Journal of Physics: Conference Series

Thermo-physical Properties of TiO2-SiO2 Hybrid Nanofluids Dispersion with Water/Bio-glycol Mixture

To cite this article: S N M Zainon *et al* 2021 *J. Phys.: Conf. Ser.* **2000** 012003

Thermo-physical Properties of TiO_2-SiO_2 Hybrid Nanofluids Dispersion with Water/Bio-glycol Mixture

S N M Zainon[1], W H Azmi[1,2,*] and A H Hamisa[1,3]

[1] Department of Mechanical Engineering, College of Engineering, Universiti Malaysia Pahang (UMP), Lebuhraya Tun Razak, Gambang, Kuantan 26300 Pahang, Malaysia
[2] Centre for Research in Advanced Fluid and Processes, Lebuhraya Tun Razak, Gambang, 26300 Kuantan, Pahang, Malaysia
[3] School of Engineering, Faculty of Science, Engineering and Agrotechnology, University College of Yayasan Pahang (UCYP), Taman Gelora, Jln Dato' Abdullah, Kuantan 25050 Pahang, Malaysia

*Corresponding author: wanazmi2010@gmail.com

Abstract. Introducing nanoparticles in liquid-based mixtures began to gain attention in various industries. This is supported by previous studies to improve the performance and provide energy saving for the system. Among its uses is in the VCRS and automotive air conditioning (AAC) system. The lubricant used in this system has the potential to have a good effect on the performance. Before testing the nano-lubricant enhancement performance, an automotive air conditioning (AAC) system test rig based on hybrid electric vehicles (HEV) AC system has to be developed; therefore, this paper presented the development process of AAC test rig specific for the HEV. In order to analyze the performance, 11 thermocouples, digital pressure gauges with the data logger, and AC/DC power clamp were assembled and used. After that, the experiment was conducted with five different initial refrigerant charges and three different compressor speeds. This method was applied to both pure POE lubricant and SiO_2/POE nano-lubricant. Then, the heat absorbs, compressor work, and coefficient of performance (COP) were evaluated. The highest average COP for SiO_2/POE nano-lubricant was achieved at a 40 % duty cycle (2520 RPM) speed with a value of 2.84. The highest enhancement of the COP is 25.1% at 60% duty cycle (3180 RPM) speed with 160 grams of initial refrigerant charged an average enhancement of the COP is 13.16%.

1. Introduction

The energy crisis has long been discussed globally. As technology advances in many industries, continuous energy consumption has led to increased energy shortages and costs. By 2050, energy demand is expected to increase twice as much as the energy currently supplied [1]. Therefore, dependence on fossil fuels as an energy source should be reduced as these sources are finite and currently depleting at high rates. Furthermore, greenhouse gas emissions cannot be effectively controlled due to the combustion of fossil fuels to produce electricity. Hence, many researchers conducted investigations on thermal management to increase the efficiency of the thermal system and reduce its size to reduce the rate of energy consumption.

The efficiency of heat transfer can be increased by enhancing the thermal conductivity of the working fluids. However, the enhancement of heat transfer using conventional fluids has been stunted due to the poor thermal properties possess by conventional fluids. Therefore, the development of new heat transfer fluids with high thermal conductivity is essential to increase the heat transfer rate. In the last few years, nanofluids rise as a new heat transfer fluid due to their superior thermal properties compared to conventional fluids such as water, oil, propylene glycol, and ethylene glycol. Nanofluids are suspended with nano-sized particles like Cu, Al_2O_3, TiO_2, CuO, SiO_2, Fe_2O_3, and graphene. The act of dispersing nanoparticles in the base fluids probably started when Masuda et al. [2] dispersed a small amount of Al_2O_3, TiO_2, and SiO_2 in the water at different particle concentrations. Improvement in thermal conductivity has been demonstrated in their experiment with the addition of nanoparticles in base fluids, which led to many further investigations on nanofluids using different types of nanoparticles. Fluids containing milli and micro-sized particles can probably achieve the same enhancement in thermal properties as nanoparticles; however, there is a high possibility for the system to clog due to the large agglomeration of the particles [3]. Besides, compared to the fluids suspended with milli and micro-sized particles, nanofluids displayed better suspension stability [4]. Due to these advantages, nanofluids have high potential as a new heat transfer fluid for many engineering applications involving cooling and heating processes.

