly convection dominated. Nevertheless, the coefficient of convective heat transfer strongly depends on the thermal conductivity of the fluid. To improve thermal conductivity, suspension of solid particles in the fluid medium is an effective strategy as thermal conductivity of solids is an order of magnitude greater than that of fluids [2, 3].

With an effect of Al_2O_3/water nanofluids in convective heat transfer, Heris S. et al. [4] studied laminar flow forced convective heat transfer inside a circular tube and found that heat transfer coefficient increases by increasing the concentration of nanoparticles in nanofluid. Teng T. et al. [5] examined the effect of particle size, temperature and weight fraction on the thermal conductivity ratio, and concluded that the weight fraction and temperature carry a proportional relationship with the thermal conductivity ratio and shrinkage of particle size enhance the thermal conductivity ratio of nanofluid. Prajapati O. and Rajvanshi A. [6] investigated experimentally the turbulent flow forced convection heat transfer of nanofluid inside an annular tube with variable wall temperature, and The Nusselt numbers of nanofluid were obtained for various heat flux, Reynolds numbers and nanoparticle concentrations at atmospheric pressure. Heris S. et al. [7] presented study convective heat transfer heat transfer through square cross-section duct under constant heat flux in laminar flow, a square cross section duct has the advantage of lower pressure drop, but it has a lower heat exchange rate than that of a circular duct.

Khedkar R. et al. [8] studied the effect of CuO nanoparticles on the thermal conductivity of base fluid, the enhancement was investigated with regard to various factors; concentration of nanoparticles, types of base fluids (water and monoethylene glycol), sonication time and settlement time. Torii S. and Yoshino H. [9] presented study of the forced convective heat transport phenomenon of nanofluids (Al_2O_3/ethylene-glycol and CuO/ethylene-glycol) inside a horizontal circular tube subjected to a constant and uniform heat flux at the pipe wall, and showed effect of volume fraction and Reynolds number on thermal transport phenomena. Heat transfer enhancement is also proposed by Asirvatham L. et al. [10] who used copper nanoparticles.

Using graphene nanofluids, Sadeghinezhad E. et al. [11] performed experimental and numerical studies on the turbulent heat transfer of nanofluids in a horizontal stainless steel tube subjected to a uniform heat flux at its outer surface. Yu W. et al. [12] studied the effect of graphene nanosheets on thermal conductivity of the base fluid and estimated the thermal conductivity of graphene and graphene oxide. Ghozatloo A. et al. [13] showed study of convective heat transfer behavior of nanofluids through the shell and tube heat exchanger under laminar flow. Hajjar Z. et al. [14] measured thermal conductivity of graphene oxide nanofluids with different concentrations and temperature.

The purpose of this study is to disclose the thermal fluid flow transport phenomenon of nanofluid in a circular tube by measuring thermal conductivity, effective viscosity, and the convective heat transfer performance for various concentrations. Emphasis is placed on the effects of the suspension with the particles, i.e., the volume fraction of particles on heat transfer performance in the turbulent flow region. Here, pure water is employed as basic fluid and graphene oxide/water nanofluids are tested in the present study.

MATERIALS AND METHODS

Materials

Preparation of Graphene Oxide

Graphite fine powders (45 μm) was purchased from Wako pure chemical industries (Japan), concentrated sulfuric acids (H_2SO_4), sodium nitrate ($NaNO_3$), potassium permanganate ($KMnO_4$), hydrogen peroxide (30% H_2O_2), hydrochloric acid (5% HCL) and deionized water were used throughout the experiment. Graphene oxide (GO) was synthesized from natural graphite powder by a modified Hummers method [15]. Used 5g graphite powder and 2.5g sodium nitrate $NaNO_3$ were added to 115 ml concentrated sulfuric acid H_2SO_4 with mechanical stirring for 1 hr. Then, in a bottom-round flask (500 mL) with ice-water bath, 15g potassium permanganate $KMnO_4$ was added slowly to keep the temperature of the suspension lower than 20 ºC. with continuously stirring until a uniform liquid paste was formed (40 min.). Next, the flask was placed in a 35 ℃ water baths with stirring e for 60 min.. At room temperature 230 ml DI water was added gradually, and rapid stirring was restarted to prevent effervescing (30 min.). Next, the flask was placed in a 90-95 ℃ oil bath and stirred the mixture for 30 min. without boiling, 400 ml and 50 ml of 30% H_2O_2 was added to the mixture with continuously stirring for I hr. if the synthesized succeed the colour change to yellow colour. 100 ml 5% HCL was added in succession. The suspension was then repeated washing and centrifugation (10000 rpm) to remove impurities. The centrifugation repeated by using distilled at least twelve times to remove the acids and improve pH value, and finally it was dried at 50 ºC.

