Heat transfer and friction factor of composite TiO$_2$–SiO$_2$ nanofluids in water-ethylene glycol (60:40) mixture

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Abstract. The need for high performance of heat transfer has been evaluated by finding different ways to enhance heat transfer rate in fluid. One of the methods is the combination of two or more nanoparticles and it is known as hybrid/composite nanofluids which can give better performance of heat transfer. Thus, the present study focused on combination of Titanium oxide (TiO$_2$) and Silicon oxide (SiO$_2$) nanoparticles dispersed in 60:40 volume ratio of water and ethylene glycol mixture as the base fluid. The TiO$_2$-SiO$_2$ hybrid nanofluids are prepared using two-step method for different concentration of 2.0%, 2.5% and 3.0%. The experimental determination of heat transfer coefficients are conducted in the Reynolds numbers range from 2000 to 10000 at a bulk temperature of 30°C. The experiments are undertaken for constant heat flux in a circular tube. The Nusselt number of composite TiO$_2$-SiO$_2$ nanofluids is observed to be higher than the base fluid. The finding on heat transfer coefficient shows that 3.0% volume concentration is the highest enhancement with 45.9% compared with base fluid. While at concentration 2.0% and 2.5%, the enhancement recorded were 29.4% and 33.2%, respectively. The friction factor of nanofluids shows a decreased with the increasing of Reynolds numbers. However, the friction factor slightly increased with the increased of concentration.

1. Introduction

In recent decades, the researchers have been carried out on the development of convective heat transfer enhancement techniques. Previously, the used of conventional fluids such as water, ethylene glycol and oil as an additives is one of the techniques. However, the conventional fluids have relatively low thermal conductivity compared with solid particles. The addition of micron sized particles as an additive in a base fluid enhanced the heat transfer. Some disadvantages with micron-sized particles are large particles sized, its caused some problems such as clogging, settle down rapidly, erosion of the heat transfer device and pressure drop increases rapidly [1]. Therefore, nanofluids was introduced by Choi et al. [2] with size dimensions of less than 100 nm in a liquid.

According to Hatwar et al. [3], nanofluids have potential to be used for wide applications in industries such as microelectronics, transportations and manufacturing because of several factors which are (i) higher thermal conductivity and the larger surface area enhanced the heat transfer rate, (ii) pressure drop is minimum because of small size particles, (iii) most effective in rapid heating and cooling system [3]. A study was done by Azmi et al. [4] for the heat transfer coefficient and friction factor of single TiO$_2$ and SiO$_2$ water based nanofluids. To observe the heat transfer performance, the experimental study is conducted at working temperature of 30°C for volume concentration up to 3.0%.

The findings from the study showed that the TiO$_2$ nanofluids enhanced 26% in heat transfer coefficient at 1.0% concentration, while 33% enhancement for SiO$_2$ nanofluids at 3.0% concentration.

Recently, the researchers gave a comprehensive review about the combination of nanoparticles which are known as hybrid nanofluids [5-8]. Hybrid nanofluids is the combination of two or more dissimilar nanoparticles in the base fluid [9-12]. The aim of synthesizing hybrid nanofluids is to improve the properties and heat transfer of single materials. Suresh et al. [7] studied the effect of hybrid Al$_2$O$_3$-Cu water based nanofluids in heat transfer. The convective heat transfer increases with increasing of Reynolds numbers with 13.56% enhancement compared with pure water at volume concentration 0.1%. For the friction factor of hybrid nanofluids, it slightly higher compared with Al$_2$O$_3$/water single nanofluids. However, the friction factor correlations are in good agreement with the experimental data. Therefore, hybrid nanofluids have potential in improving the performance of heat transfer.

Since there are very limited information on convective heat transfer for hybrid nanofluids, the present study is conducted experimentally using hybrid TiO$_2$-SiO$_2$ nanofluids dispersed in 60:40 (water/EG) volume ratio for various concentration with bulk temperature of 30°C.

