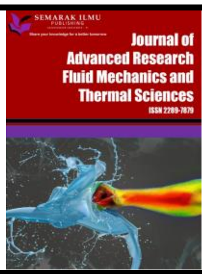
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Experimental Study on Thermo-Physical Properties of TiO_2-SiO_2 Nanofluids (70:30) in Water/Ethylene Glycol Mixture

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ARTICLE INFO

Article history:
Received 3 June 2023
Received in revised form 13 August 2023
Accepted 20 August 2023
Available online 31 August 2023

Keywords:
Dynamics viscosity; hybrid nanofluids; stability; temperature; thermal conductivity

ABSTRACT

Nanofluid is a solid particle that does not have a larger size than the 100 nm diffusion in the liquid. Its use can improve the nanofluids properties versus base fluid. More recently, many researchers are keen to know more about the combination of nanoparticles either two or more because of its effect to increase heat transfer in liquid heat. Thus, preparations between Silica (SiO_2) and Titania (TiO_2) in water (W) and ethylene glycol (EG) were carried out experimentally in volume concentrations between 0.3 and 1% and temperatures between 30-70 °C and 60:40 (Water: EG); 70:30 (TiO2-SiO2) with one step method. Thermal conductivity is measured by heat and viscosity method with viscometer equipment. Thermal conductivity results show that the increase with different temperatures. However, dynamic viscosity decreases with different temperatures. Studies show that hybrid nanofluids between SiO_2 and TiO_2 have an excellent thermal conductivity at a volume of 1.0% and a temperature of 70 °C indicating a right combination of nanofluid TiO_2-SiO_2.

1. Introduction

Nowadays, thermal energy is crucial to preserve the world's environment for green technology. Most researchers study nanofluid related to increased thermal energy demand which involves the heating and cooling process. This investigation proves that it is an application for the equipment industry such as cooling device, lubrication, solar collector, heat exchanger and vehicle cooling system [1-12].

According to Sundar *et al.,* [13], the combination of two or more different nanoparticles in the liquid base is intended for hybrid nanofluids. Higher heat conductivity and lower viscosity than microfluidics are the advantages of using nanofluid in heat transfer applications. There are many studies and reviews have published on the hybrid nanofluids for future investigation [14-24]. Their

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https://doi.org/10.37934/arfmts.108.2.200214

papers relate to hybrid nanofluid preparation, performance and application methods. Hence, to understand hybrid nanofluid behavior, investigation of thermal conductivity and viscosity is essential in the application of heat transfers.

Thereby, the investigation of thermal conductivity and dynamic viscosity of TiO_2-SiO_2 nanofluids is essential for understanding the heat and performance and physical behavior of nanofluids. There are many experimental studies conducted on hybrid nanofluids due to various advantages [25-32]. Some researchers have been conducting studies on thermal conductivity and dynamic viscosity of the necessary water mixture: ethylene glycol (EG). The results show that several factors have influenced the increase in thermal conductivity; including focus, working temperature, particle size, surface-to-volume ratio of nanoparticles and stability nanofluid [33-41]. The results show that thermal conductivity is mostly increased with the addition of nanoparticles into the base fluid.

Lately, many researchers carry out studies on hybrid nanofluids for thermal conductivity and dynamic viscosity [42-48]. Baghbanzadeh *et al.,* [49] have presented its working papers on thermal conductivity and dynamic viscosity of SiO_2 / MWCNT nanofluids. The results show that nanofluids concentration increases are essential and it affects the nanofluid hybrid. However, improvements are found to be lowest in high concentrations. Thus, the combination of nanofluids increases with increasing nanofluids concentration is a sufficient thermal conductivity. Performance of heat transfer is important in giving an understanding of its behavior by investigating dynamic viscosity and thermal conductivity of TiO_2-SiO_2 nanofluids. Therefore, the volume concentration of 0.3 to 1.0% has provided for TiO_2-SiO_2 nanofluids with water/EG mixture to obtain the thermal conductivity and dynamic viscosity below 30-70° C with 10° C intervals. The measurement on TiO_2 and SiO_2 nanoparticles dispersed in a mixture of water/EG are very limited. Investigator such as Hamid *et al.,* [50] and Nabil *et al.,* [51] were measured TiO_2-SiO_2 nanofluids in water/EG mixture (60:40) with volume concentrations up to 3.0%, and the temperatures range from 30 to 80° C. Furthermore, some researchers use TiO_2-SiO_2 nanofluid with a ratio of 50:50.