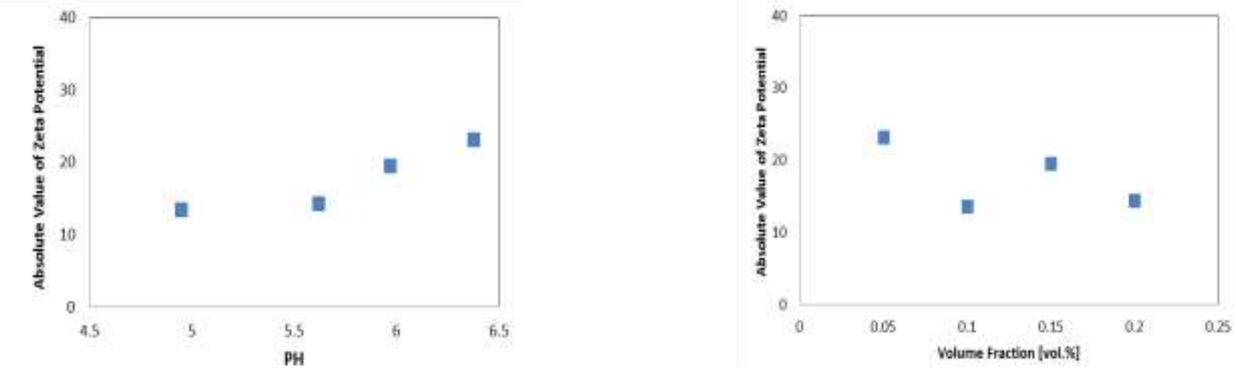
Nanofluids

A two steps method was used to prepare the graphene oxide nanofluids [16]. A graphene oxide nanoparticles was dispersed in pure water. The mixture was sonicated by using an ultrasonic washing machine (Tokyo, Fu-22H).

Four volume fractions was prepared for graphene oxide nanofluids 0.05%, 0.1%, 0.15% and 0.2% with different pH values 6.38, 4.95, 5.97 and 5.62 respectively.

Stability of Nanofluid

In terms of the colloidal stability or stable nanoparticles-dispersion, zeta potential is a key parameter. Zeta potential is the potential on the surface of a particulate. The repulsion between particles becomes strong and the stability of particles increases as the absolute value of zeta potential increases. On the contrary, it become easy to condense particles as zeta potential becomes close to zero. Therefore zeta potential can use as an index of the stability of suspension. Zeta potential is measured by Otuka Densi ELSZ. ELSZ measure zeta potential and particle diameter by electrophoresis light scattering method. Change of the zeta potential of particle by change of the value of pH of nanofluid is shown in a Figure 1. The absolute value of the zeta potential of nanofluid becomes large as the value of pH of nanofluid becomes large.



(a) Zeta potential as function of PH value *(b) Zeta potential as function of volume fraction*

Figure 1: Zeta potential of nanofluids as a function of PH value and volume fraction

Nanoparticle suspensions are far more stable than suspensions of larger particles [17]. One of the few methods of assessing nanofluid stability is to visually inspect fluid sample over an extended period of time. Figure 2 depicts the picture of GO nanofluids after 90 days.

One observes that no concentration gradient appears in nanofluids. It implies long-term degradation in thermal performance due to setting inside the cooling system's reservoir. The nanofluids with concentrations 0.1% and 0.2% were less stability than other concentrations, these agree with the values of zeta potential (Figure 1, (b)). Change of the zeta potential of particle by change of volume fraction of nanofluid is shown in a Figure 1, (b).