Although there are inconsistencies in reports on how these particles can increase the rate of heat transfer, several factors that have been reported in previous research are fluid concentrations, type of nanoparticles, base fluids, and temperature [5-9]. The thermo-physical properties of nanofluids, such as thermal conductivity, dynamic viscosity, density, and specific heat, can show maximum or minimum increment depending on the abovementioned factors. Recently, hybrid nanofluids have been developed by dispersing two or more dissimilar nanoparticles in base fluids to extend the study of single nanofluids. Taherialekouhi et al. [10] performed an experimental study on the thermal conductivity of water-based GO-Al_2O_3 hybrid nanofluid at various volume fractions and temperatures. They observed an enhancement of thermal conductivity up to 33.9% with increasing concentrations and temperature. Kakavandi and Akbari [11] also reported a similar pattern for the study of MWCNTs-SiC hybrid nanoparticles in the mixture water-EG base fluid. The thermal conductivity of the nanofluids was increased by up to 33% at 0.75% volume fractions and a temperature of 50 °C. Oliveira et al. [12] investigated the thermal conductivity of diamond-silver hybrid nanoparticles dispersed in ethylene glycol base fluid. The experiment was carried out at different volume fractions range between 0 to 0.1% of nanodiamond, and the temperature range between 10 to 60 °C. The thermal conductivity was enhanced by 6.92% at the highest concentration of nanodiamond, which is 0.1%. Besides, they also showed that the increase in thermal conductivity is more affected by concentration than temperature.

The addition of nanoparticles in the base fluids causes an increase in the dynamic viscosity, resulting in a higher pressure drop, leading to an increase in pumping power. Thus, the study on the dynamic viscosity in literature can be seen as thermal conductivity. Hamid et al. [13] studied the dynamic viscosity of the suspended TiO_2-SiO_2 nanoparticles in the mixture of water and EG at 1.0% volume concentration. The TiO_2-SiO_2 was combined at a different mixture ratio of 20:80, 40:60, 50:50, 60:40, and 80:20. In the experiment, the dynamic viscosity varied with the temperature, where it decreases as temperature increases. The variation of the dynamic viscosity with the mixture ratio of nanoparticles is not following any increasing or decreasing pattern; however, the dynamic viscosity of TiO_2-SiO_2 hybrid nanofluids at all mixture ratios was found lower than the TiO_2-SiO_2 hybrid nanofluids at a mixture ratio of 50:50. Wole-Osho et al. [14] also experimented with studying the effect of the nanoparticle mixture ratio on the dynamic viscosity. They formulate Al_2O_3-ZnO nanoparticles suspended in water at 1:2, 2:1, and 1:1 at various volume concentrations range between 0.33 to 1.67%. The dynamic viscosity increase as the concentration increase, and the maximum dynamic viscosity, 96.37%, was observed with Al_2O_3-ZnO nanofluids at a mixture ratio of 2:1. In a study conducted by Dalkılıç et al. [15], SiO_2 and graphite were formulated at different volume concentrations (0.1 to 2%) and mixed at 20:80, 40:60, 60:40, and 80:20 mixture ratio. The dynamic viscosity of the hybrid nanofluids was measured in the temperature range between 15 to 60 °C. They reported an increment of the dynamic viscosity with the increase of concentrations but decreased as temperature increases. Besides, the dynamic viscosity was found to decrease when the ratio of SiO_2 nanoparticles decrease, with the lowest average increment of the dynamic viscosity found at 80:20 graphite- SiO_2 mixture ratio at all concentrations.

The study on the thermo-physical properties of various combinations of nanoparticles is essential to understand how these factors influence the improvement of heat transfer. Recently, Abdolbaqi et al. [16] conducted a study on the thermal conductivity and viscosity of SiO_2 single nanofluid in the water/Bio-glycol base fluid. As a result, they found a significant improvement in the thermal conductivity of the nanofluid. However, the study on thermo-physical properties of hybrid nanoparticles suspended in a Bio-glycol is very limited in the literature. Hence, the present study investigates the thermo-physical properties of TiO_2-SiO_2 hybrid nanofluid in the mixture of water and Bio-glycol at various concentrations and temperatures.