The present study is carried out by preparation and thermo-physical properties of TiO_2-SiO_2 nanofluids ratio 70:30 in water/EG (60:40) mixture with volume concentrations 0.3, 0.5, 0.7 and 1.0% and the temperatures range from 30-70°C. The measurement of thermal conductivity and dynamic viscosity were measured by using KD2 Pro Thermal Properties Analyser and Brookfield LVDV III Ultra Rheometer.

2. Methodology

2.1 Preparation of Nanofluids

The nanoparticles used in the study were Titanium Oxide (TiO_2) and Silicone Oxide (SiO_2). Those procured from US Research Nanomaterials, Inc. (USA) in a water suspension with 40 wt. % concentration and 30-50 nm in size for TiO_2 and 25 wt. % concentration and 30 nm in size for SiO_2 as shown in Figure 1(a) and Figure 1(b). Eq. (1) is used to convert weight concentration to volume concentration while Eq. (2) Is utilized to prepare the hybrid nanofluid in a volume concentration range of 0.3 to 1.0% using dilutions by adding the base fluid [52]. A mixture of water and ethylene glycol at a volume ratio 60:40 used as base fluid in the present study and the nanofluids prepared was subjected to a mixing process using a mechanical stirrer for 30 minutes and underwent a sonication process using a Fisherband ultrasonic bath for 2 hours for each concentration prepared to enhance the stability of the nanofluid [53,54]. Table 1 presented the characteristics of TiO_2- SiO_2 nanoparticles and water/ EG.

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

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

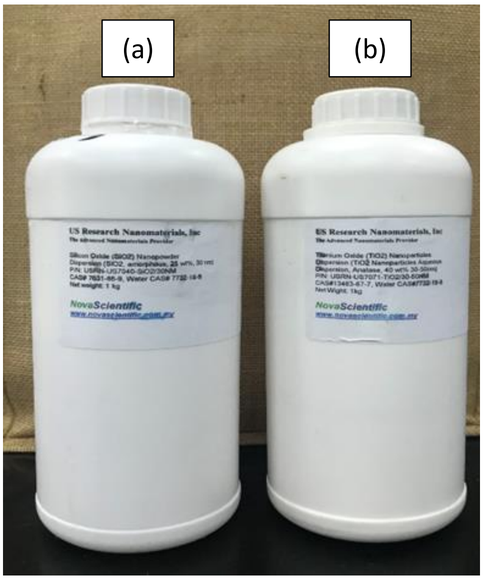
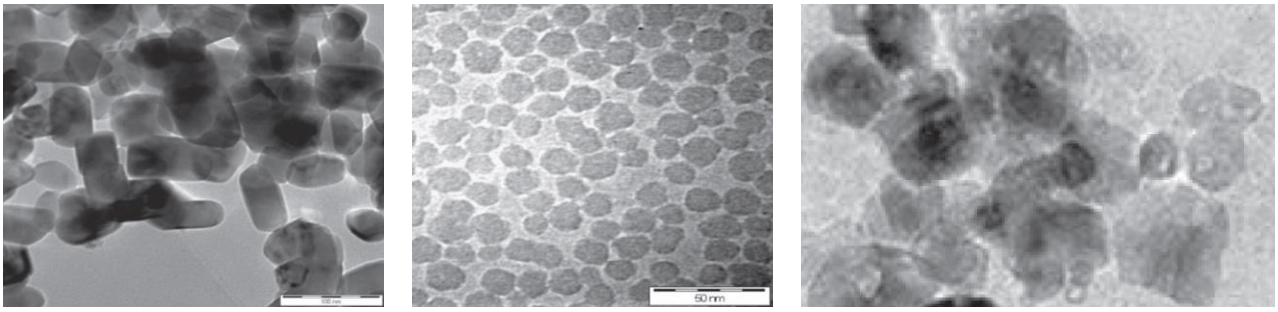