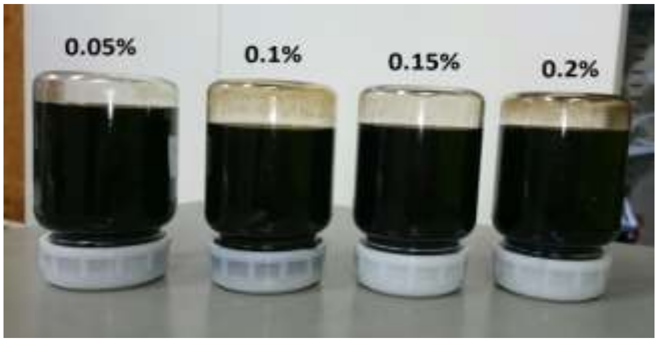


Figure 2: Nanofluids after 90 days

Experimental Apparatus

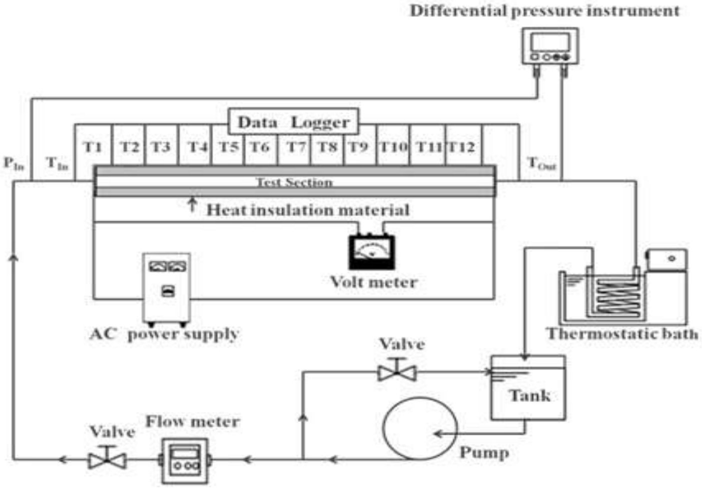


Figure 3: Schematic of Experimental Apparatus

The experimental system used for measuring the convective heat transfer characteristics of nanofluids flowing in a tube is shown schematically in Figure 3. It consisted of a flow loop, a heat unit, a cooling part, and a measuring and control unit. The flow loop included a pump with a built-in flow meter, a collection tank and a test section. A straight stainless tube with 2000 mm length, 3.96 mm inner diameter, and 0.17 mm thickness was used as the test section. Two electrodes for the direct electric current heating are installed at both ends. The power supply is adjustable. The test tube is surrounded by a thick thermal insulation material to obtain a constant heat flux condition along the test section. The twelve K-type thermocouples, which are welded on the outer surface of the test tube at axial positions, are used to measure the local wall temperature along the heated surface of the tube, and the other thermocouples are inserted into the flow at the inlet and outlet of the test section to measure the bulk temperature of working fluid. In addition, the inlet and outlet was connected with a differential pressure instrument to measure the pressure drop at test section.

RESULTS AND DISCUSSION

Thermal conductivity

Thermal conductivity is one of the most effective parameters which has significant effect on enhancement of heat transfer coefficient. The effective thermal conductivity of nanofluids is measured with the aid of a KD2 thermal property meter (Labcell Ltd, UK), which is based on the transient hot wire method. Here the thermal conductivity of the nanofluids and base liquid (pure water) are measured at 298 K.

For reference, the prediction which is obtained by the Hamilton and Crosser equation [18] (H-C equation) is superimposed in the Figure 4 as straight lines. This equation is a classical formula to predict thermal conductivity of solid-liquid mixture.

$$\frac{k_{nf}}{k_f} = \frac{k_p + (n-1)k_f + (n-1)\,(k_p - k_f)\phi}{k_p + (n-1)k_f - \,(k_p - k_f)\phi} \qquad (1)$$

Where k_f is the thermal conductivity of the base fluid, k_p is the thermal conductivity of solid particles, k_{nf} is the thermal conductivity of nanofluid, ϕ is the volume fraction of particles and n is the shape factor (n = 3 for spherical shape).

