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Forced convection heat transfer and friction factor of water/bio-glycol mixture based TiO_2-SiO_2 nanofluids

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Abstract. The research on nanofluids as heat transfer fluid has been done for many years and the manipulation of nanoparticles kept evolving as time passes by. After an exceptional heat transfer performance enhancement was found in single nanofluids, combining two types of nanoparticles in a base fluid has garnered researcher's attention all over the globe. The study on performance of heat transfer for a combination of two types of nanoparticle in a mixture of water and Bio-glycol has yet to be established; hence, the present study was conducted to investigate the heat transfer performance of TiO_2-SiO_2 nanofluids in 60:40 mixture of water and Bio-Glycol. The TiO_2-SiO_2 nanofluids was prepared by using the two-step method at three different particle concentration, namely 0.5%, 1.0% and 1.5%. Forced convection heat transfer experiment was carried out at bulk temperature 30°C and Reynolds number in the range of 1000 to 8000. A constant heat flux was supplied to the test section throughout the experiment. The Nusselt number of TiO_2-SiO_2 nanofluids was found at particle concentration 1.5%, 70.11% enhanced from the base fluid. The average enhancement of heat transfer coefficient for each particle concentration 0.5%, 1.0% and 1.5% are 40.3%, 63.4% and 70.3%, respectively. Heat transfer coefficient enhancement for 1.0% and 1.5% particle concentration almost similar at low concentration, however, as Reynolds number increase, the augmentation gap increases. The results of friction factor displayed a decrease trend with the increase of Reynolds number. While the friction factor of TiO_2-SiO_2 nanofluids insignificantly increased from the base fluid, the increment between particles concentration almost negligible.

1. Introduction

In the past few years, the evolution of research on heat transfer fluid has grown rapidly due to the limitation of conventional heat transfer fluids like water, oil, and ethylene glycol that stunted the enhancement of the heat transfer [1, 2]. Demand to improve efficiency of industrial applications of heating and cooling such as heat exchange has become the focus of researchers in designing a compact heat exchanger while reducing its cost, basically by increasing heat transfer to accommodate heat transfer coefficient [3, 4]. As a result, fuel consumption will be significantly reduced, and the service life of machinery could be extended. The act of dispersing ultra-fine particles in a base fluid pioneered by Masuda et al. [5] to investigate the thermal conductivity enhancement triggered many experimental investigations in the heat transfer performance of heat transfer fluid due to its potential in enhancing the thermo-physical properties of fluids. However, heat transfer fluid dispersed with miniature metallic oxide leads to an increase in viscosity, thereby contributing to high pumping penalty. Hence, to fully utilize the colloidal suspension as heat transfer fluid, selection of type of particles, their size and shape, thermal conductivity, and particle concentration should be wisely chosen. A comprehensive review on thermo-physical properties of hybrid nanofluids was presented by Nabil et al. [6] and Azmi et al. [7]. In addition, various studies were undertaken to investigate the thermal conductivity and dynamic viscosity of nanofluids [8-11].

A previous study on heat transfer and pressure drop by Pak and Cho [3] in circular tube under turbulence flow revealed how the colloidal suspension improves the heat transportation in fluids. The authors used Al_2O_3 and TiO_2 nanoparticles dispersed in water as working fluids at different concentrations and observed the increment in Nusselt number when volume concentration of fluids and Reynolds number increased. At fixed Reynolds number, the researcher compared the Al_2O_3 nanofluids at different concentrations 1.34% and 2.78% and found 45% and 75% of convective heat transfer coefficient being augmented, respectively. Despite the anomaly improvement in convective heat transfer coefficient, the increase in pumping penalty cannot be avoided as viscosity increased at high volume concentration. The friction factor and pumping penalty for Al_2O_3 nanofluids at 2.78% volume concentration was reported to be 28% and 31% higher than water, respectively.

Azmi et al. [12] utilized Al_2O_3 nanofluids that was dispersed in a mixture of water and ethylene glycol to study the heat transfer performance under turbulence flow regime using forced convection setup. As a result, they found the highest increase in convective heat transfer coefficient at 1.0% volume concentration. This enhancement was found at 60:40 mixture ratio of water and ethylene glycol, which is 24.6%. In addition, the increase in friction factor is not apparent which 5% only, influenced by the low volume concentration of nanoparticles applied in this study. Further heat transfer performance studies were investigated in the recent works [13, 14]. Another study conducted by Abdolbaqi et al. [15] for properties evaluation and Abdolbaqi et al. [16] using water/Bio-glycol based TiO_2 nanofluids also found about 28.2% enhancement of the Nusselt number from the base fluid. Since there is no study on combination of two particles dispersed in a mixture of water and Bio-Glycol, the present study aimed to investigate the heat transfer performance of water/Bio-Glycol based TiO_2-SiO_2 nanofluids at low concentration range from 0.5% to 1.5% with working bulk temperature 30 °C.