Fig. 1. Commercial nanoparticles for (a) Titanium Oxide (TiO_2) and (b) Silicone Oxide (SiO_2)

Table 1
Characteristics of TiO_2-SiO_2 nanoparticles and Water/EG [19]

Characteristics	TiO_2	SiO_2	Water/EG
Purity (%)	99	99.99	99.5
Color	White	Colorless	Colorless
Size (nm)	30-50	22	-
Concentration (wt %)	40	25	-
Density (kg/m^2)	4230	2220	-

The diffusion of nanoparticles in the base liquid is used to be observed via a transmission electron microscope (TEM) [55,56]. Other researchers also use this technique extensively [55,56]. Figure 2(a) and Figure 2(b) show TEM images for both TiO_2 nanoparticles (enlargement X 140,000) and SiO_2 (enlargement X 35,000). TiO_2 nanoparticles are observed almost round with an average size of 100 nm as shown in Figure 2(a). Additionally, SiO_2 nanoparticles found in the sphere with an average size of 22 nm as shown in Figure 2(b) and 2(c) illustrated TEM images with X 39,000 magnification for the distribution of particles of both SiO_2 and TiO_2 nanoparticles suspended in W: EG-based nanofluids. From Figure 2(c), larger particle sizes represent TiO_2 while smaller sizes represent SiO_2 nanoparticles. SiO_2 nanoparticles fill the gap between TiO_2 nanoparticles. This condition will contribute to the reduction of space between particles. In general, the mixed ratio representing the percentages of each nanoparticle in the final solution depends on the coordination of two nanoparticles. Thermal conductivity and thermal properties can provide thermal properties, and these conditions may contribute to the reduction of space between more massive particles. Additionally, changes in physical properties such as viscosity and density are expected to change according to these conditions. Hence, the work is now investigating the ratio of nanoparticle with 70:30 mixtures to the effective thermal conductivity and dynamic viscosity of TiO_2-SiO_2 nanofluid.



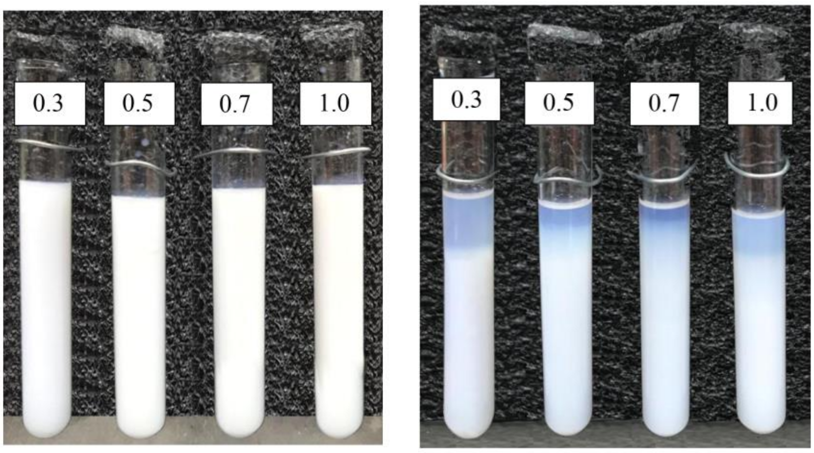
(a) (b) (c)

Fig. 2. Transmission electron microscope (TEM) Images [50]; (a) Single TiO_2, (b) Single SiO_2, (c) Hybrid TiO_2/SiO_2

2.2 Stability of Hybrid Nanofluid

One of the factors that can affect the performance of nanofluids is stability [57]. Decreasing the thermal conductivity of nanofluid is the solution and blockage of microchannels produced through the accumulation of nanoparticles. Hence, the properties that affect nanofluid are also of stability. It is one of the significant issues that can change the nature of the nanofluid either to analyze factors affecting the spread of nanofluid stability or nanofluid stability directly related to its electro-kinetic properties. The balance of the Al_2O_3-Cu nanofluids hybrid investigated at different volumes of volume, and it occurred when the delay in freezing caused their potential loss of heat transfer [58]. Therefore, stability in the evaluation and investigation should not ignore. In the heat transfer application, the thermal properties of the hybrid nanofluid thermal if it can be reduced then good stability can change and produce an efficient performance.

