Heat Transfer Performance Of Tio_2–SiO_2 Nanofluid In Water-Ethylene Glycol Mixture

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ABSTRACT

In recent years, there has been an increasing interest in combination of two or more nanoparticles due to the improvement in force convection heat transfer of fluids. Through recent studies, combination of two different nanoparticles suspended in base fluid and known as hybrid nanofluids have a better performance of heat transfer. This paper presents the heat transfer performance of the 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 a base fluid. The hybrid nanofluids were prepared using two-step method and homogenized to firm the suspension for three different volume concentration of 0.5%, 1.0% and 1.5%. The forced convection heat transfer experiment was conducted at working temperature 70 °C with a constant heat flux condition. The Nusselt number and heat transfer coefficient of hybrid nanofluids was compared with the base fluid. It shows that, the increment in nanofluids concentration affect an increasing of Nusselt number and heat transfer coefficient. The enhancement of convective heat transfer is 22.9% and 15.1% for volume concentration of 1.0% and 0.5%, respectively. The highest enhancement of convective heat transfer is found at 1.5% volume concentration by 30.8%.

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Introduction

Nowadays, the demand of heat energy is increasing with the evolution of the industry that involved heating and cooling process. In order to reduce processing time, saving the energy, raise the thermal rating and lengthen the working life of the system, the enhancement of heat transfer coefficient are needed [1]. Thus, heat transfer fluid plays an important role in the development of heat transfer applications such as in automotive, buildings, and industrial process [2].

Previously, conventional fluids such as water, ethylene glycol and oil (non-metallic liquids) were used in forced convection heat transfer have relatively low thermal conductivity when compared with solid particles. The addition of micron sized particles as an additive in a base fluid enhances the heat transfer. However, using micron sized solid particles causes problems such as tends to clog, settle down rapidly, erosion of the heat transfer device and pressure drop increases rapidly [3]. Therefore, researchers are highly motivated and showing keen interests in nanometer-sized particles that will disperse in the base fluids. This fluids known as "nanofluids" that was introduced by Choi et al. [2]. Nanofluids are defined as the dispersion of nanoparticles in a conventional working fluid such as water, ethylene glycol and oil with principal dimensions of less than 100 nm in a liquid [2, 4-7]. For the past decades, nanofluids was used for wide applications in industries 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 [8]. In a continuation of nanofluids research, a few studies have recently discussed the topic of hybrid nanofluids [9-13]. Hybrid nanofluids are considered as an extension of nanofluids in research work, which can be prepared by suspending two or more dissimilar nanoparticles either in mixture or composite form in the base fluids [9].

The main objective of synthesizing hybrid nanofluids is to improve the properties of single materials where great enhancement in thermal properties or rheological properties can be achieved. Until recently, the convective heat transfer studies on hybrid nanofluids either experimental or numerical are very limited. Therefore, the convective heat transfer study is conducted experimentally using the combinations of TiO_2 and SiO_2 nanoparticles dispersed in 60:40 volume ratio of water and ethylene glycol mixture at various volume concentrations and working temperature of 70°C.

Hybrid Nanofluids Preparation

Two different types of nanoparticles which are TiO_2 and SiO_2 nanofluids was used in the present study. The nanomaterials of TiO_2 (40 wt.%) and SiO_2 (25 wt.%) was supplied by US Research Nanomaterials, Inc. The average diameter size for TiO_2 and SiO_2 nanoparticles were 50 nm and 22 nm respectively. The distilled water and ethylene glycol used as the base fluid and mixed at volume ratio of 60:40. The single nanofluid of TiO_2 and SiO_2 in water/EG based was prepared separately at concentration 1.5%. Equation (1) is used to convert the weight concentration to volume concentration. Both TiO_2 and SiO_2 nanofluid were then mixed together to produce hybrid nanofluid by mixing process for 1 hour. The hybrid nanofluid was then subjected to sonication process for 2 hours to ensure the stability of the samples. The dilution from 1.5% concentration to lower concentration 1.0% and 0.5% were prepared by adding the base fluid water/EG into the nanofluid using Eq. (2).

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

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

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 %.

Thermo-physical Properties

The thermal conductivity and dynamic viscosity of TiO_2-SiO_2 nanofluids were measured for each concentration using KD2 Pro Thermal Properties Analyzer and Brookfield LVDV-III Ultra Rheometer. The density and specific heat of the hybrid nanofluids were obtained using classical model solid-liquid mixture relation as shown in Eq. (3) and Eq. (4). The thermo-physical properties for the TiO_2-SiO_2 nanofluids in water/EG mixture based are presented in Table 1.

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

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

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.