2. Methodology

2.1. Composite nanofluids preparation

The nanomaterials of TiO$_2$ and SiO$_2$ nanofluids were procured from US Research Nanomaterials, Inc. are used in the present study. The water/EG based nanofluids at volume ratio of 60:40 contained TiO$_2$ (40 wt.%) and SiO$_2$ (25 wt.%) nanoparticles with an average diameter of 50 nm and 22 nm, respectively. Equation (1) is used to convert the weight concentration to volume concentration. The single nanofluids are prepared separately at concentration of 3.0%. Both TiO$_2$ and SiO$_2$ nanofluids are then mixed together to produce composite nanofluids by mixing process for an hour. The composite nanofluids is then subjected to ultrasonic hemogenization for 2 hours. This to ensure the solution are stable. For record, the samples were found to be stable for more than a month. The dilution from 3.0% concentration to lower concentration 2.5% and 2.0% are prepared by adding the base fluid water/EG into the nanofluids using equation (2).

$$\phi = \frac{\omega \rho_{bf}}{\frac{\omega}{100}\rho_{bf} + \rho_p\left(1 - \frac{\omega}{100}\right)} \tag{1}$$

$$\Delta V = (V_2 - V_1) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

where ϕ is volume concentration in %; ω is weight concentration in %; ρ_{bf} is density of base fluid in kg/m^3; ρ_p is density of nanoparticles in kg/m^3; ΔV is additional volume in mL; V_1 is initial volume in mL; V_2 is final volume in mL; ϕ_1 is initial volume concentration in %; and ϕ_2 final volume concentration in %.

2.2. Thermo-physical properties

The density and specific heat of composite nanofluids for different concentrations are obtained from the solid-liquid mixture relation as shown in equations (3) and (4), respectively.

$$\rho_{hnf} = (1-\varphi)\rho_{bf} + (0.5\times\varphi)\rho_{p_1} + (0.5\times\varphi)\rho_{p_2} \tag{3}$$

$$C_{hnf} = \frac{(1-\varphi)\rho_{bf}C_{bf} + (0.5\times\varphi)\rho_{p_1}C_{p_1} + (0.5\times\varphi)\rho_{p_2}C_{p_2}}{\rho_{hnf}} \tag{4}$$

where ρ_{hnf} is density of hybrid nanofluids in kg/m^3; φ is volume fraction; ρ_{bf} is density of base fluid in kg/m^3; ρ_p is density of nanoparticles in kg/m^3; C_{hnf} is specific heat of hybrid nanofluids in J/kg.K; C_{bf} is specific heat of base fluid in J/kg.K; and C_p is specific heat of nanoparticles in J/kg.K.

The dynamic viscosity and thermal conductivity of TiO$_2$-SiO$_2$ nanofluids were measured for each concentration using Brookfield LVDV-III Ultra Rheometer and KD2 Pro Thermal Properties Analyzer. The thermo-physical properties for the TiO$_2$-SiO$_2$ nanofluids in water/EG mixture based are presented in Table 1.

Table 1. Thermo-physical properties of TiO$_2$-SiO$_2$ nanofluids at temperature 30°C.

Volume concentration, ϕ (%)	Density, ρ (kg m^{-3})	Viscosity, μ (kg m^{-1}s^{-1})	Thermal conductivity, k (W m^{-1}K^{-1})	Specific heat, C (J kg^{-1}K^{-1})
2.0	1098.78	3.06	0.450	3338.12
2.5	1109.63	3.09	0.456	3299.15
3.0	1120.48	3.12	0.467	3260.94

2.3. Experimental setup

As shown in Figure 1, the force convection experimental setup is integrated with a collecting tank, pump, flow rate meter, test section, differential pressure transducer, voltage regulator, chiller and the data logger. The 1.5 m length of copper tube as a test section (ID = 16 mm and OD = 19 mm) was insulated with fibre glass insulators. Six K-type thermocouples are fixed at different location on the body of tube wall (surface temperature) whereas the other two of thermocouples is placed at the inlet and outlet of test section to measure the temperature of working fluid (bulk temperature). A constant 7955 W/m^2 heat flux is supplied by the heater regulator, while the chiller is provided in the system to cool and maintain the bulk fluid temperature of 30°C. Thermocouple and pressure transducer are connected to the data logger (data acquisition system). The flow meter is used to measure the fluid flow rate in LPM by controlling the bypass regulator. The experimental value of Nusselt number for water/EG mixture base fluid is compared with single-phase liquid relation by Dittus-Boelter [13] as in equation (5) for the validation of experimental setup.