Based on this research, each sample provided with a minimum of 200 ml. Each sample exposed to sonication for 2 hours. For each particle, this process improves stability and reduces the size of agglomeration [59,60]. Visually, in the method of nanofluid measurement is stable and each sample will be observed after preparation and after 60 days of preparation through visual deposition. When the particle size of the supernatant particles is kept constant, nanofluid is considered stable [50]. Figure 3 below shows a sedimentation observation for hybrid nanofluid. According to Yu and Xie [59], nanofluid considered stable when the concentration or particle size of the supernatant particles is kept constant. Sedimentation observations for hybrid nanofluids shown in Figure 3. The value of nanofluid stability determined by Ultra Violet-Visible (UV-Vis) spectrophotometer. The absorption and diffusion of light were measured by comparing TiO_2-SiO_2 nanofluid light intensity with the primary fluid 60:40 (water: EG) [50]. In this study, the ratio of different concentration absorption to the sedimentation time is observed accordingly at a constant 850 nm wavelength.

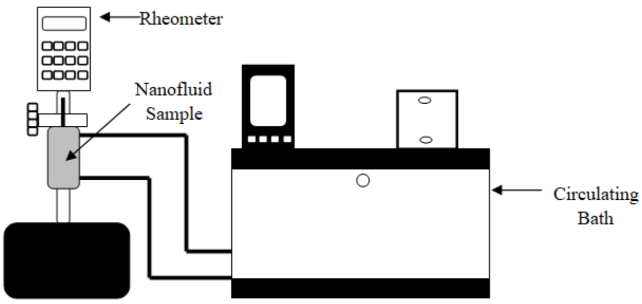


(a) (b)

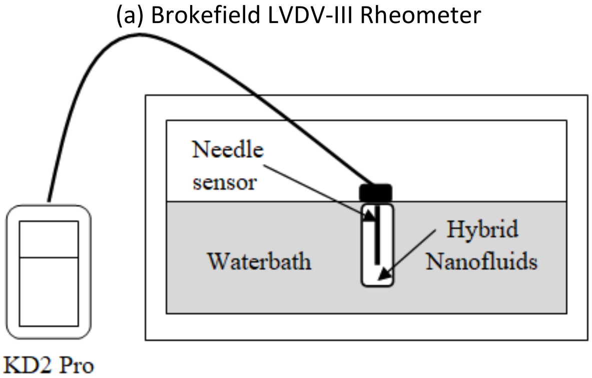
Fig. 3. Sedimentation observation of TiO_2-SiO_2 nanofluids samples; (a) first day, (b) after 60 days

2.3 Thermal Properties Measurement

The thermal conductivity and dynamic viscosity of nanofluid measured with a KD2 Pro Thermal Analyzer and a Brokefield LVDV-III Rheometer as shown in Figure 4(a) and (b) respectively. For the setup of KD2 Pro Property Analyzer (Decagon Devices) according to the ASTM D5334 and IEEE 442-1981 standards can measure thermal conductivity. The heat source is used to measure the thermal properties at different temperatures. Maintain a constant sample temperature; measurements can perform in a bath. Decagon Devices are supplying standardized instrumentation achieved through the liquid conductance thermal conductivity sensor of the glycerin.



