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Viscosity determination of titanium dioxide in water and ethylene glycol mixture based nanofluid

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This paper exposes the viscosity investigation of titanium dioxide (TiO_2) based nanofluids. The viscosity measurements have been carried out for nanofluids of titanium dioxide suspended in 60:40 (by volume) water and ethylene glycol (EG) mixture. Titanium dioxide nanofluids were prepared in concentration ranges of 0.5 to 1.5 %. The viscosity measurement has been performed by the spindle rotation technique using Brookfield LVDV-III Ultra Rheometer at temperatures of 30 to 80 °C. The results indicate that the viscosity of nanofluids increases with increase in volume concentration and decreases with increase in temperature. The relative viscosity is independent of temperature. The design correlation equation is fitted for the nanofluids mixtures in the range of $0 \le \phi \le 1.5$ % and $30 \le T \le 80$ °C.

Keywords: Viscosity, Nanofluid, Titanium dioxide, Ethylene glycol

1 Introduction

The potential outcomes on nanofluids as thermal fluid lead to deeper investigation of its properties. The measurement and estimation of thermo-physical properties of nanofluids mainly comprise the four main properties namely, thermal conductivity, viscosity, density and specific heat. These properties are essential for the determination of the overall heat transfer performance of nanofluids. The thermo-physical properties are measured using scientific instruments or estimated from the available models in literature. The studies by Abdul Hamid *et al*[1] and Yasinskiy *et al*[2] proved that the dispersion of single nanoparticles to the base fluid is able to improve the thermal conductivity compared to the conventional fluid and further increased the heat transfer rate. The majority of previous studies suggest that nanofluids have the best performance with the combination of high thermal conductivity and low viscosity[3,4]. Most of the investigations have limitations on their scope such as temperature and concentration based on their designed work[5-9]. Besides that, most researches conducted their investigation using nanofluids dispersed in water-based. Hence, the effect of base fluid such as a mixture of different pure liquid types is still insufficient. Since the heat transfer fluid demands high thermal conductivity but low viscosity, therefore base fluid in mixture is found to be suitable to encounter the disadvantages of water such as limited operating temperature range, high vapour pressure and high corrosivity[10].

Limited reports describe the effect of base fluid in mixture. The detailed study of magnetic Fe_3O_4 nanoparticles dispersed in three mixture EG/water ratio (60:40, 40:60 and 20:80), concentration less than 1.0 % and temperature range of 0 to 50 °C has been investigated by Sundar *et al*[11]. They found that 1.0 % volume concentration of Fe_3O_4 in 60:40 EG/water is enhanced by 2.94 % compared to other base fluids. The magnetic nanofluids are applicable as heat transfer fluids due to its magnetic response even in a fluid dispersion. Another research on rheological investigation conducted by using Al_2O_3 in mixture of EG and water for volume ratio of 45:55 and volume fraction of 0.02. The researchers found that the nanofluids exhibit Newtonian behaviour below 45 °C. The viscosity of the nanofluids strongly depends on both temperature and volume concentration[12]. One of the researches conducted for Al_2O_3 nanoparticles in EG/water mixture at 60:40 ratio. The findings show that Al_2O_3-EG/water nanofluids exhibit Newtonian behaviour for low concentrations of below 40 °C. Moreover, the nanofluid viscosity also depends on the volume concentration, temperature and base fluid

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used. The hysterisis behaviour was observed even for low concentrations[13]. Apart from that, an investigation on effect of base fluid and temperature to heat transfer characteristics is studied[10]. An experimental investigation was done using SiC dispersed in EG/water mixture in a volume ratio of 50:50. The results show that the efficiency of nanofluids improves with increase in temperature as viscosity decreases. Also, the efficiencies are higher for suspension mixture based nanofluids compared to water based nanofluids.

Most of the investigations on viscosities of nanofluid are conducted in pure fluids such as water and oil based. Due to the lack of investigation on the viscosity of mixture based nanofluids, the motivation of this study is to investigate and provide reliable experimental data for nanofluid in mixture ratio of 60:40 water/EG according to climate conditions in Malaysia. Through this paper, the behaviour of viscosity using titanium dioxide nanofluids for concentration range from 0 to 1.5 % and temperature range from 30 to 80 °C is presented.