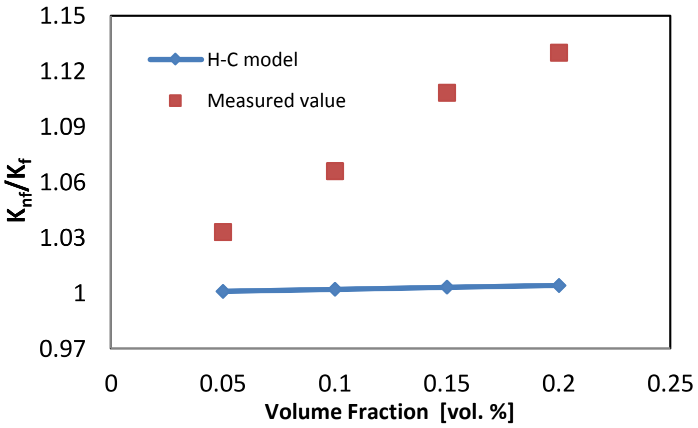


Figure 4: Thermal conductivity versus volume fraction.

The effective thermal conductivity increases with increasing the volume fraction and the measured thermal conductivity of nanofluids are much higher than that of prediction. This is probably because these traditional models don't account for various parameters like particle size, Brownian motion, nanolayering and effect of nanoparticles clustering, which are important to nanoparticles in nanofluids [8].

Electrical conductivity analysis

Though important, the electrical conductivity of nanofluids has not yet been widely studied as compared to thermal conductivity. Electrical conductivity was also measured for four volume fractions of GO nanofluid. Figure 5 shows electrical conductivity for four different volume fractions at room temperature. The figure shows the electrical conductivity also enhanced by increasing volume fraction.

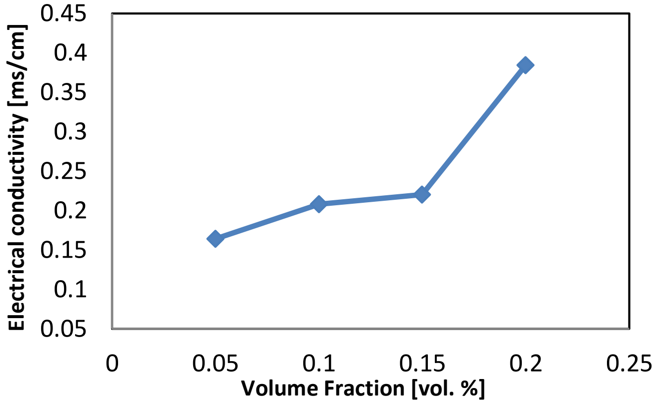


Figure 5: Electrical conductivity of GO nanofluid with different volume fraction

Viscosity of nanofluids

The viscosity of nanofluids is measured with the use of a rotary viscometer (BROOKFIELD Co. DVII+ProCP). The measurement is carried out at 298 K for the nanofluids of different concentrations. The viscosity of GO nanofluids as a function of shear rate shown in Figure 6. At given the viscosity of nanofluids increases with an increase in the particle concentration. From Figure 6 the viscosity of nanofluid increased rapidly with volume fraction. Therefore an increase of volume fraction of nanoparticle in nanofluid causes the reduction of flow property, and the high decrease in viscosity value of nanofluids is seen at shear rates lease than 370 s-1.