(a) Brokefield LVDV-III Rheometer



(b) KD2 Pro Thermal Analyzer

Fig. 4. Measurement devices

However, for viscosity measurement, the tool used is Brookfield LVDV III Ultra Rheometer (Brookfield). The rheometer with a sample of 16 mL is inserted into a screwed cylinder and sealed it. For viscosity measurements, the Rheocal program connected to the laptop used. The speed of the spindle rotation is changed to obtain the viscosity of the sample assessed. Circulating water baths can control through sample temperature, the average value reported by repeating the measurement three times.

In this research, the measurement conducted at a temperature range of 30-70 °C. The sample temperature was controlled by immersing in a water bath during the analysis. A minimum of three readings for each temperature set and concentration took, and average values considered. The previous researchers that used the same apparatus for thermal conductivity and viscosity measurement were such as Hamid *et al.,* [61], Abareshi *et al.,* [62], Usri *et al.,* [63] and Iqbal *et al.,* [64]. The accuracy of the instrument and experimental procedure is validated using data from ASHRAE [65] at the same mixture ratio of water (60): EG (40).

3. Results

3.1 Stability of Hybrid Nanofluids

Ultra-sonicator is used to ensure nanofluid is stable and reduces agglomerate size through sonication process. A total of 200 mL of nanofluid provided and exposed to the sonicator for 2 hours, and then the results throughout the nanofluid measurement process are in a very stable state. As in Figure 3(a), nanofluids prepared through a one-step method do not show deposition, and this proves that the nanofluid is in a good state. Based on this visual examination, many researchers are doing the same thing and their stability assessments studied at different temperatures [66,67].

To evaluate the stability of the TiO_2-SiO_2 nanofluid hybrid volume concentration, spread in W: EG with a 60:40 mixing ratio, easy deposition testing performed inside. Parameters taken into account during the sedimentation process occur at the percentage of velocity progress in time. The faster process occurs if the setting is higher as shown in Figure 5. The initial height of the homogenous nanofluid space represents ho in millimeters and the elevation of sedimentation hs in time (days). TiO_2-SiO_2 nanofluid stability is determined by the absorption as shown in Figure 3(b). The sample left for 60 days at the return temperature. The ideal absorption ratio will be one (100%) representing excellent stability during the deposition period. A closer rate is one with an increase in deposition time to determine the balance of the sample.

The same investigation of nanofluid stability using UV-Vis spectrophotometer was previously recommended and studied by Hwang *et al.,* [57] and Lin *et al.,* [68]. Nanofluid TiO_2-SiO_2 absorption and sedimentation time are observed frequently for 240 hours for a different wavelength of 850 nm as shown in Figure 6. Thus, it can conclude here that nanofluid has more potential for agglomeration and rapid deposition at lower concentrations. In terms of absorption, it also shows a high concentration of more suspended nanoparticles.