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \tag{5}$$

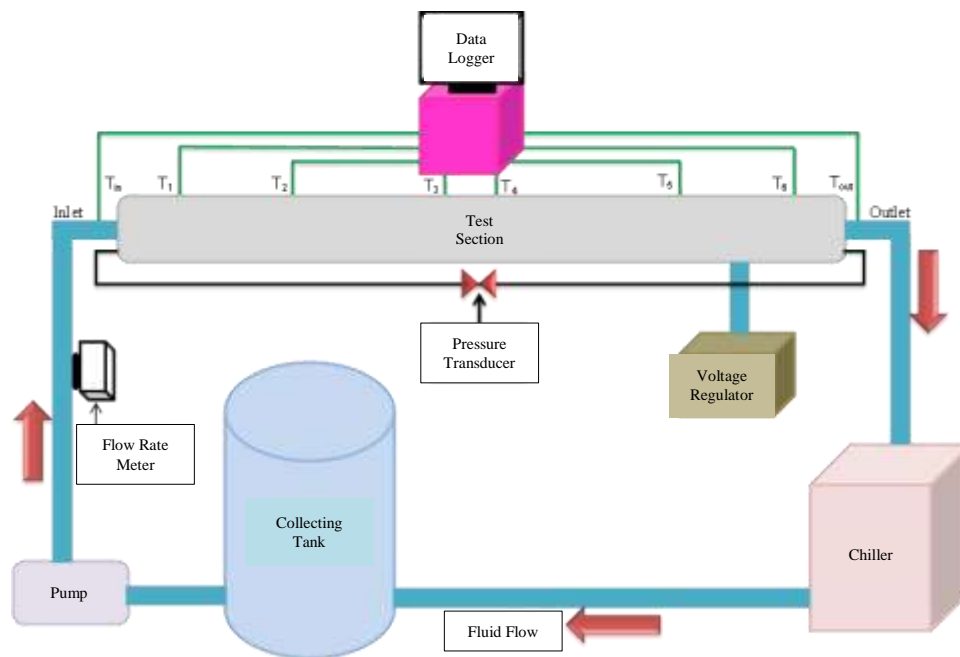where *Nu* is Nusselt number; *Re* is Reynolds numbers; *Pr* is Pradtl number.

Figure 1. Schematic diagram of test rig.

3. Results and discussion

The force convection heat transfer experiment is started with water/EG base fluid and the data was compared to Dittus-Boelter [13] equation as shown in Figure 2. The experiment is conducted at working temperature 30°C with volume concentration of 3.0%, 2.5% and 2.0%. Figure 3 shows the variation of Nusselt number against Reynolds numbers ($2000 < Re < 10000$). The variation of graph shows that, the fluid that contain large amount of particles (high concentration) in base fluid solutions has higher Nusselt number. The same pattern is founded by Chiam et al. [14] which indicated that the thermal conductivity depend on volume concentration and affect the Nusselt number. The highest enhancement of thermal conductivity could be achieved on high volume concentration. At this condition, the Nusselt number is efficient for the convection process.

The distribution of heat transfer coefficient versus Reynolds number for the TiO_2-SiO_2 nanofluids in mixture water/EG is shown in Figure 4. From the figure, it shows that the heat transfer coefficient increases with increasing of Reynolds numbers and volume concentration. The maximum enhancement of heat transfer coefficient is achieved at volume concentration of 3.0% with 45.9% compare to the base fluid. While, at concentrations 2.0% and 2.5%, the heat transfer coefficient enhanced to 29.4% and 33.2%, respectively. The average enhancement percentage of heat transfer coefficient for each concentration is shown in Figure 5 and Table 2, respectively. This shows that the addition of small amount of the combination of TiO_2-SiO_2 nanoparticles to the mixture base of water/EG improved the heat transfer performance. Previous studies also encounter similar findings [4, 15-17]. However, in their studies the single nanofluids were used such as Al_2O_3, TiO_2, and SiO_2.

Table 2. Heat transfer coefficient enhancement of TiO_2-SiO_2 nanofluids at temperature 30°C.