2. Methodology

2.1. TiO_2-SiO_2 nanofluids preparation

TiO_2 and SiO_2 water-based nanofluids were considered in the present heat transfer analysis. There were commercially produced by US Research Nanomaterials, Inc for research purposes in the form of liquid suspension with 40 wt% concentration sized range from 30-50nm while SiO_2 nanopowder dispersion also acquired from US Research Nanomaterials, Inc. (USA) with 25 wt% concentration sized 30nm. The procured TiO_2 and SiO_2 nanofluids will then be prepared to a new concentration by the dilution technique using equation (1) and equation (2). In order to prepare the nanofluids by dispersing the nanoparticles in a water/Bio-glycol based fluid, proper mixing and stabilization of the particles are required.

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

$$\Delta V = \left(V_2 - V_1\right) = V_1\left(\frac{\varphi_1}{\varphi_2} - 1\right) \tag{2}$$

In the present study, TiO_2 and SiO_2 nanoparticles were mixed with water/Bio-glycol based fluid then were sonicated continuously by an ultrasonic vibrator generating ultrasonic pulses of 80 W at 36 ± 3 kHz for 3 h to break down agglomeration of the nanoparticles prior to being used as the working fluid.

2.2. Thermo-physical properties

Thermo-physical properties like thermal conductivity, dynamic viscosity, specific heat, and density are fluid properties that change with temperature. These properties have long been studied by various researchers in different kind fields to evaluate the characteristic of heat transfer fluid and determine the optimum condition for heat transfer fluid to work effectively in the system. In the present study, Thermal conductivity of TiO_2-SiO_2 nanofluids was measured using C-Therm Thermal Conductivity Analyzer with 5% accuracy and 1% precision, supplied by C-Therm Technologies (Ltd.). While the measurement for dynamic viscosity was carried out using Anton Paar RheolabQC Rotational Rheometer. Density Meter was used to measure the density of the nanofluids, while specific heat was estimated using equation (3) or also known as mixture relation equation.

$$C_{hnf} = \frac{(1-\phi_p)\rho_{bf}C_{bf} + (0.2\times\phi)\rho_{TiO_2}C_{TiO_2} + (0.8\times\phi)\rho_{SiO_2}C_{SiO_2}}{\rho_{hnf}} \tag{3}$$

All these properties were evaluated at temperature 30 °C and particles concentration 0.5% to 1.5%. Summary of the thermo-physical properties are presented in table 1.

Table 1. Thermo-physical properties of TiO_2-SiO_2 nanofluids at 30 °C.

Volume Concentration, ϕ *(%)*	**Thermal Conductivity, *K (W/m. K)***	**Dynamic Viscosity, *μ (Pa.s)***	**Density, ρ *(kg/m³)***	**Specific Heat, *c* *(J/kg.K)***
0.5	0.430589	0.0039054	1053	3753.84
1.0	0.432905	0.0041633	1058	3715.763
1.5	0.438889	0.0040707	1068	3678.255

2.3. Experimental setup

The experimental setup used for forced-convection experiment is shown in figure 1. Forced-convection test rig built with control panel, collecting tank capable of accommodating a maximum of 0.08 m^3 working fluids, 1.0 HP circulating pump, 1.5 m long test section with inner diameter (ID) 16 mm, outer diameter (OD) 19 mm, and thickness of 3 mm. The test section is made of copper tube and was well insulated with fibre glass to minimize heat loss to the surroundings. 600 W heat was supplied using a voltage regulator by attaching two nichrome to the outer wall of the test section to supply a constant heat flux. Eight K-type thermocouples were wrapped at 6 different locations of the section and the other two were fixed at test section inlet and outlet, labelled from T_1 to T_8. A data logger type ADAM View Advanced Data Acquisition was connected to the test rig to record and display data measured from the experiment. The outlet of the test section is connected to a 2.8kW chiller to cool down the hot working fluid before circulating it back to the collecting tank. A battery-powered flow meter measured in LPM is installed between the pump and inlet test section. A pressure transducer is placed between the inlet and outlet of the test section and displayed as T_9 at the data logger. Validation of experimental setup was carried out by comparing the Nusselt number data of base fluid, water/Bio-Glycol calculated using equation (4):

$$Nu_{\exp} = \frac{hD}{k} \tag{4}$$

where h is heat transfer coefficient, D stands for inner diameter of test section, and k is thermal conductivity of nanofluids, with estimated Nusselt number using Dittus-Boelter equation, shown in equation (5).