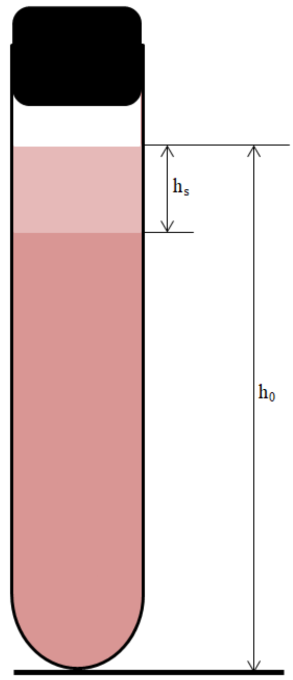


Fig. 5. Illustration of the nanofluid sample on the sedimentation process

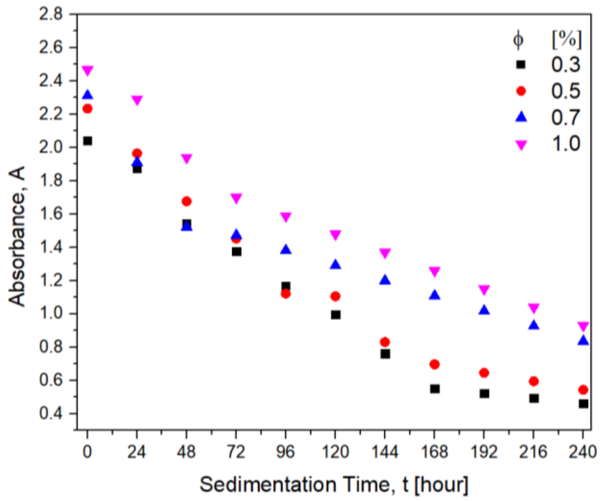
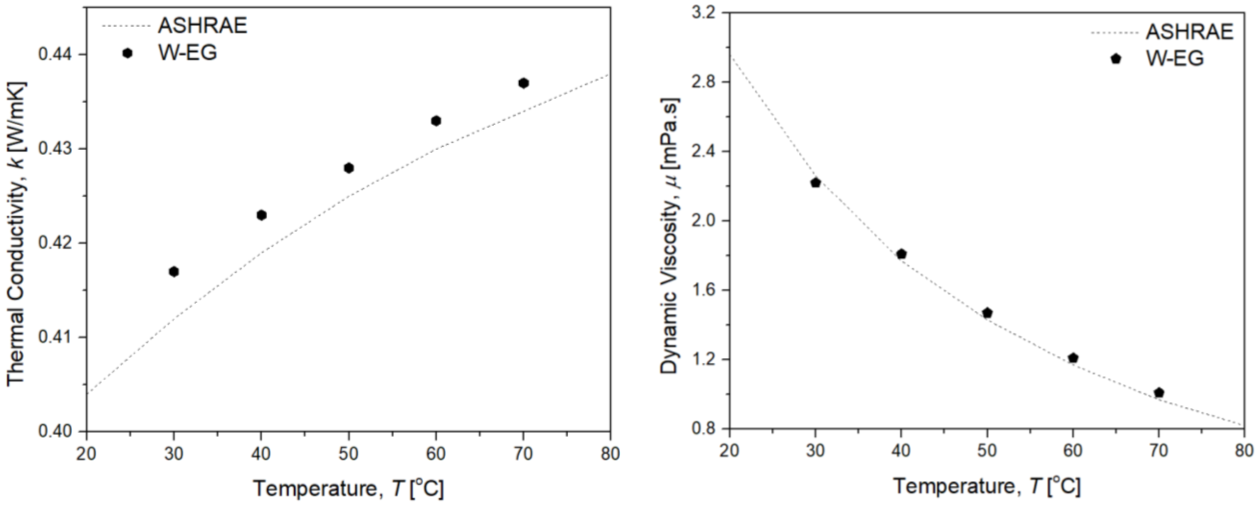


Fig. 6. Absorbance with sedimentation time

3.2 Thermo-physical Properties Validation

Comparison of data between ASHRAE [65] and water/EG mixtures confirm the thermal conductivity and viscosity measurements. The verification result with a 0.9% error for thermal conductivity measurements using KD2 Pro can show in Figure 7(a). A total of 0.7% water/ EG data mixed at maximum deviation. Reddy and Rao [69] find that their primary liquid difference over ASHRAE [65] is up to 2.5% during the verification test. Therefore, this study can be adopted as there is only a small deviation. The same method also used for viscosity data. Figure 7(b) shows that there is good agreement with ASHRAE [65] when the viscosity data compared. Based on the input on the plot it is found that the primary liquid data of the water / EG mixture obtained according to the same trend as ASHRAE [65]. Thus, the nanofluid TiO_2-SiO_2 hybrid for various volume concentrations conducted and investigated for further measurement purposes for thermal conductivity and dynamic viscosity.