2 Materials and Methods

2.1 Preparation of titanium dioxide nanofluid

The raw material used in this study is titanium dioxide (TiO_2) of 99.8% purity procured from US Research Nano materials, Inc. in water dispersion with weight concentrations of 40 wt% and average diameter of 50 nm. A mixture of water and EG in a volume ratio of 60:40 was used as the base fluid. Conversion from weight concentration of raw titanium dioxide to desired volume concentrations is completed using Eq. (1) for the maximum concentration prepared; 1.5% where ω is weight concentration and ϕ is volume concentration. The dilution process for lower concentration (0.5 to 1.3%) is performed by Eq. (2) where ΔV is volume of additional base fluid, V_1 and V_2 are initial and final volumes, respectively[4]:

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

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

The titanium dioxide nanofluid is prepared by measuring the pre-calculated desired volume at 1.5 % concentration. The sample is then mixed with 100 mL of base fluid with a magnetic stirrer at a suitable speed for 15 min. To ensure the dispersion of nano fluids with base fluid and its stability, the sample is immersed in Fisher brand ultrasonic bath with ultrasound frequency and ultrasound power RMS of 37 kHz and 80 W, respectively for two hours. The dilution for lower concentration is then prepared by adding the base fluid into the sample. The above process is repeated until all sample concentrations of 0.5, 0.7, 1.0, 1.3 and 1.5 % is completed. The illustration of these processes is shown in Fig. 1.

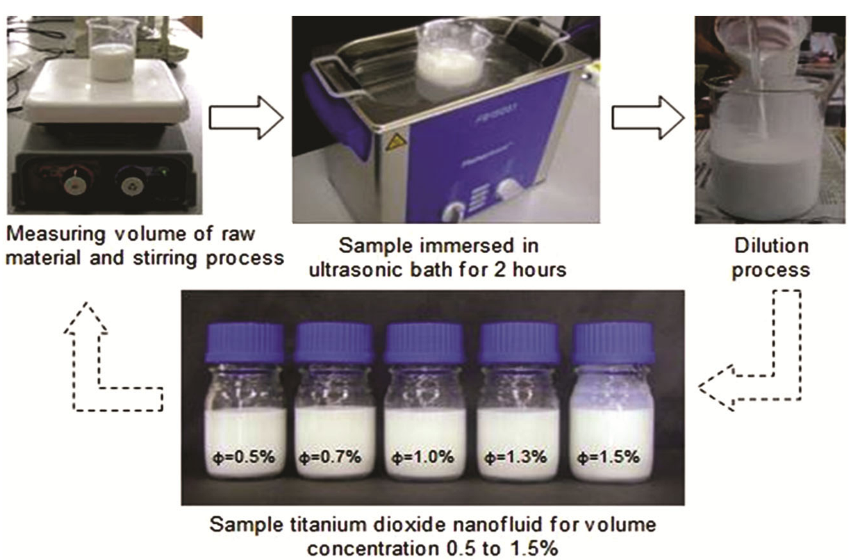

Fig. 1 — Preparation process of titanium dioxide nanofluid.

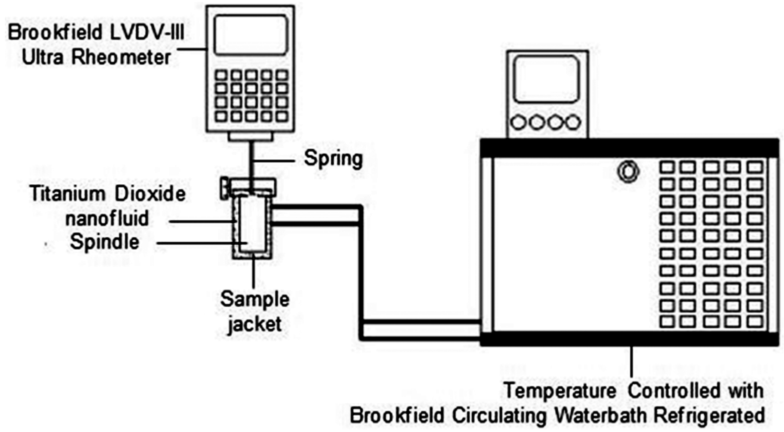

Fig. 2 — Viscosity measurement of titanium dioxide nanofluid using Brookfield Rheometer.

2.2 Viscosity measurement

The viscosity of titanium dioxide nanofluid was measured with Brookfield LVDV-III Ultra Rheometer connected to a Refrigerated Circulating Water Bath that controls temperature. This instrument has a viscosity range of 1 mPa.s to 6×10^6 mPa.s and temperature accuracy of 0.1 °C. The method of viscosity measurement is spindle rotation within the liquid sample. A viscous drag of the fluid against the spindle is developed along with deflection of the spindle, thus the viscosity is determined through the spindle deflection. Figure 2 shows the schematic diagram of Brookfield Rheometer with the attached nanofluid sample. The viscosity of titanium is measured in the temperature range of 30 to 80 °C, volume concentrations range from 0.5 to 1.5 %. To validate the accuracy of our instrument and experimental procedure, data from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook[14] was compared with the present data.

