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Experimental study on dynamic viscosity of aqueous-based nanofluids with an addition of ethylene glycol

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Abstract. In this study, the effect of adding different nanoparticles in the mixture of deionised water and ethylene glycol on dynamic viscosity is investigated experimentally. In order to prepare for single nanofluids, the dry nanoparticles of SiO_2, Al_2O_3 and ZrO_2 were dispersed into 60% volume of deionised water and 40% volume of ethylene glycol as a base fluid using a two-step method. The experiments were performed in the temperature range of 30°C and 70°C and weight fraction ranging between 0.1wt.% and 1wt%. No surfactant used in preparing the nanofluids. The dynamic viscosity data were collected using DV-II+ Pro Brookfield viscometer. The single, dual-hybrid and tri-hybrid aqueous based nanofluids dynamic viscosity results are explicitly presented. From the results, it is exhibited that nanofluid viscosity decreases with increasing liquid temperature and increases with increasing of nanoparticles volume concentration. The viscosity decreases with increasing of deionised water volume percentage in the base fluid. Zirconia single nanofluid at 1wt.% recorded 2.5 times maximum enhancement of viscosity over the base fluid. The results display that single nanofluids have higher dynamic viscosity compared to hybrid nanofluids.

Keywords. Nanofluid; Deionized Water; Ethylene Glycol; Dynamic Viscosity; Temperature; Concentration.

1. Introduction

Nanofluid is a next-generation liquid which certain volume concentration of nanoparticles dispersed in a base fluid. This is an innovative approach of nano-technology that regards on the engineered colloidal suspension to overcome limited capabilities of thermal-physical properties of conventional liquids. A combination of solid and liquid in transferring the heat is more efficient rather than the liquid itself due to the mass motion of particles circulating in the system. The main idea of this concept introduced by Maxwell during his study in 1873 by adding solid particles into the liquid to improve the physical properties of conventional liquid[1]. However, due to multiple problems such as clogging and abrasion when micrometres particles were dispersed, there was no real application in any engineering system had been tested since then.

The era of nanofluid begins in 1995 after Choi discovered its great potential[2]. Single nanofluid is referred to a one-type or mono-type of nanoparticle with a small percentage of concentration disperse into the base fluid. While in recent years, dispersing two or more different types of nanoparticle in the base fluid, which can be considered as hybrid nanofluid attracts great attention of scholars globally to further enhance thermal-physical properties of single nanofluid [27]. According to Zhang et al.[3] and Li et al.[4], that hybrid or composite nanoparticles that disseminate in the base fluid exhibited higher and significantly improved heat transfer, cooling effect and antifriction performance than single nanofluid, especially in the metal cutting process. Due to its advantages, particularly on enhancing thermal-physical properties of the base fluid, nanofluid receives greater attention nowadays and promising in the future6. Therefore, researchers have focused on the potential of nanofluid on thermal conductivity[5][6], heat transfer[7][8], a viscosity[9][10] and the application of nanofluid in heat exchanger[11], photovoltaic[12] as well as in machining[13].