(a) (b)

Fig. 7. Validating of Water-EG with ASHRAE [65]; (a) thermal Conductivity for validating, (b) viscosity for validating

3.3 Thermal Conductivity and Dynamic Viscosity of TiO_2-SiO_2 Nanofluids

All nanofluids thermal conductivity at this concentration is higher than its primary liquid. Figure 8 shows the thermal conductivity of the TiO_2-SiO_2 nanofluids at a concentration of 0.3, 0.5, 0.7 and 1.0% and a temperature between 30-70 °C with a difference of 10 °C, improved at concentrations and temperatures can cause thermal conductivity as well as increased TiO_2-SiO_2 nanofluids. Figure 8 shows the thermal conductivity of TiO_2-SiO_2 nanofluids. At a concentration of 1.0% and a temperature of 70 °C, there was a maximum increase higher than the base fluid. The observation of this trend seems to be related to the Brownian movement. At high temperatures, particle collisions occur at higher rates, thereby bringing more kinetic energy. Therefore, thermal conductivity increased [70,71]. The same trend was investigated in nanofluid thermal conductivity faced by Vajjha and Das [72] with primary water fluids and EG mixes but with different nanoparticles.

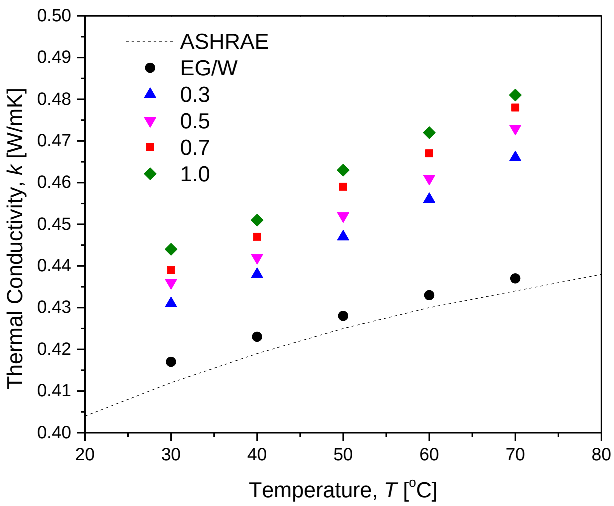


Fig. 8. The thermal conductivity of nanofluids at different temperatures and volume concentrations

Viscosity is essential in determining the properties of nanofluids. Figure 9 shows different viscosity data for different concentration and temperature. Based on the graph, the nanofluid TiO_2-SiO_2 viscosity is higher than the base liquid and increases according to the concentration of the liquid. For high volume concentration, it is clearly showing that the increase of viscosity concerning concentration and base fluid. As compared to a single type of nanofluid, the interaction between hybrid nanofluids and base fluid contributes better enhancement. It found by Bahrami *et al.,* [44], Soltani and Akbari [47] Hamid *et al.,* [50], and Nabil *et al.,* [51]. The base fluid trend decreases with temperature rise following the nanofluid viscosity. When the bonding of nanoparticle is weak, and temperatures increase, the viscosity will decrease [48,73,74]. The finding is consistent with the results of past studies by Duangthongsuk and Wongwises [75], Hamisa *et al.,* [76] and Fikri *et al.,* [77].