2. Methodology

2.1 Preparation of TiO_2-SiO_2 hybrid nanofluids

In the present study, TiO_2 and SiO_2 nanoparticles were used for dispersion with the base fluid. The TiO_2 and SiO_2 nanoparticles with 40% and 25% weight concentration and diameter approximately 30-50 nm and 30 nm, respectively, were acquired from US Research Nanomaterials, Inc. (the USA). The mixture of water and Bio-glycol (W/BG) at a 60:40 mixture ratio was considered the base fluid. Bio-glycol (BG) is an odorless and colorless heat transfer fluid supplied by Dynalene with a pH range between 7 to 11. The TiO_2 and SiO_2 single nanofluids were prepared separately at 0.5 to 1.5% volume concentrations, and then the nanoparticles were mixed at a 20:80 ratio to produce hybrid nanofluids. First, Eq.(1) is used to convert the weight concentration of the nanoparticles to the volume concentration. Then, by using the dilution method [17, 18], Eq.(2) is employed to obtain the desired concentration by adding the volume (ΔV) of W/BG to the nanofluid. Finally, the TiO_2 and SiO_2 hybrid nanofluids were subjected to 3 hours sonication hour to break the agglomeration of the particles and improve the stability.

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

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

2.2 Measurement of thermal conductivity

The thermal conductivity of TiO_2-SiO_2 hybrid nanofluids was measured by using the C-Therm TCi Thermal Analyzer, as shown in figure 1. It is rapid measurement equipment procured from C-Therm Technologies (Ltd.) with 5% accuracy and capable of measuring thermal conductivity between 0 to 500 W/m.K at temperatures between -50 to 200 °C. The sensor in the system has been calibrated in the factory and does not require further calibration in the future. Nevertheless, the validation process was still carried out using the standard solution provided by the manufacturer to verify the accuracy of the measurement. In the present study, the thermal conductivity of TiO_2-SiO_2 hybrid nanofluids was measured at a temperature between 30 to 70 °C. The temperature of the nanofluids to be measured was controlled by placing a small amount of sample in Memmert Universal Oven (UN30), as shown in figure 2. Once the desired temperature is reached, the measurement for thermal conductivity is taken several times for each sample.

Figure 1. C-Therm TCi Thermal Analyzer

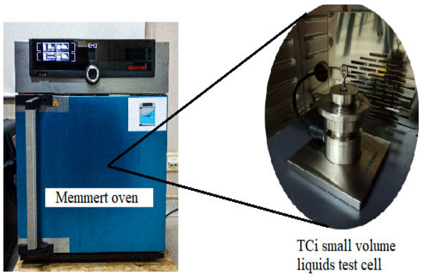


Figure 2. Memmert Universal Oven (UN30)

2.3 Measurement of dynamic viscosity

Figure 3 shows the Anton Paar Rheolab QC rotational rheometer used for the dynamic viscosity measurement. This equipment is fitted with a temperature control device that uses air to control the temperature of the sample. It can be operated at a speed between 0.01 to 1200 pm and can measure the dynamic viscosity between 1 to 10^9 mPa.s at a temperature in the range of 0 to 180 °C. A double gap measuring system (DG42), as presented in figure 4, was used to measure fluids with low viscosity. To start the measurement, approximately 14 mL of sample was taken and place in the measuring cylinder. Then, the DG42 measuring cylinder is attached to the rheometer motor for the Rheocompas software to detect the measuring system. The operating temperature to measure the dynamic viscosity of W/BG and TiO_2-SiO_2 hybrid nanofluids was set in the software in the range of 30 to 70 °C. The measurement was repeated several times to obtain reliable data for the dynamic viscosity.