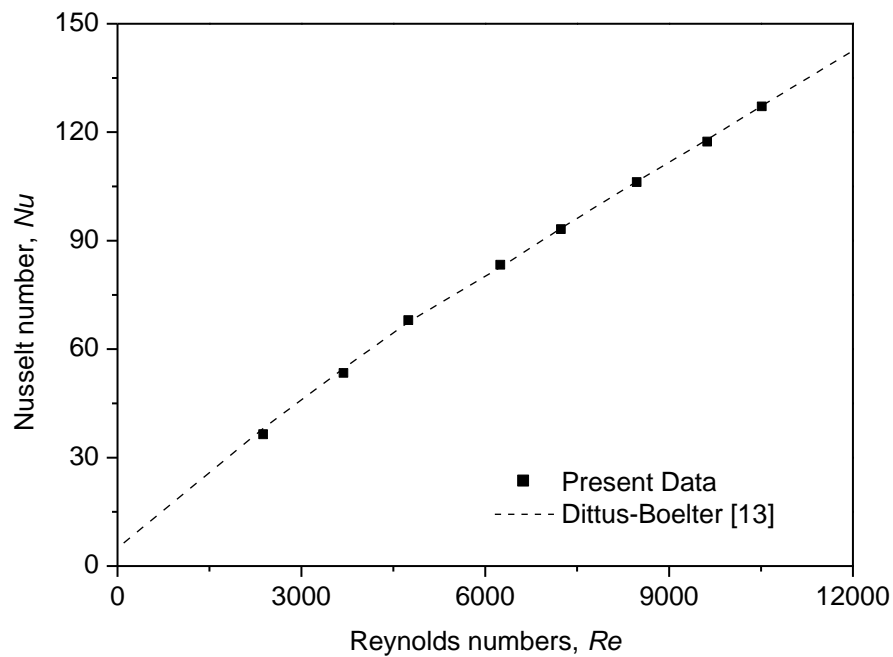| Volume concentration, ϕ (%)	Average enhancement, (%)
2.0	29.4
2.5	33.2
3.0	45.9

Figure 2. Validation of Nusselt number base fluid with Dittus-Boelter [13] relation.
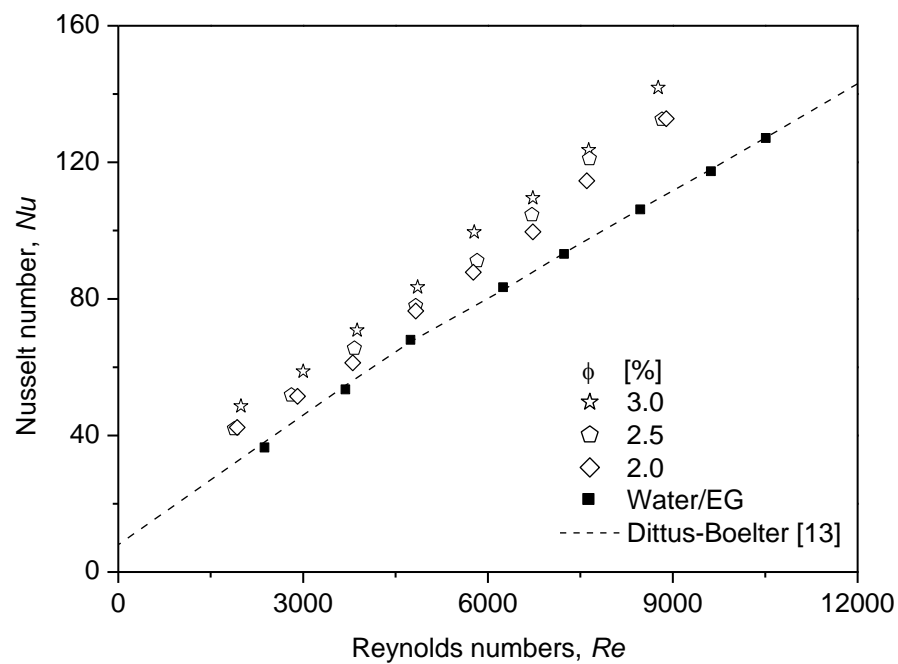