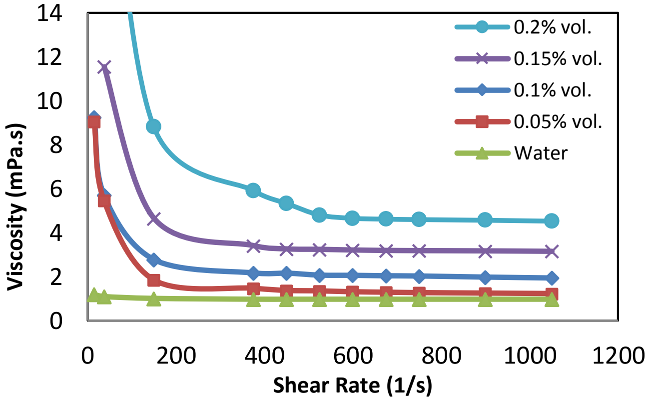


Figure 6: Nanofluids viscosity as function of shear rate

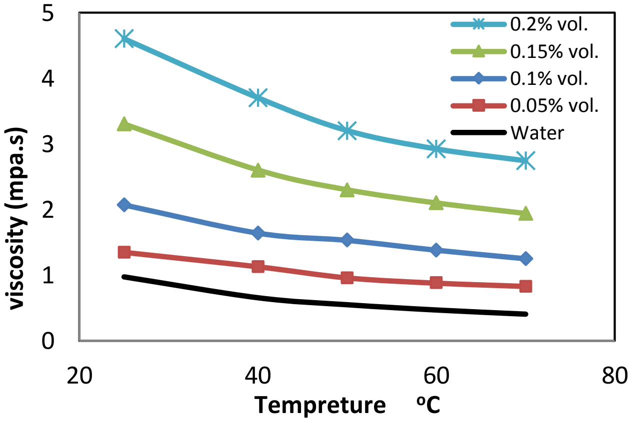


Figure 7: Viscosity versus concentration at various temperatures and constant shear rates

The temperature is the main effective parameter on viscosity of nanofluids. The viscosity of nanofluids reduced with the raising of temperature at constant shear rate as shown in Figure 7. Moreover, by rising the temperature, the nanoparticles are motivated more and create a more space for them. This is expected due to the weakening of the inter-particle and inter-molecular adhesion forces and similar trends are been observed for almost all other varieties of nanofluids [11].

Convective heat transfer

The heat transfer performance of the flowing nanofluids was defined in terms of the following convective heat transfer coefficient (h) and Nusselt number (Nu):

$$h(x) = \frac{q}{(T_w(x) - T_f(x))} \qquad (2)$$

$$Nu(x) = \frac{h(x)\,D}{\mathrm{k}} \qquad (3)$$

where x represents axial distance from the entrance of test section, q is the heat flux, Tw is the measured wall temperature , Tf is the fluid temperature , D is the tube diameter, and k is the nanofluids thermal conductivity. The fluid temperature in the test section was estimated by the following energy balance:

$$T_f(x) = T_{in} + \frac{q\ S(x)}{(\rho\, C_p\, U\, A)} \qquad (4)$$

where Cp is the heat capacity, A and S are the cross sectional area and perimeter of test tube, respectively, and Tin is the fluid temperature at the inlet.

Convective heat transfer of pure water

The experiments were initially conducted for pure water to validate the reliability of the experimental setup for calculating the Nusselt number and the convective heat transfer coefficient and for providing a baseline to compare the GO nanofluid data. The experimental results for water at uniform heat flux conditions were compared with the results from the standard equations, such as the Gnielinski, Petukhov, and Dittus-Boelter equations for turbulent flow (equations 5, 7 and 8 respectively) [11, 19].

$$Nu = \frac{(f/8)(Re - 1000)Pr}{1.07 + 12.7\sqrt{f/8}\ \ (Pr^{2/3} - 1)} \qquad (5)$$

Where Pr is the Prandtl numbers and f is the friction factor for a fully developed turbulent flow depends on Re and is calculated by Colebrook, predicted by equation [6]