Even though most of the study focus on nanofluid thermal conductivity, however, nanofluid dynamic viscosity deserves the same attention because it has a severe effect on pumping power requirement and the coefficient of heat transfer in engineering systems[10]. Furthermore, the enhancement of nanofluid viscosity over the base fluid is higher than the enhancement of nanofluid thermal conductivity[10]. Garg et al.[14] reported that viscosity of copper nanoparticles enhanced four times over ethylene glycol and about 2 times enhancement of thermal conductivity for the same nanofluid and base fluid. Viscosity can be described as the internal resistance of the liquid to flow. For instance, in a laminar flow, the pressure drop is directly related to liquid viscosity that circulating in a system. Hence, viscosity is one of the essential characteristics, and the behavior of nanofluids viscosity should be explored. Sharma et al.[15] studied various hybrid nanofluids viscosity of different concentrations between 0.5 vol% and 3 vol.%. and viscosity was examined between 25°C and 50ºC. The results exhibited Newtonian behavior of hybrid nanofluids and viscosity ratio of hybrid nanofluids decrease with increasing of temperature. The maximum enhancement of viscosity recorded was 52.8% of (80%CeO_2+20%Cu) hybrid nanofluids. Sundar et al. [16] reported various viscosity results of Fe_3O_4-ethylene glycol/water nanofluids with different nanoparticle volume fractions and liquid temperatures. Based on experimental results, it showed that the viscosity of Fe_3O_4-ethylene glycol/water nanofluids increased by increasing the nanoparticle volume fraction and decreasing temperature. The maximum enhancement was recorded 2.9 times over the base fluid at a nanoparticle volume fraction of 1%. Bahadir et al.[17] reported that nanofluids have different rheology behavior. Based on the investigation at low temperature which below than 10°C, Alumina behaves non-Newtonian liquid and CNTs behave as a Newtonian liquid especially in high shear rate.

Esfe et al.[18] investigated viscosity of MWCNTs-TiO_2 hybrid nanofluids in 70% water and 30% EG as a base fluid. At 0.45% and 0.5% volume concentration, the results exhibited that hybrid nanofluids have a close Newtonian behavior, however, at 0.85vol.%, the graph of shear rate over shear stress indicated non-linear correlation which resulting non-Newtonian liquid. Moreover, at a lower concentration, the result indicated that no effect on hybrid nanofluids viscosity upon adding 10% excess of nanoparticles. Kerim et al.[19] studied viscosity dependency on nanoparticle size and concentration ranging from 5wt.% to 20wt.% of various metal oxide nanofluid. The measurements reveal that nanofluid greater than 5wt.% regardless of nanoparticles exhibited non-Newtonian behavior between 10^0 and 10^4 of shear rate. The relative viscosity has a strong dependency on particle size and nanoparticle loading, especially at higher weight concentration. Murshed and Estelle[20] suggested that nanofluid pH value, nanoparticle size and shape should be considered when investigating nanofluid viscosity as the published articles are very limited. Mahbubul et al.[9] also recommended considering nanoparticle size as one of the influencing factors when investigating nanofluid viscosity. Based on published articles and to the best of authors' knowledge, an evaluation of single, dual-hybrid and tri-hybrid of dynamic viscosity and a comprehensive comparison between them is very limited.

Therefore, the objective of this study is to evaluate dynamic viscosity of different nanofluids consists of single, dual-hybrid and tri-hybrid nanoparticles that dispersed in the mixture of deionised water and ethylene glycol. The effect of concentration, composition and temperature of dynamic viscosity of Al_2O_3/water-EG, SiO_2-Al_2O_3/water-EG and Al_2O_3-SiO_2-ZrO_2 / water-EG nanofluids are presented.

2. Methods and materials

In this study, to prepare for single nanofluids, the dry nanoparticles of SiO_2, Al_2O_3 and ZrO_2 were dispersed into 60% volume of deionised water and 40 % volume of ethylene glycol as a base fluid using a two-step method. Two concentrations were prepared at 0.2wt.% and 1wt.%. The nanoparticle size of SiO_2, Al_2O_3, and ZrO_2 are 20 nm – 21 nm, 13 nm -18 nm and 17 nm- 25 nm as the information was given by the manufacturer Sigma-Aldrich. Ethylene Glycol in liquid form which has 99.8% purity that contains water percentage less than 0.003% also purchased from Sigma-Aldrich. For dual-hybrid nanofluids, SiO_2-Al2O3 nanoparticles with 60:40 composition were dispersed in 60:40 of deionized water and ethylene glycol at 0.1wt.%. In order to evaluate tri-hybrid nanofluid dynamic viscosity, two different tri-hybrid nanofluids were prepared which SiO_2-Al_2O_3-ZrO_2 and Al_2O_3-ZnO-MWCNT. The composition of Al_2O_3-ZnO-MWCNT tri-hybrid nanofluid was 45:45:10 and 80:20 was the base fluid ratio of deionized water and ethylene glycol. While, for SiO_2-Al_2O_3-ZrO_2 tri-hybrid nanofluid, the hybrid composition was 60:30:10 and the base fluid ratio remain as 60:40. The base fluid was prepared at two different ratios due to evaluate the dependency of dynamic viscosity on the base fluid at a different ratio.