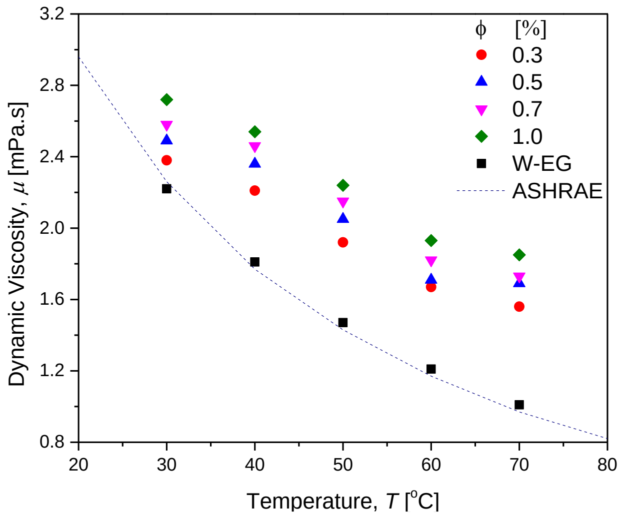


Fig. 9. Dynamic viscosity of nanofluids with different temperatures

3.4 Comparison with Literatures

Figure 10 and 11 demonstrate comparisons of the thermal conductivity and viscosity of the present study with the data from Nabil *et al.,* [51]. In the present study, the thermal conductivities of the nanofluids were enhanced by 1.05–1.1 times compared to the base fluids. Nabil *et al.,* [51] TiO_2-SiO_2 nanoparticles in EG / Water mixture used in their studies are lower than the present study. Comparison dynamics viscosity from literature in demonstrated Figure 11 showed 0.98% and 1.05%, 1.14% higher at 30-50 °C respectively, compared to the present study. According to Sundar *et al.,* [34], the magnitude of enhancement in thermal conductivity or relative viscosity depends on the types of nanoparticles and base fluid, hence it was observed and illustrated in Figure 10 and Figure 11.

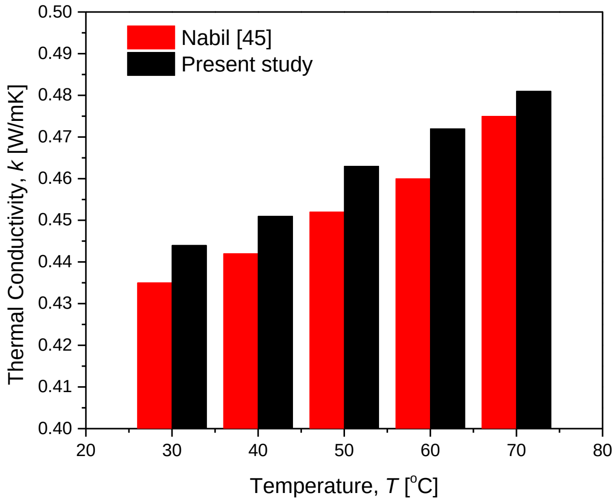


Fig. 10. Comparison thermal conductivity of nanofluids from literature

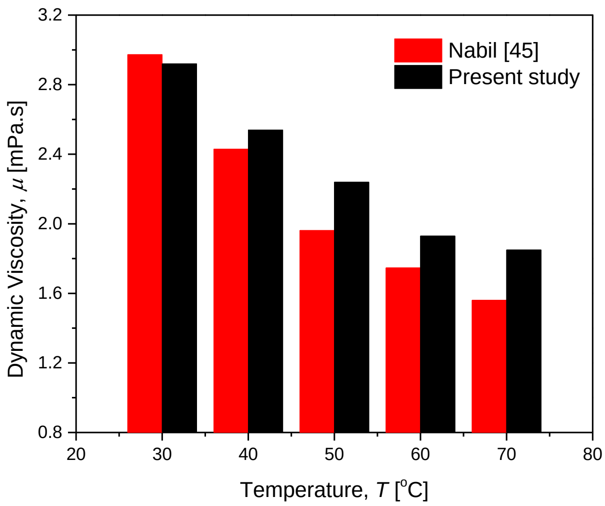


Fig. 11. Dynamic viscosity of nanofluids with different temperatures

4. Conclusions

The purpose of this study was to investigate and study the thermal conductivity and dynamic viscosity of TiO_2-SiO_2 nanofluid based on Water/Ethylene Glycol. This study is concerned with the analysis of the experiments of TiO_2-SiO_2 nanofluids of 70:30 ratio mixed with W/EG in a 60:40 ratio mixes at various temperatures at 30-70 °C. Based on the results obtained, summarized the main findings for this investigation: (i) the ultrasonication process which is prolonged and without the use of any surfactant, nanofluid hybrid in a stable condition of volume concentration of 0.3-1.0%. Visual checks and stability of sample deployment checked. (ii) the increase in thermal conductivity observed at a concentration of 1.0% and a temperature of 70 °C. (iii) the thermal conductivity of TiO_2-SiO_2 nanofluids shows increasing with an increase in temperature, while viscosity shows the decreasing with the rise of temperature.

Acknowledgement
The facilities of a laboratory to the authors by the Advanced Automotive Liquid Laboratory, Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah is gratefully acknowledged.

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