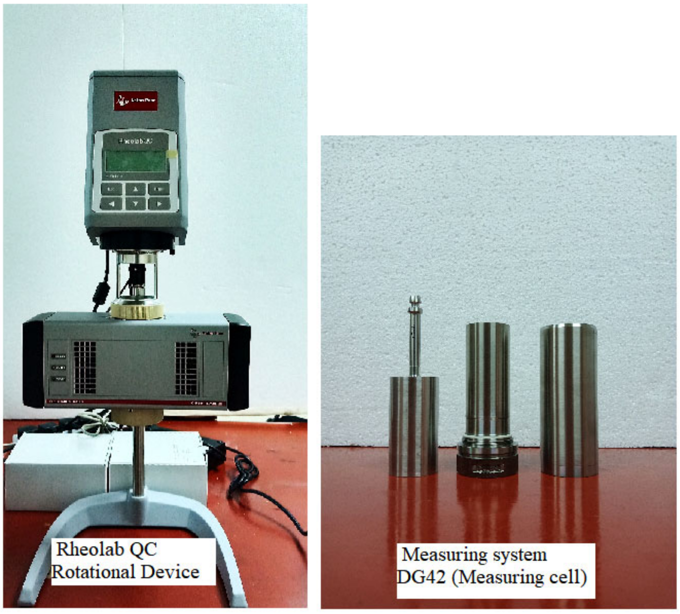


Figure 3. Rehab QC rotational rheometer

2.4 Estimation density and specific heat

In the present study, the density and specific heat of TiO_2-SiO_2 hybrid nanofluids at 20:80 mixture ratio was estimated using a mixture relation equation. The equations are presented in Eq. 3, which is related to the particle concentrations, the density of the base fluid, and density of nanoparticles, and Eq. 4, which is related to the density and specific heat of base fluid, density, and specific heat of nanoparticles, and particle concentrations. Teng and Hung [19] used mixture relation in their study to estimate the density and specific heat of alumina nanofluids. The results obtained from the estimation deviate from the measured data in the range of -1.50% to 0.06% and 0.25% to 2.53% for the density. At the same time, the deviation from the measured data using specific heat was calculated to be between -0.07% to 5.88% and -0.35% to 4.94%. The equations also were used by several researchers such as Raja et al. [20], Ahammed et al. [21], Hormozi et al. [22], and Sundar et al. [23].

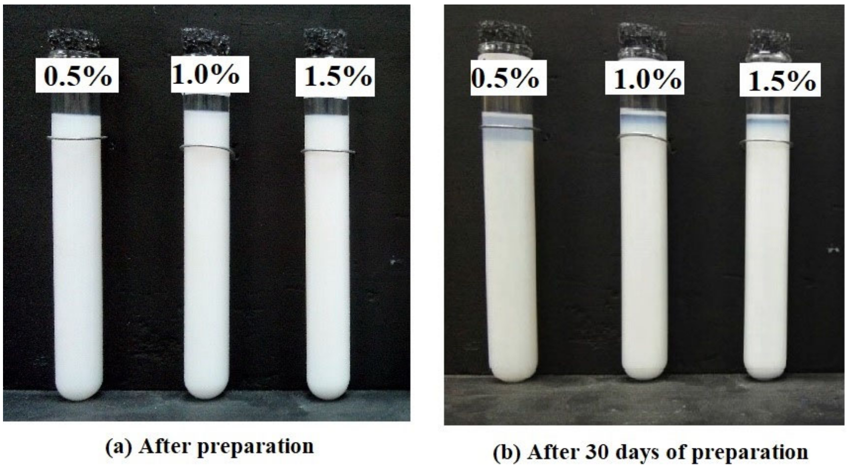
$$\rho_{hnf} = (1-\phi_p)\rho_{bf} + (0.2\times\phi)\rho_{TiO_2} + (0.8\times\phi)\rho_{SiO_2} \tag{3}$$

$$C_{hnf} = \frac{(1-\phi_p)\rho_{bf}C_{bf} + (0.2\times\phi)\rho_{TiO_2}C_{TiO_2} + (0.8\times\phi)\rho_{SiO_2}C_{SiO_2}}{\rho_{hnf}} \tag{4}$$