$$Nu_{DB} = 0.023\mathrm{Re}^{0.8}\,\mathrm{Pr}^{n} \tag{5}$$

where Re is Reynolds number and Pr represents Prandtl number. Since the nanofluids in the present study is heated, value of n=0.4 is used.

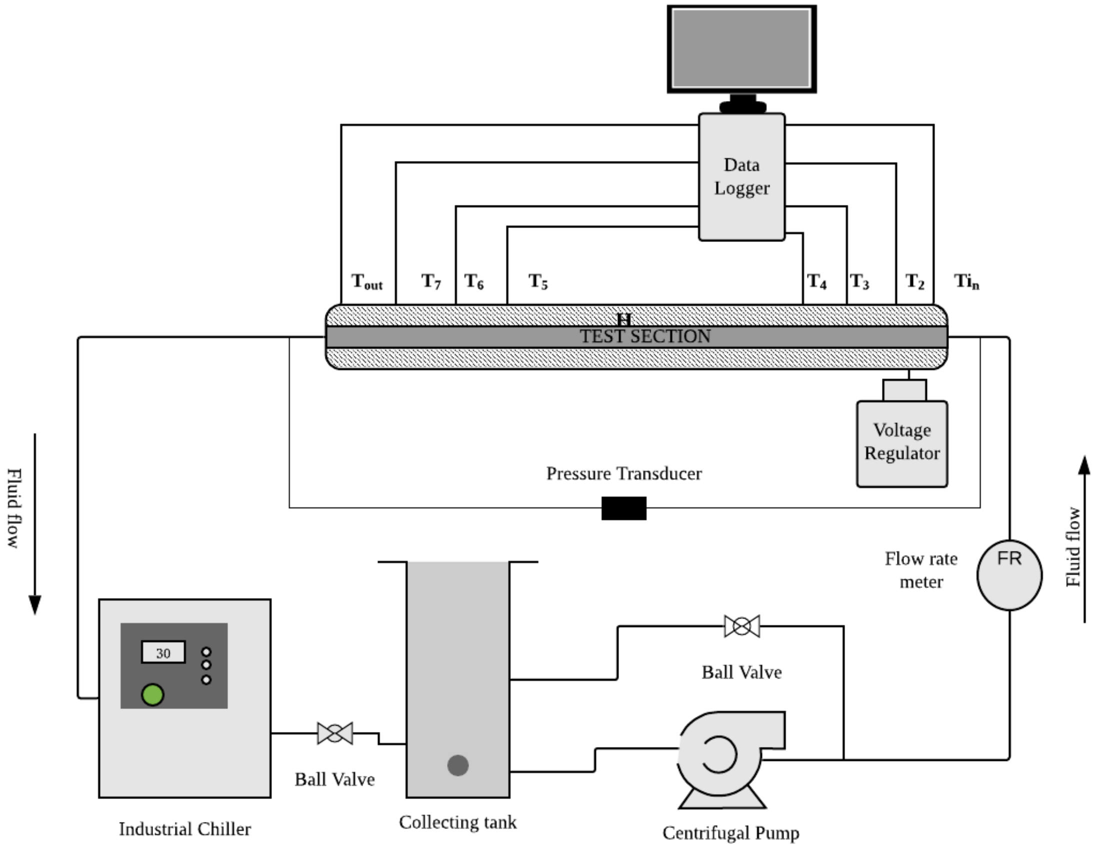

Figure 1. Schematic diagram of forced convection experimental setup.