3 Results and Discussion

3.1 Viscosity validation

The validation of the apparatus has been conducted using a mixture of water and EG in a volume ratio of 60:40, temperature range from 30 to 80 °C. The measurements were compared with viscosity data from ASHRAE Handbook[14] where the deviation is in range of 6 to 13.4 %. From Fig. 3, the validation of the present data is in good agreement with ASHRAE. According to Namburu *et al*[15] the mixture of water and EG shows Newtonian behaviour hence it governs the rheological property and the nanofluids have Newtonian behaviour.

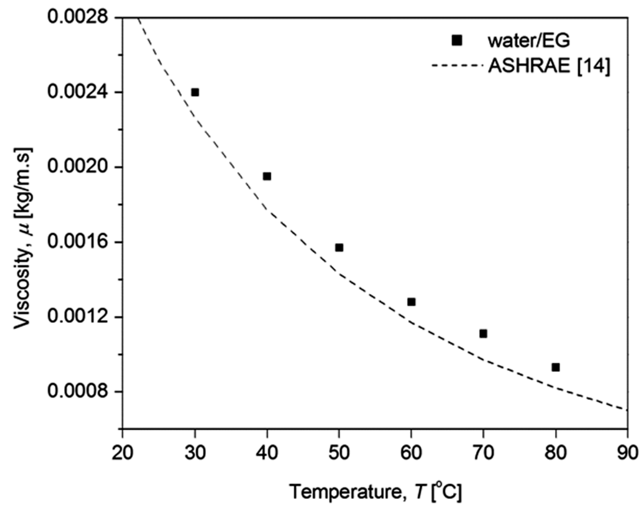

Fig. 3 — Comparison of base fluid with ASHRAE data.

3.2 Nanofluid viscosity

Figure 4 shows the variation of titanium dioxide nanofluid viscosity with temperature for all concentrations. It shows that the nanofluids follow the base fluid trend where it decreases exponentially with temperature. However, as the concentration increases, the viscosity value is increasing. Figure 5 shows the effect of volume concentration to the viscosity for each set of temperature. The increase in nanoparticle loading in the nanofluid will increase the resistance of the molecules of the base fluid, hence the viscosity increases[15]. The viscosity of nanofluid decreases with the increasing in temperature. At this condition (temperature increasing), the velocities of individual molecules increase but the interaction time between each other decreases, thus resulting in viscosity decrease[16]. The same outcome has been reported in previous literature[15-17].

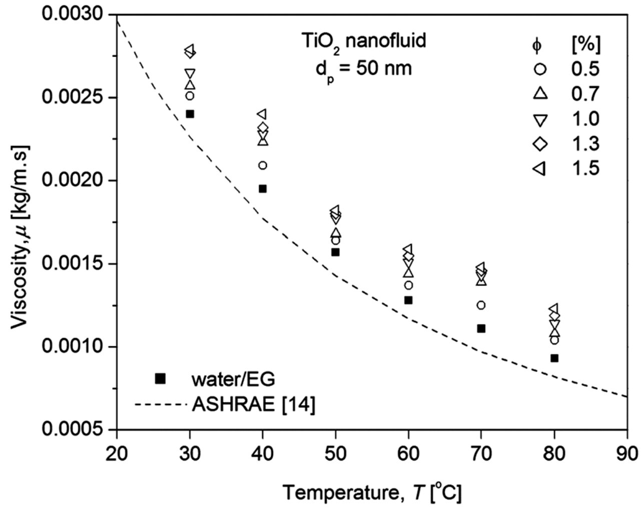

Fig. 4 — Effect of temperature to nanofluid viscosity.

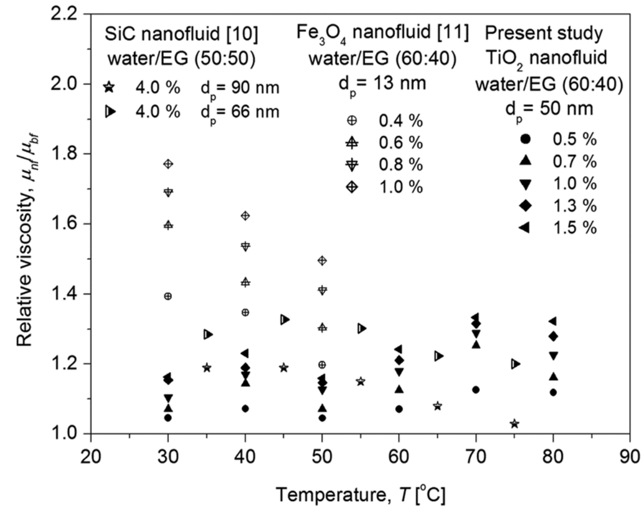

Fig. 6 — Comparison of titanium dioxide nanofluid with Timofeeva *et al*[10] and Sundar *et al*[11].