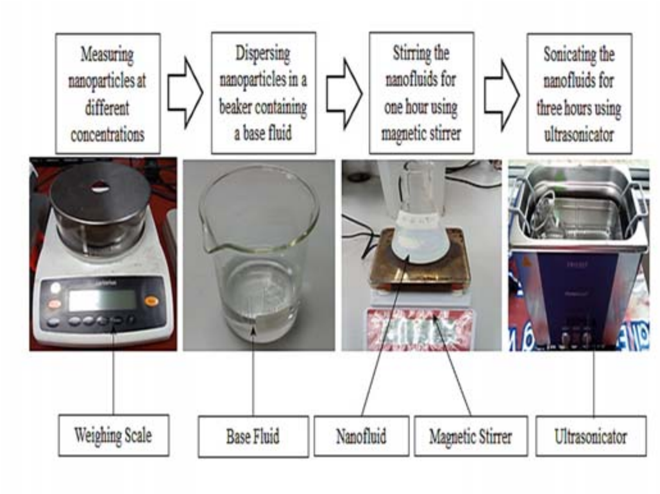


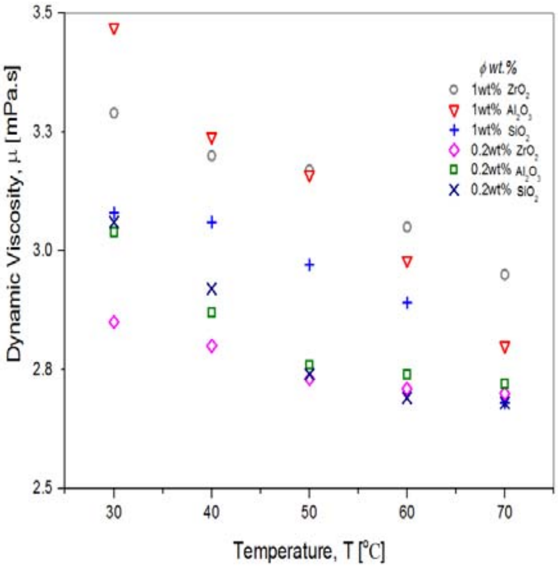
Figure 1. Step by step process of various nanofluids preparation at different concentrations.

The use of surfactant in preparing nanofluid is one of the effective methods to obtain homogenize suspension. However, the presence of surfactant in this study must be avoided due to it has an additional effect on the nanofluid dynamic viscosity. This additional factor besides weight concentration, temperature and type of nanofluid which would increase the complexity of the study. Hence, no surfactant was used in preparing the suspensions. The samples were stirred for one hour using magnetic stirrer. Then, the single, dual-hybrid and tri-hybrid nanofluids were being ultra-sonicated for 3 hours in ultrasonicator to obtain a homogenised suspension. Figure 1 shows step by step technique in preparing nanofluids from the early process until obtaining a homogenised suspension. Dynamic viscosity of these nanofluids was measured using DV-II+ Pro Brookfield viscometer, as shown in figure 2, with the temperature range within 30°C and 70ºC.