3. Results and discussion

To establish an accurate experimental method, a validation on the experimental setup was done by using a base fluid water/Bio-Glycol (W/BG) at bulk temperature 30 °C. The results presented in figure 2 confirmed the reliability of the experiment by comparing the Nusselt number data of W/BG with estimation from Dittus-Boelter [17] with ±2% average deviation. The forced convection experiment in this study was conducted using TiO_2-SiO_2 nanofluids at three different concentrations (0.5%, 1.0%, 1.5%) and operating bulk temperature of 30°C. The variation of the Nusselt number in Reynolds number ranges from 1000 to 8000 is shown in figure 3. From the figure, it evident that the Nusselt number is influenced by the nanofluids concentration and Reynolds number. The Nusselt number shows an increment as concentration and the Reynolds number increases, which the highest Nusselt number can be obtained at 1.5 vol.%, about 70.11% higher than the base fluid. The possible explanation behind this enhancement is due to the fact the higher volume concentration possessed higher thermal conductivity compared to the lower volume concentration [18]. Several investigators like Torii [19], Chandra Sekhara Reddy and Vasudeva Rao [20] and Kayhani et al. [21] also found similar trend in their researches.

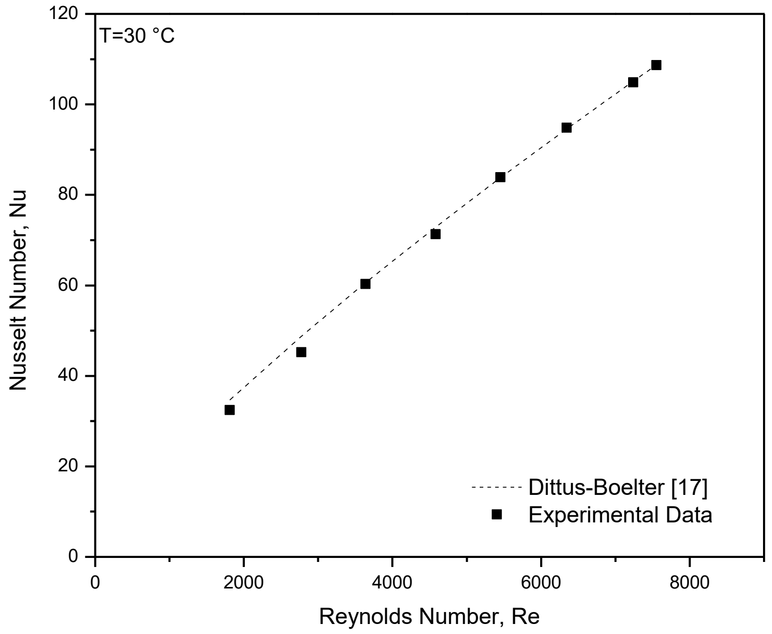

Figure 2. Validation of Nusselt Number of W/BG with Dittus-Boelter [17].

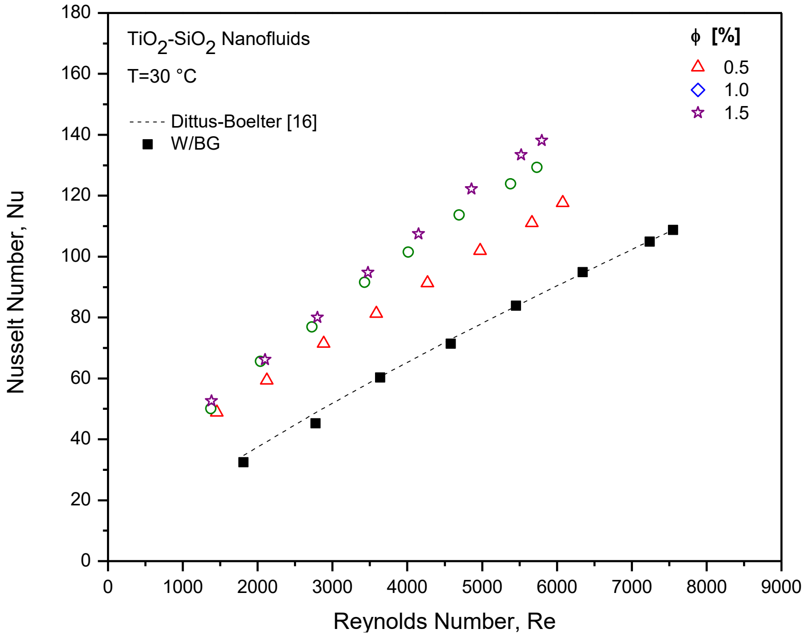

Figure 3. Nusselt number of TiO_2-SiO_2 nanofluids at different particle concentration.