3. Result and discussion

3.1 Stability of TiO_2-SiO_2 hybrid nanofluids

The stability of the TiO_2-SiO_2 hybrid nanofluids was evaluated by using visual observation. The sample of the hybrid nanofluids at various concentrations was stored in the test tube and placed in space at room temperature. The hybrid nanofluids were observed for more than 30 days, as shown in Fig. 4(a) and 4(b). The sample was observed stable within seven days after preparation, with no separation layer was observed. After 30 days, the TiO_2-SiO_2 hybrid nanofluids at 1.5% showed the least sedimentation, followed by 1.0 and 0.5% volume concentration. In addition to visual observation, the measurement using zeta potential was also performed to evaluate the stability of the TiO_2-SiO_2 hybrid nanofluids. Based on the measurement, the zeta potential value obtained for the hybrid nanofluids is -53.46, which can be interpreted as having excellent stability.



(a) After preparation (b) After 30 days of preparation

Figure 4. Sample of TiO2-SiO2 hybrid nanofluids at various concentrations

3.2 Thermal conductivity of TiO_2-SiO_2 hybrid nanofluids

The thermal conductivity obtained from the C-Therm TCi Thermal Analyzers was validated by comparing the measured thermal conductivity of W/BG at a 60:40 mixture ratio to data provided by Dynalene [24]. The maximum deviation between the measured thermal conductivity with data provided by Dynalene [24] is 6.2% which is considered small. Hence, the data measured using the equipment is confirmed to be reliable. The variation of thermal conductivity of the TiO_2-SiO_2 hybrid nanofluids with temperature is plotted in figure 5. Based on the figure, the thermal conductivity of TiO_2-SiO_2 hybrid nanofluids for all concentrations is following the trend shown by the W/BG. Figure 5 showed that the thermal conductivity of W/BG and TiO_2-SiO_2 hybrid nanofluids increases with the temperature. The thermal conductivity of the hybrid nanofluids also was enhanced with particle concentrations. The highest thermal conductivity of TiO_2-SiO_2 hybrid nanofluids was found at a 1.5% volume concentration and temperature of 70 °C., and it was enhanced up to 6.83% from the base fluid, W/BG. The enhancement of thermal conductivity for hybrid nanofluids are more prominent at the higher temperature; however, the thermal conductivity of the hybrid nanofluids did not show a significant increase between concentrations. The significant improvement in the thermal conductivity as temperature increases is due to the effect of Brownian motion—the rate of collision between the suspended particles and molecules in the fluid increases when temperature increase. Similar findings were also observed in prior investigations performed by Akilu et al. [7] and Humic et al. [25].