Figure 3. Variation of Nusselt number against Reynold numbers for concentration $2.0 < \phi < 3.0\%$.
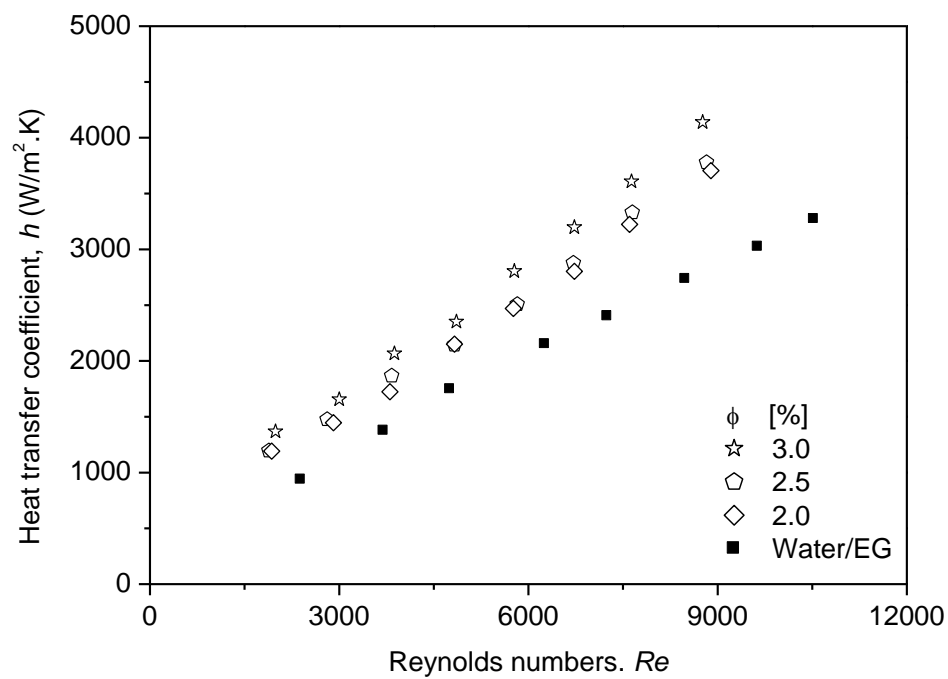
Figure 4. Distribution of heat transfer coefficient versus Reynolds numbers for concentration $2.0 < \phi < 3.0\%$.
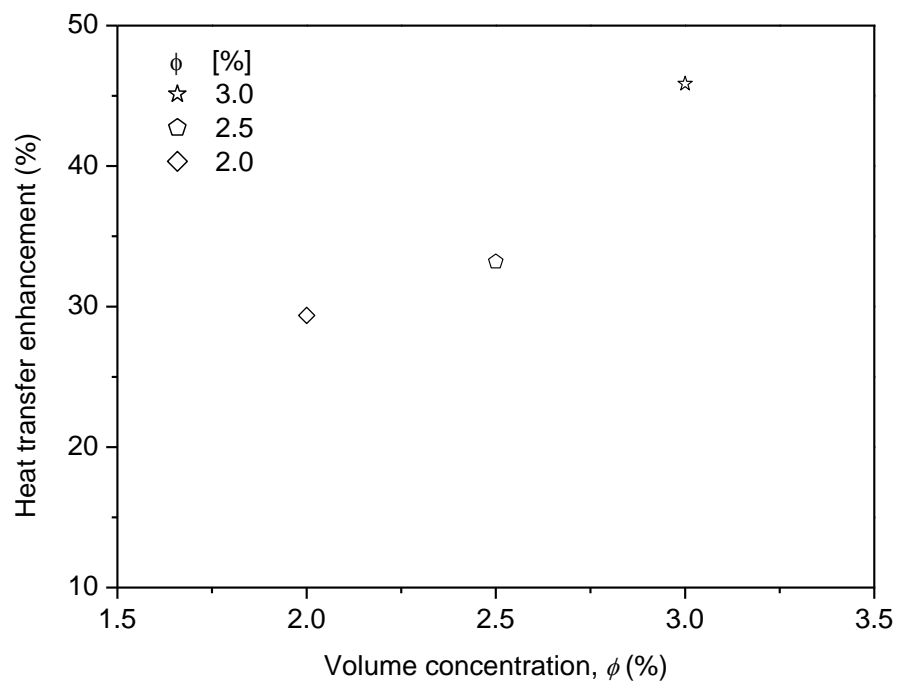

Figure 5. Enhancement of heat transfer coefficient for concentration $2.0 < \phi < 3.0\%$ at 30°C.