Variation of heat transfer coefficient of TiO_2-SiO_2 nanofluids against Reynolds number at different concentration is plotted in figure 4. An increase trend was found in heat transfer coefficient as the volume concentration increase. From the pattern observed in figure 3, it is obvious that small addition of nanoparticles can greatly influence the heat transfer coefficient of the heat transfer fluid. This statement was supported by average enhancement achieved at 1.5%, which is approximately 70.3%, following by 1.0% volume concentration that was enhanced up to 63.4% and 40.2% for 0.5% volume concentration. Enhancement of heat transfer concentration in the function of Reynolds number at different volume concentration is presented in figure 5. Based on the data showed in this figure, the

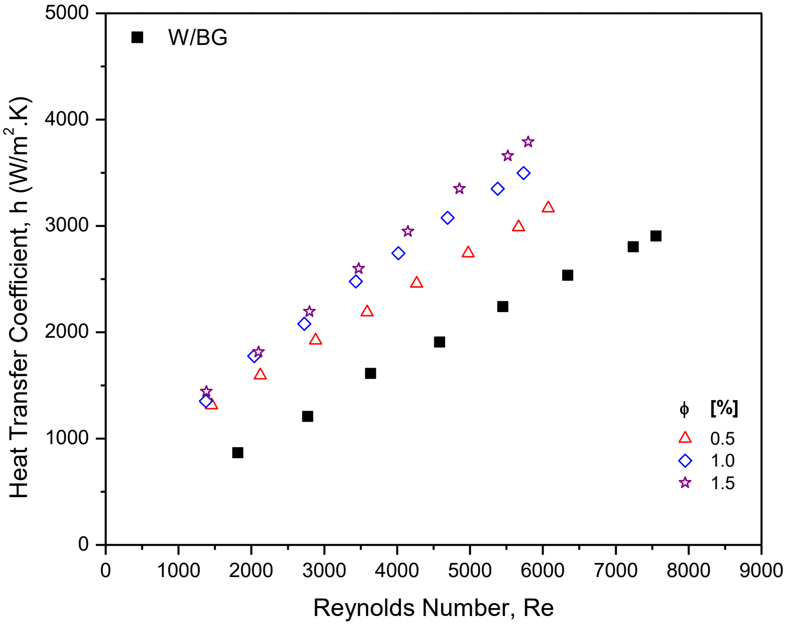

Figure 4. Heat transfer coefficient of TiO_2-SiO_2 nanofluids at different particle concentration.

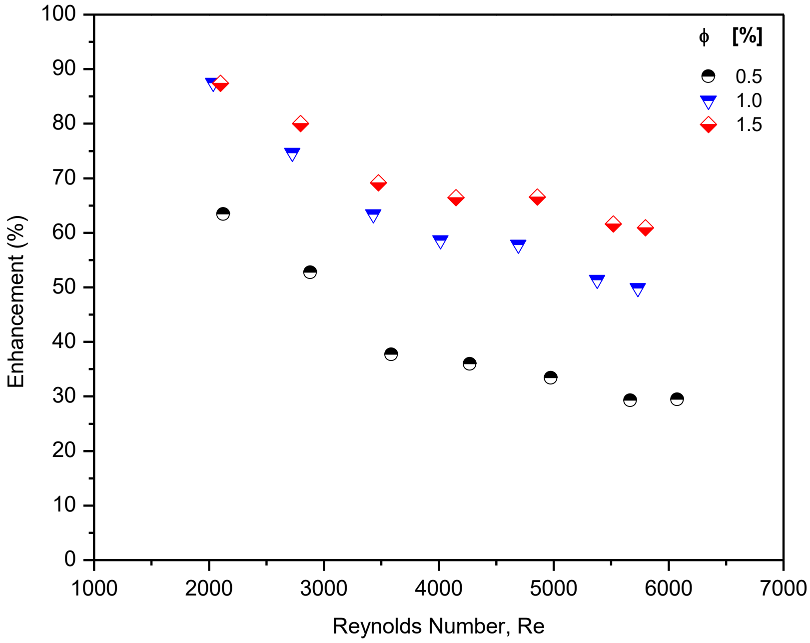

Figure 5. Enhancement of heat transfer coefficient of different particle concentration with Reynolds number.

enhancement TiO_2-SiO_2 nanofluids for 1.0% and 1.5% particle concentration almost similar at low Reynolds number, however the difference become obvious as Reynolds number increase. The outcomes from this experiment showed that the enhancement of heat transfer coefficient increases with particle concentration. Similar findings also can be seen in the researches performed by Bhanvase et al. [22] that achieved maximum of 105% augmentation in heat transfer coefficient using water/ethylene glycol based TiO_2 nanofluids at 0.5% volume fraction. Azmi et al. [23] encountered same results where the enhancement of heat transfer coefficient increases as particle concentration increase up to

3%, however, further increase in particle concentration caused the enhancement to decrease. Another researcher that encountered similar results is Hamid et al. [24].