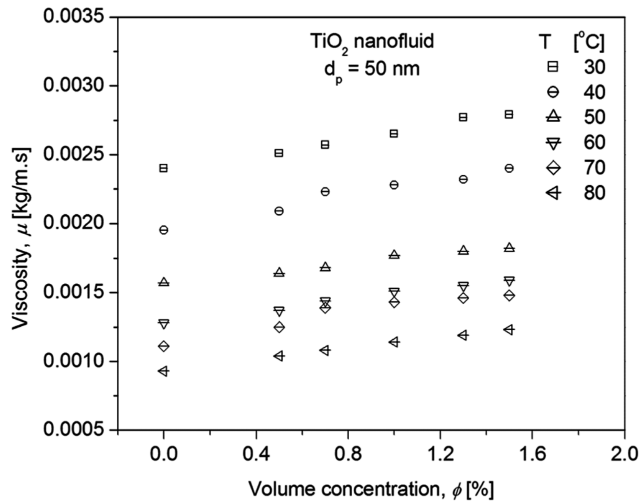

Fig. 5 — Effect of concentration to nanofluid viscosity.

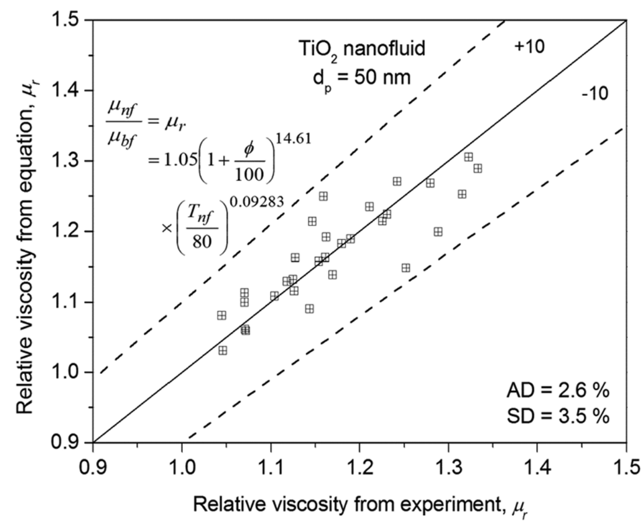

Fig. 7 — Comparison of present data with Eq. (3).

Figure 6 shows the comparison or relative viscosity of present data with Timofeeva *et al*[10] and Sundar *et al*[11]. The selected literature data is chosen as it is the exact or nearly approximate with the present base fluid ratio (60:40 water/EG). The relative viscosity of titanium dioxide nanofluids is independent of temperature. However, the increase in relative viscosity is proportional to the volume concentration observed at each temperature. There is no comprehensive explanation on such behaviour. However, this behaviour may also relate to the difference in the structure and thickness of the diffuse fluid layers around the nanoparticles in base fluids, which affects the effective volume concentration and ultimately the viscosity of the suspension[18].

Equation (3) is developed for the estimation of viscosity for mixture based nanofluids using the present experimental data. The equation is valid for particle concentration ranges from 0.5 to 1.5 %, liquid temperature from 30 to 80 °C and particle diameter less and equal to 50 nm. Figure 7 shows that the experimental data is in good agreement with the equation where the average deviation, standard deviation and maximum deviation are 2.6 %, 3.5 % and 9.1 %, respectively.

$$\frac{\mu_{nf}}{\mu_{bf}} = \mu_r = 1.05\left(1+\frac{\phi}{100}\right)^{14.61} \times \left(\frac{T_{nf}}{80}\right)^{0.09283} \quad \ldots (3)$$

4 Conclusions

The viscosity of titanium dioxide in mixture based increased with volume concentration. However, the increase in temperature will reduce the viscosity, which is advantageous for nanofluids to be applied in heat transfer application. The relative viscosity is independent with temperature, possibly due to the effect of mixture based on the overall viscosity. The provided equation is valid for nanofluids in mixture based for ranges of $0 \le \phi \le 1.5$ % and $30 \le T \le 80$ °C.

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List of symbols

Variables

ΔV additional volume (L)

T_{nf} temperature of nanofluid (°C)

V_1 initial volume (L)

V_2 final volume (L)

Greek symbols

ϕ volume concentration (%)

ϕ_1 initial volume concentration (%)

ϕ_2 final volume concentration (%)

μ viscosity (W/m.K)

μ_{bf} viscosity of base fluid (W/m.K)

μ_{nf} viscosity of nanofluid (W/m.K)

μ_r viscosity ratio

ω weight concentration (%)

ρ_{bf} density of base fluid (kg/m^3)

ρ_p density of nanoparticle (kg/m^3)

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