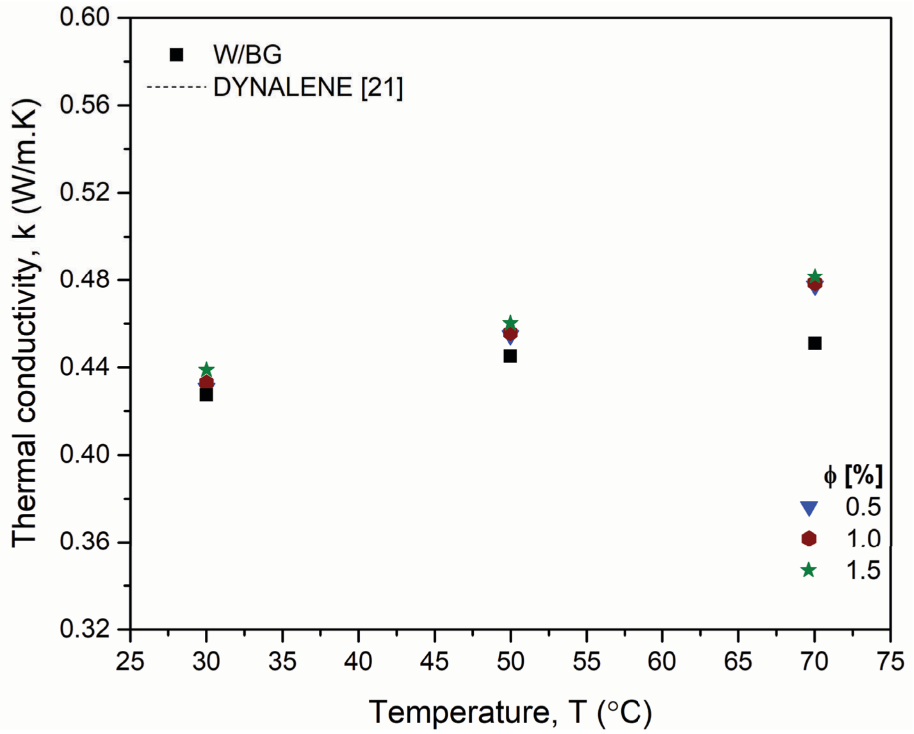


Figure 5. Thermal conductivity of TiO_2-SiO_2 hybrid nanofluids at various concentrations

3.3 Dynamic viscosity of TiO_2-SiO_2 hybrid nanofluids

The validation of the equipment was performed by comparing the measured dynamic viscosity of the base fluid, W/BG, with the data provided by Dynalene [24]. The maximum deviation calculated was considered slight. Less than 1% confirmed the reliability of data produced from the equipment. The variation of dynamic viscosity with temperature for W/BG and TiO_2-SiO_2 hybrid nanofluids are displayed in Figure 6. At all concentrations, the dynamic viscosity of the TiO_2-SiO_2 hybrid nanofluids follows the behavior of the base fluid. The dynamic viscosity of the hybrid nanofluid is observed to decrease when the temperature increases but increases with particle volume concentration. A similar pattern can be observed in previous studies, such as Nabil et al. [17] and Akilu et al. [26]. At 70 °C, the viscosity was found to increase by up to 45% at a concentration of 1.5%, while the lowest viscosity can be obtained at a concentration of 0.5% and temperature of 70 °C with an increment of 24% from the base fluid. At low temperatures, the viscosity of the hybrid nanofluids significantly increased from the base fluid; but, as the temperature increases, the increase in the viscosity of the hybrid nanofluids from the base fluid reduces. According to Wole-Osho et al. [14], the reduction in viscosity at higher temperatures increases the intermolecular distance between nanoparticles and base fluid.

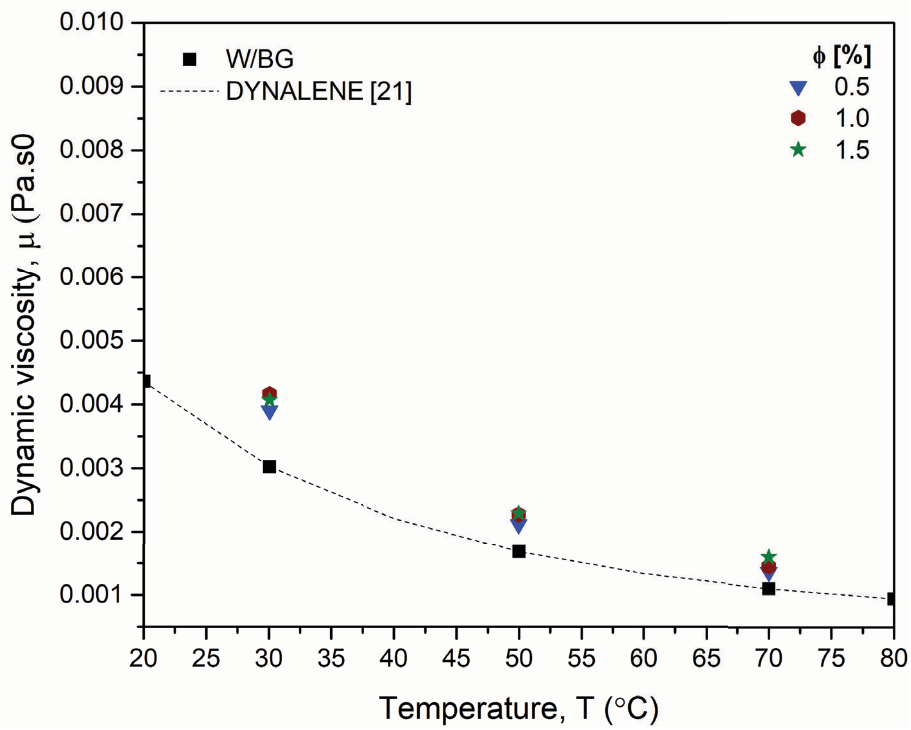


Figure 6. Dynamic viscosity of TiO_2-SiO_2 hybrid nanofluids at various concentrations