The friction factor of W/BG and TiO_2-SiO_2 nanofluids in the function of Reynolds number is provided in figure 6. It shows that the friction factor decreases as the Reynolds number increases. The estimation of friction factor for base W/BG using Blasius [25] and Petukhov [26] seems in good agreement especially at higher Reynolds number. A little increase in the friction factor of TiO_2-SiO_2 nanofluids from the base fluid was observed. However, the increase almost insignificant at high Reynolds number. In comparison, between particle concentration, results revealed a negligible increment of friction factor. Friction factors of all concentration fall closely to Blasius [25] and Petukhov [26], proved the TiO_2-SiO_2 particles are not a strong influencer to the friction factor. Similar findings also reported in prior researches [12, 14, 27, 28].

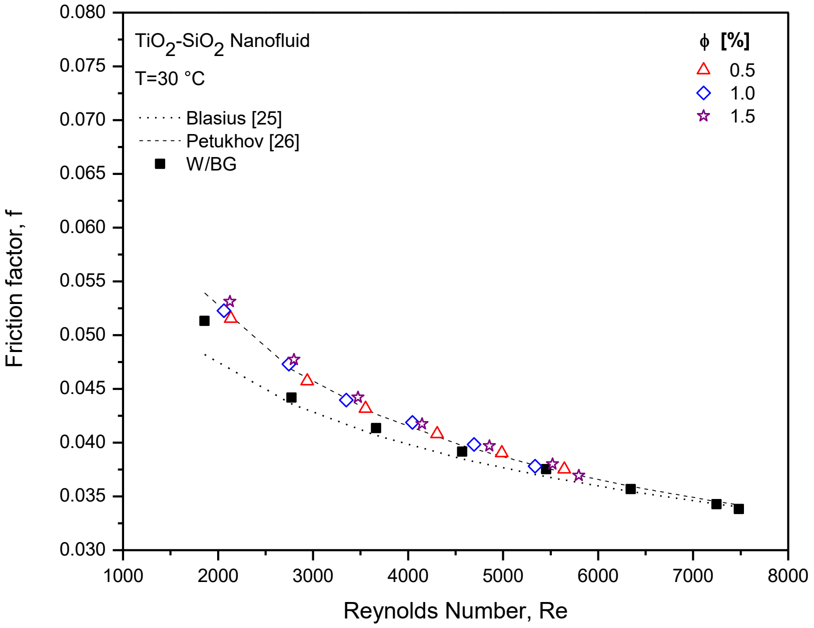

Figure 6. Variation of friction factor of TiO_2-SiO_2 nanofluids at different particle concentration with Reynolds number.

4. Conclusion

Conventional heat transfer fluids have reached its limit in improving heat transfer performance of heating and cooling system. Thus, the employment of small amounts of nanoparticles dispersed in base fluid has become a trend in research due to its anomalous heat transfer enhancement. Water/Bio-Glycol based TiO_2-SiO_2 nanofluids at low concentrations was employed in this experimental study on forced convection heat transfer at bulk temperature 30 °C. The study leads to the following conclusions:

i. Nusselt number of nanofluids increases with particle concentration and Reynolds number, where the highest Nusselt number was observed at 1.5 vol.%, which is 70.11% higher than base fluid.
ii. Small addition of nanoparticles led to great heat transfer enhancement. Average enhancement for 0.5%, 1.0% and 1.5% are 40.3%, 63.4% and 70.3%, respectively. At high Reynolds number, maximum of 60.9% heat transfer coefficient augmentation was observed at 1.5 vol.%.
iii. Friction factor TiO_2-SiO_2 nanofluids decrease as the Reynolds number increases. Dispersing TiO_2 and SiO_2 in a mixture of water and Bio-Glycol did not significantly influence the friction

factor especially at high Reynolds number, and there is no apparent increment of friction factor in term of concentration.

Acknowledgments

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