Table 1. Thermo-physical properties of TiO_2-SiO_2 nanofluids at temperature 70°C.

Volume concentration, ϕ (%)	Density, ρ (kg/m^3)	Viscosity, μ (kg/m.s)	Thermal conductivity, k (W/m.K)	Specific heat, C (J/kg.K)
0.5	1044.33	1.48	0.453	3590.82
1.0	1055.29	1.71	0.475	3546.59
1.5	1066.24	1.80	0.486	3503.26

Experimental Setup

In order to conduct the experimental of forced convection heat transfer, the system is designed as in Fig. 1. The experimental set up consists of a test section that is insulated with fibre glass insulators. The inner and outer diameter of test section is 16 mm and 19 mm respectively. Six thermocouples are welded to the body of tube wall and the other two is placed at inlet and outlet of the test section. Heat flux for the experiment is fixed at 7955 W/m^2. The chiller is provided in the system to cool the working fluid after being heated. 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 singlephase liquid relation by Dittus-Boelter [14] as in Eq. (5) for the validation of the 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.

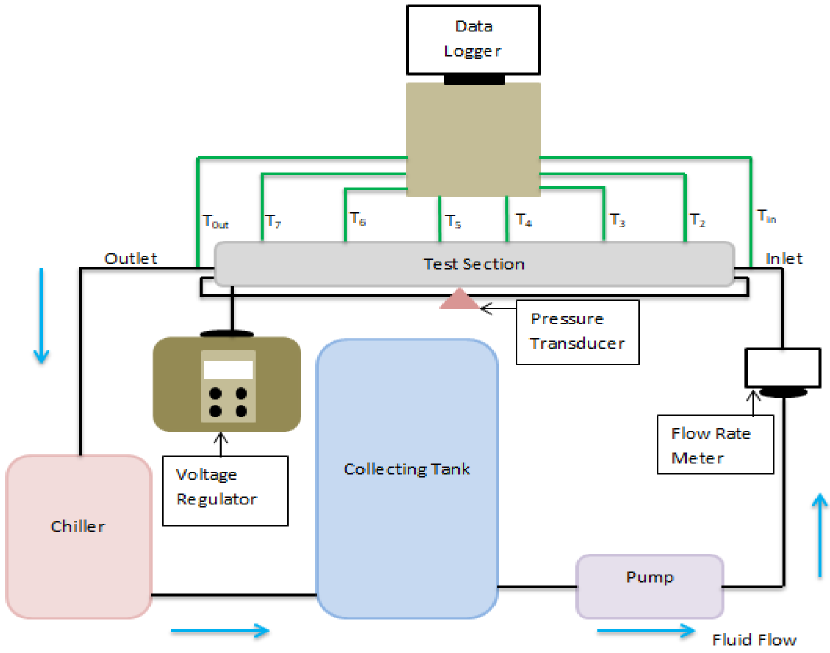

Fig. 1. Schematic diagram of test rig.

Results and Discussion

The forced convection experimental investigation was initially started with base fluid water/EG. The data is compared to Dittus-Boelter [14] equation and served as a benchmark of the experimental set up as shown in Fig. 2. The experiments were carried out at working temperature 70°C with a volume concentration of 1.5%. The experiment was repeated for lower concentration by diluting to 1.0% and 0.5%. Fig. 3. shows the Nusselt number against Reynolds numbers with Reynolds numbers range of 4000 < *Re* < 23000. The graph clearly shows that the higher the concentration of combination TiO_2-SiO_2 nanoparticles suspended in the base fluid, the Nusselt number will increase. This pattern also found by Usri et al. [15] which highlighted that the increment of thermal conductivity affects the increasing of the Nusselt number. Therefore, the higher Nusselt number shows the greater efficiency of convection process.

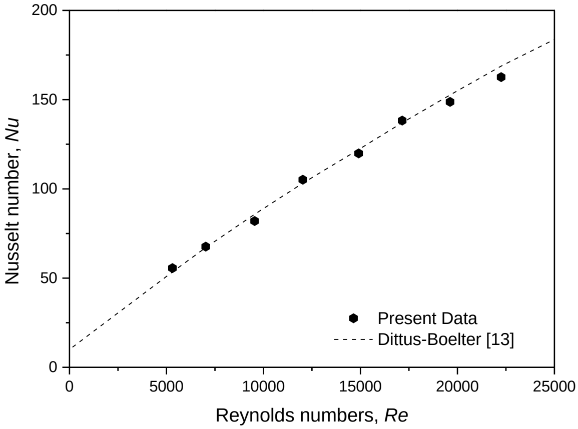

Fig. 2. Validation of base fluid Nusselt number with Dittus-Boelter [13].