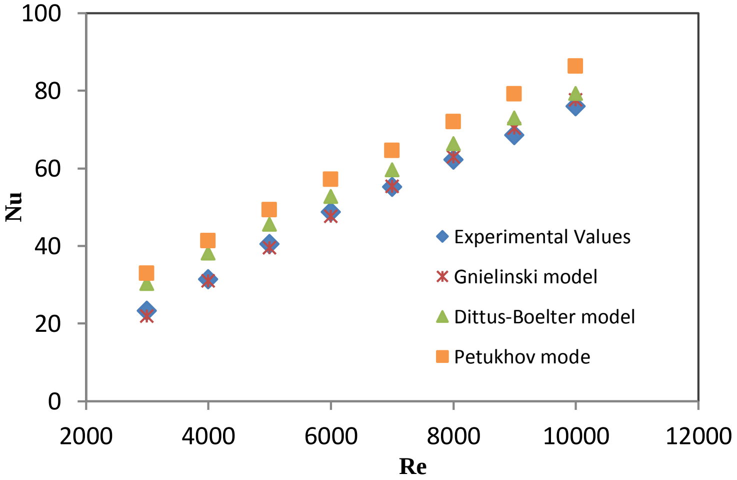
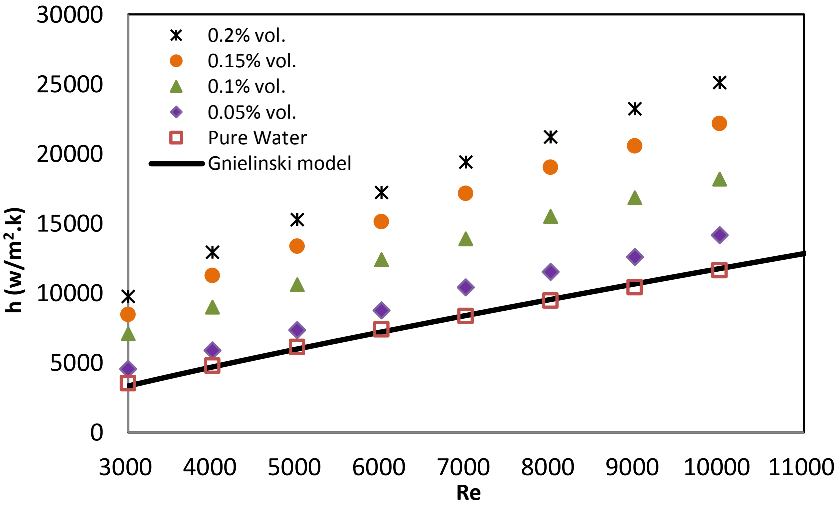


Figure 8: Comparison between the experimentally Nusselt number and theoretical equations

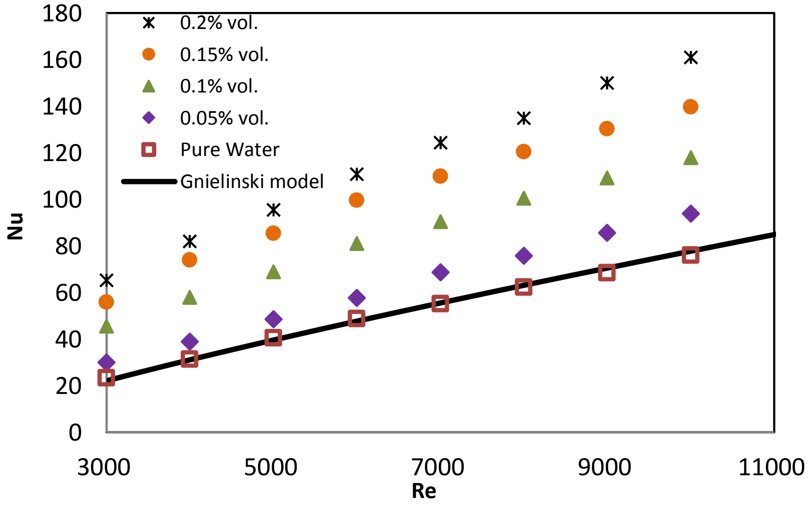
Convective heat transfer of Nanofluids

Four volumetric concentrations are tested of graphene oxide nanofluids, 0.05%, 0.1%, 0.15%, and 0.2% are tested in the present study. Figure 9 shows the effect of nanoparticles concentration on the local heat transfer coefficient (h) and Nusselt number (Nu) at various Reynolds numbers.