The present data of friction factor for composite TiO_2-SiO_2 nanofluids in mixture water/EG base fluid at different volume concentrations are shown in Figure 6. The figure shows that, the experimental friction factor is decreasing with the increment of Reynolds numbers. The friction factor of base fluid followed closely to the Blasius [18] line and decreased exponentially with the increasing of Reynolds numbers. The friction factor of hybrid nanofluids at all concentration increased slightly at about 7 to 8 % and follow the base fluid trend. However, the friction factor are higher at lower Reynolds numbers and then its decrease more closer to the Blasius [18] line.

$$f_B = \frac{0.3164}{Re^{0.25}} \tag{6}$$

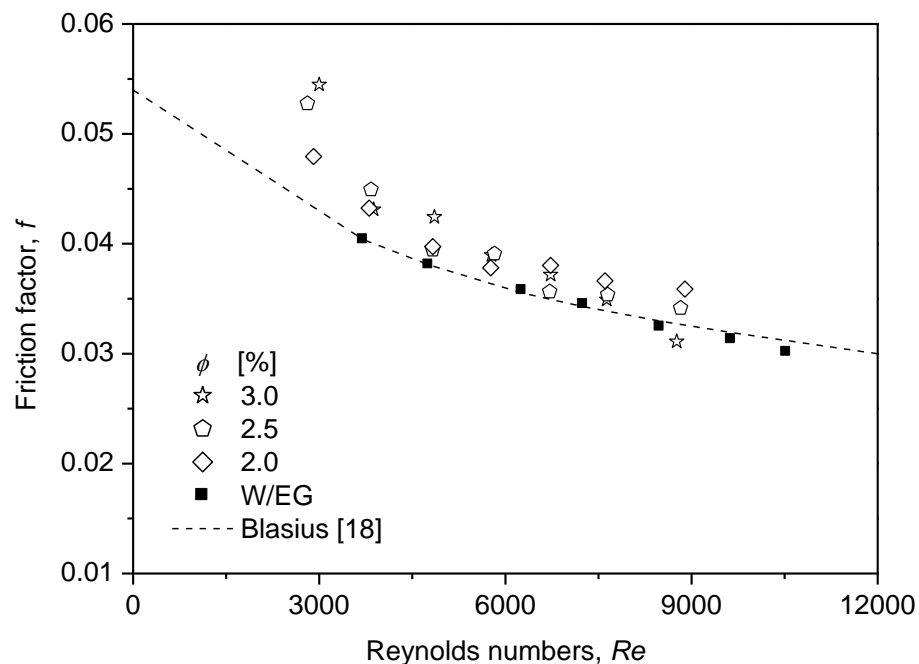where f_B is Blasius friction factor; Re is Reynolds numbers.

Figure 6. Variation of friction factor against Reynolds numbers for concentration $2.0 < \phi < 3.0\%$.

4. Conclusions
The present study is focused on the augmentation of convective heat transfer for composite TiO_2-SiO_2 nanoparticles in mixture of water/EG base fluid. The force convection heat transfer experiment was performed at working temperature of 30°C. From the experimental observations, the following conclusions are made:
   a. The fluid that contain large amount of particles (high concentration) in base fluid solutions has higher Nusselt number.
   b. The heat transfer coefficient increases with the volume concentration of hybrid nanofluids and enhanced more than 29% compared with base fluid.
   c. The maximum enhancement of convective heat transfer is found at 3.0% volume concentration by 45.9%, then followed by volume concentration of 2.5% and 2.0% with the enhancement of 33.2% and 29.4%, respectively.
   d. The friction factor of composite TiO_2-SiO_2 nanoparticles in the water/EG base fluid is decreased with increasing of Reynold numbers slightly increased for concentration 2.0-3.0%.

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