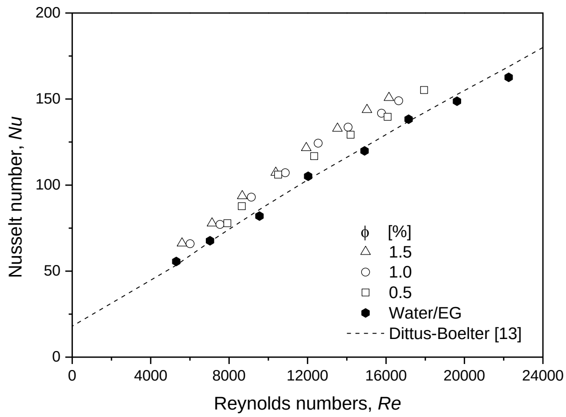

Fig. 3. Variation of Nusselt number against Reynolds numbers for $0.5 < \phi < 1.5\%$.

Figure 4. presents the heat transfer coefficient of TiO_2-SiO_2 nanofluids with various concentration. It can be seen that the heat transfer coefficient increases with respect to Reynolds numbers and volume concentration. The

enhancement of heat transfer coefficient is following the pattern of the volume concentration increment. The highest enhancement of heat transfer coefficient is found at the volume concentration of 1.5% by 30.8% whereas 1.0% and 0.5% concentrations enhanced to 22.9% and 15.1%, respectively. The percentage enhancement of heat transfer coefficient for each concentration is shown in Fig. 5. 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. Similar observation regarding the addition of nanoparticles into base fluid which improves the heat transfer performance was also found in previous study by Azmi et al. [16], Hamid et al. [17], Usri et al. [18], Abdolbaqi et al. [19]. However, in their studies, they used single nanofluids such as Al_2O_3, TiO_2, and SiO_2.

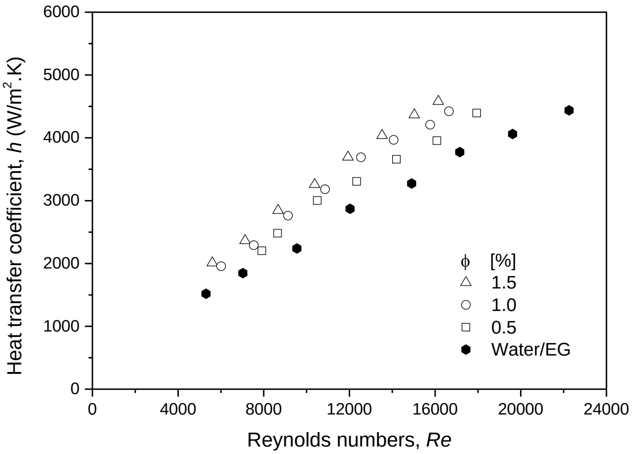

Fig. 4. Distribution of heat transfer coefficient versus Reynolds numbers.

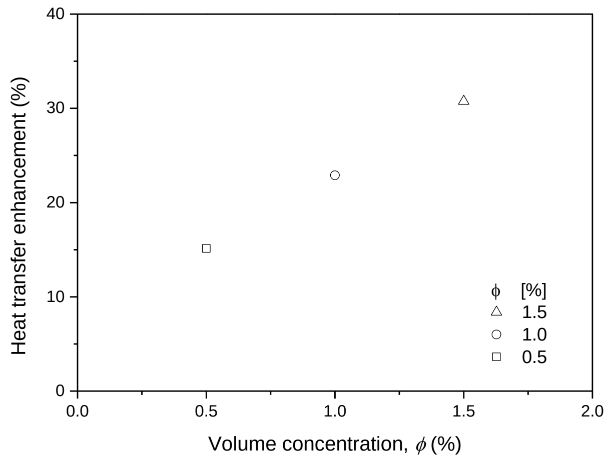

Fig. 5. Enhancement of heat transfer coefficient for $0.5 < \phi < 1.5\%$ at 70°C.

Conclusions

The performance of convective heat transfer by using the combination of TiO_2-SiO_2 nanoparticles in the mixture base water/EG at working temperature of 70°C was observed. The heat transfer coefficient increases with the volume concentration of hybrid nanofluids and it is enhanced more than 15% compared with base fluid. The highest enhancement of convective heat transfer is found at 1.5% volume concentration by 30.8% then followed by volume concentration of 1.0% and 0.5% with the enhancement of 22.9% and 15.1%, respectively. It is recommended to use TiO_2-SiO_2 hybrid nanofluids in water/EG based at concentration 1.5%, operating at 70°C.

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