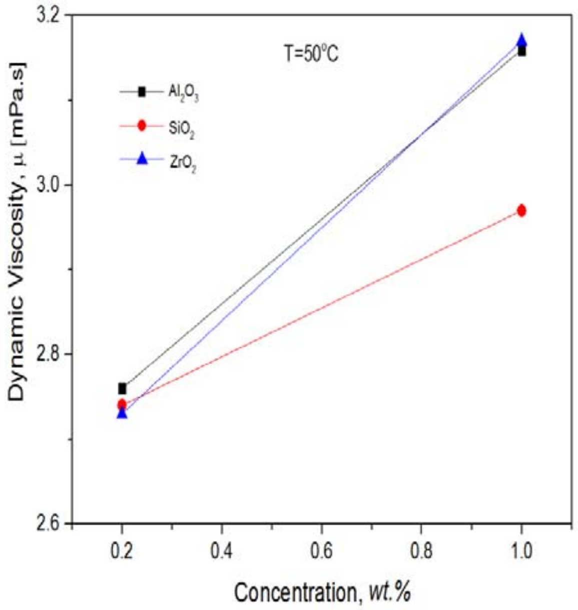
Figure 2. DV-II+ Pro Brookfield viscometer.

3. Results and discussion

Figure 3 shows the experimental results of dynamic viscosity of Al_2O_3, SiO_2 and ZrO_2 single nanofluids over temperature and concentration. Absolute dynamic viscosity of aqueous based nanofluids reduces with increasing of liquid temperature. As the temperature gradually rising, the bonding between molecules in nanofluids become weaker, resulting in low viscosity as presented in the results. The low viscosity of nanofluid at higher temperature is also associated with the increase of gases viscosity due to higher intensity of molecules movement leaving the nanofluid[21]. Dynamic viscosity increases remarkably with increasing nanoparticles weight concentration, as shown in figure 3(b). Similar findings also reported by Masoud et al. [22] Kole et al. [23] and Sundar et al. [24].



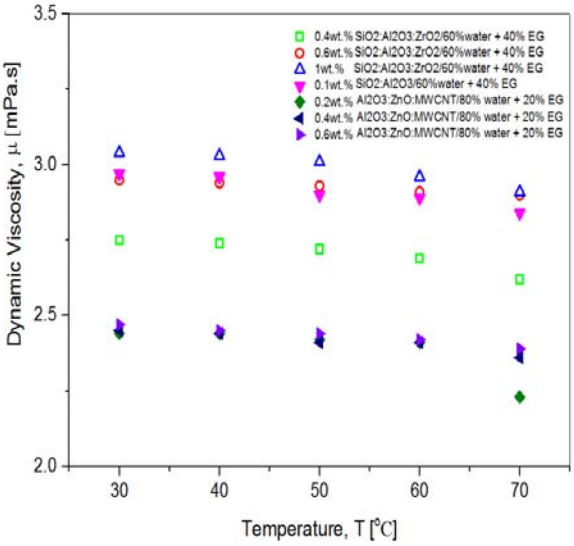
(a)



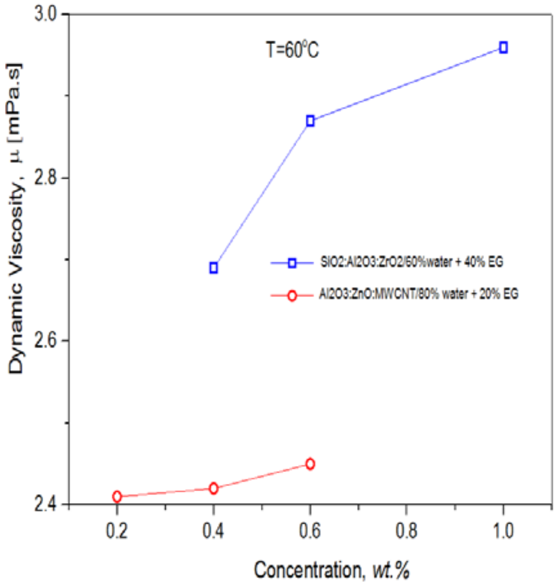
(b)

Figure 3. Dynamic viscosity of single nanofluids over (a) Temperature (b) Concentration.

Figure 4 reveals the experimental results of hybrid nanofluids dynamic viscosity over temperature and concentration. The results indicate that viscosity reduces remarkably when the volume percentage of deionised water increasing. Abdul Hamid et al.[25] also reported similar findings that the value of viscosity increased with increasing of ethylene glycol volume fraction ranging from 40% to 60%. Viscosity increases with increasing of weight concentration, indicating similar findings between single and hybrid nanofluids.