Figure 9 depicts the enhancement of heat transfer coefficient and Nusselt number with reference to base fluid (pure water). It can be seen that the heat transfer enhancement increases with increasing Reynolds number. This trend becomes larger with an increase in graphene oxide nanoparticles concentration. The convective heat transfer coefficient was increased up to 22%, 57%, 108% and 117% for GO particles concentrations of 0.05vol.%, 0.1vol.%, 0.15vol.% and 0.2vol., respectively, at Re=10000. Additionally, the Nusselt number (Nu) was increased up to 23%, 55%, 83% and 112% for the volume fractions of 0.05%, 0.1%, 0.15% and 0.2%, respectively, at Re=10000. The particle's Brownian motion, the thermo-physical properties (viscosity and thermal conductivity), and the specific surface area of nanoparticles were strongly affected in the convective heat transfer coefficient and Nusselt number [20]. Therefore, the higher concentration and Reynolds number increased the value of the convective heat transfer coefficient and Nusselt number. The enhanced heat convective performance of the GO nanofluid resulted from the higher thermal conductivity of the nanofluid and the disordered movement of the GO nanoparticles [20].



(a) Heat transfer coefficient



(b) Nusselt number

Figure 9: Effect of volume fraction on heat transfer enhancement

Previous studies claimed that the reasons for the heat transfer enhancement of the nanofluids included the mixing effects of the particles near the wall, particle migration, particle shape and rearrangement, the Brownian motion of the particles, the thermal conductivity enhancement, a reduction of the boundary layer thickness, and a delay in the boundary layer development [21, 22].

Figure 10 shows the enhancement of Nusselt number versus the volume fraction of the GO nanofluids at different Reynolds numbers. The largest enhancement of Nu which was 29%, 96%, 140%, and 181% for 0.05%, 0.1%, 0.15%, and 0.2vol.%, respectively, at Re=3000. Additionally, the enhancement increased with increase in particles concentration.

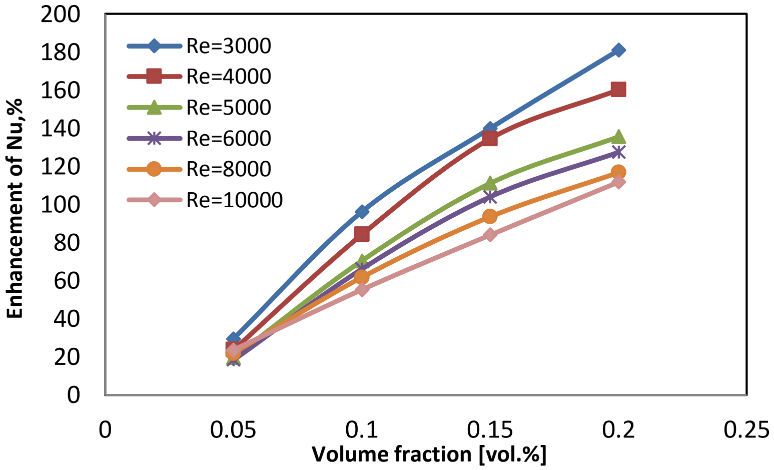


Figure 10: Enhancement of Nusselt number for different GO concentrations

CONCLUSION

Turbulent convective heat transfer rates of graphene oxide nanofluid with different concentrations were measured through a horizontal circular tube with uniform heat flux. Graphene oxide was synthesized by the modified Hammers method. The following conclusions are obtained:

- Adding graphene oxide nanoparticles to fluid can effectively increase the thermal conductivity ratio of the fluid, and the volume fraction carry a proportional relationship with the thermal conductivity ratio.
- Increase GO nanoparticles as the dispersed phase in water can significantly enhance the electrical conductivity.
- The relative viscosity of nanofluids increases with an increase in concentration of nanoparticles, and decreases with an increase in temperature.
- Heat transfer performance in the circular tube flow is amplified by suspension of nanoparticles in comparison with that of base fluid (pure water).
- The convective heat transfer coefficient and Nusselt number (Nu) increases with increasing both the Reynolds number and volume concentration.

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