(a)



(b)

Figure 4. Dynamic viscosity of hybrid nanofluids over (a) Temperature (b) Concentration.

Figure 5 depicts a comparison of single and hybrid nanofluid viscosity over the base fluid. The presence of nanoparticles in the nanofluid has enhanced rheological properties with slightly minimal degradation over temperature compared to the base fluid. Dynamic viscosity of 1wt.% ZrO_2 nanofluid recorded the maximum enhancement, which was 2.5 times over the base fluid at 70°C, as shown in figure 6. The relative viscosity of nanofluids has linear proportional, which increases with increasing temperature. According to Esfe et al. [26], the viscosity ratio also enhances with increasing particle concentration and nanoparticle's diameter.

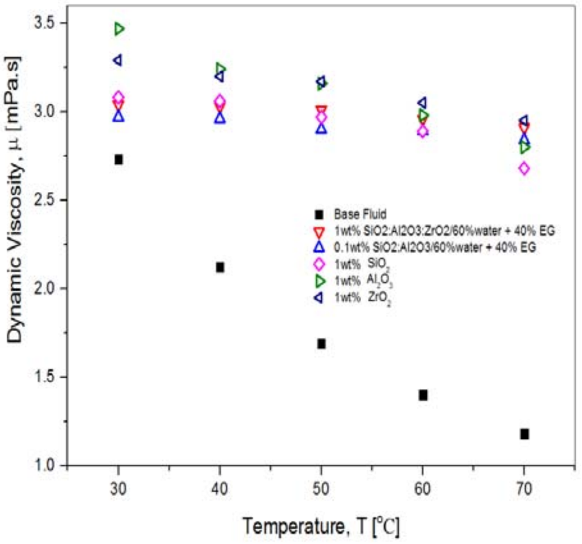


Figure 5. Comparison of the base fluid and nanofluids viscosity over temperature

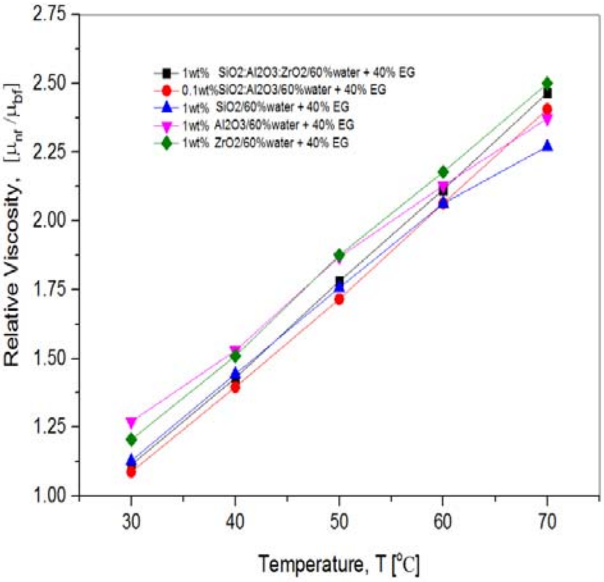


Figure 6. The relative viscosity of different nanofluids over temperature.

4. Conclusions

In this study, it can be concluded that nanofluid viscosity decreases with increasing temperature and deionised water volume percentage in the base fluid. However, nanofluid viscosity increases with increasing of weight concentration. These findings observed at both types of single and hybrid nanofluid. Zirconia single nanofluid at 1wt.% recorded 2.5 times maximum enhancement of viscosity over the base fluid. The results display that single nanofluids have higher dynamic viscosity compared to hybrid nanofluids. Nevertheless, this is an excellent finding for hybrid nanofluids because pumping and pressure losses could be minimized when the nanofluids applied in engineering systems. For future works, the dynamic viscosity of nanofluids with higher concentration and the presence of surfactant in the nanofluid can be explored.

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