3.4 Density and specific heat of TiO_2-SiO_2 hybrid nanofluids

The density and specific heat of the TiO_2-SiO_2 hybrid nanofluids were estimated using the mixture relation equation. The results calculated are presented in Figures 7 and 8. Based on Figure 7, the lowest density was found at 0.5% volume concentrations and temperature of 70 °C. The density was observed to decrease as the temperature increases. At high temperatures, the molecules in the fluid excite and move more freely, causing an increase in the rate of collision and an increase in the volume of the substance, resulting in a decrease in density. Several researchers, such as Vajjha and Das [27], Kedzierski [28], Mahbubul et al. [29], and Nabati Shoghl et al. [30], found the same trend in their study, which is that the density decreases as temperature increased.

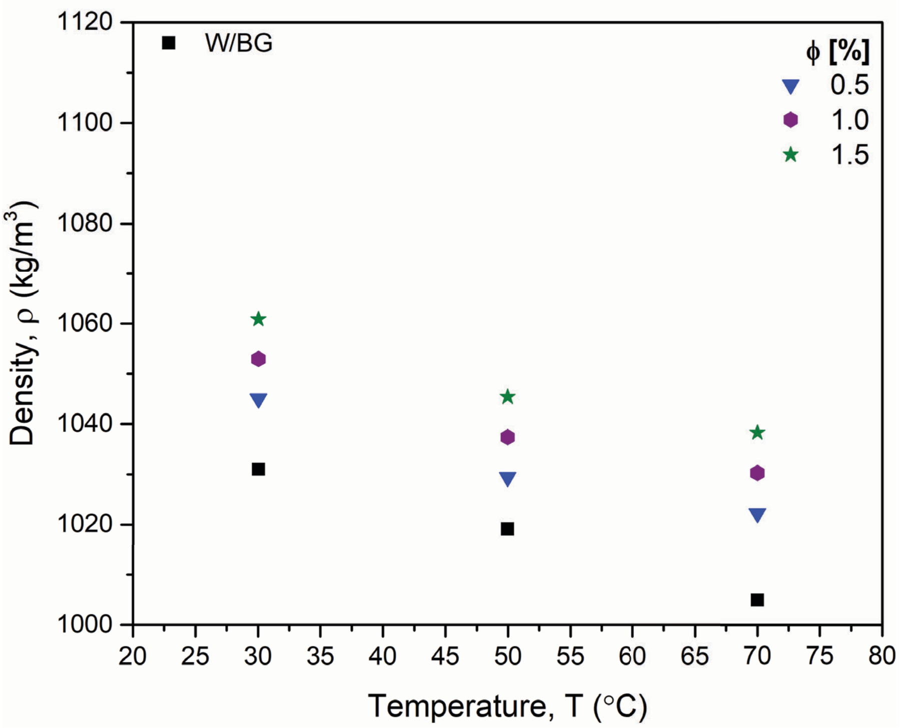


Figure 7. The density of TiO_2-SiO_2 hybrid nanofluids at various concentrations

The data for specific heat is presented in Figure 8. The specific heat was observed to be lower than the base fluid at all concentrations and increase when the temperature increased. The trend shows that the specific heat of TiO_2 - SiO_2 hybrid nanofluids is temperature-dependent. When the temperature increases, the molecules' kinetic energy increases, causing the molecules to collide aggressively with each other. The collision rate is high enough to allow the rotation of molecules to occur and increase the internal energy. Thus, the specific heat increases. Raud et al. [31] conducted an experimental study on the specific heat of Alumina (Al_2O_3) water-based nanofluids at a concentration of 2 %, 5 %, and 20 %. The specific heat was measured using a differential scanning calorimeter. They reported that the specific heat of Al_2O_3 water-based nanofluids decrease as temperature increased at all concentrations.

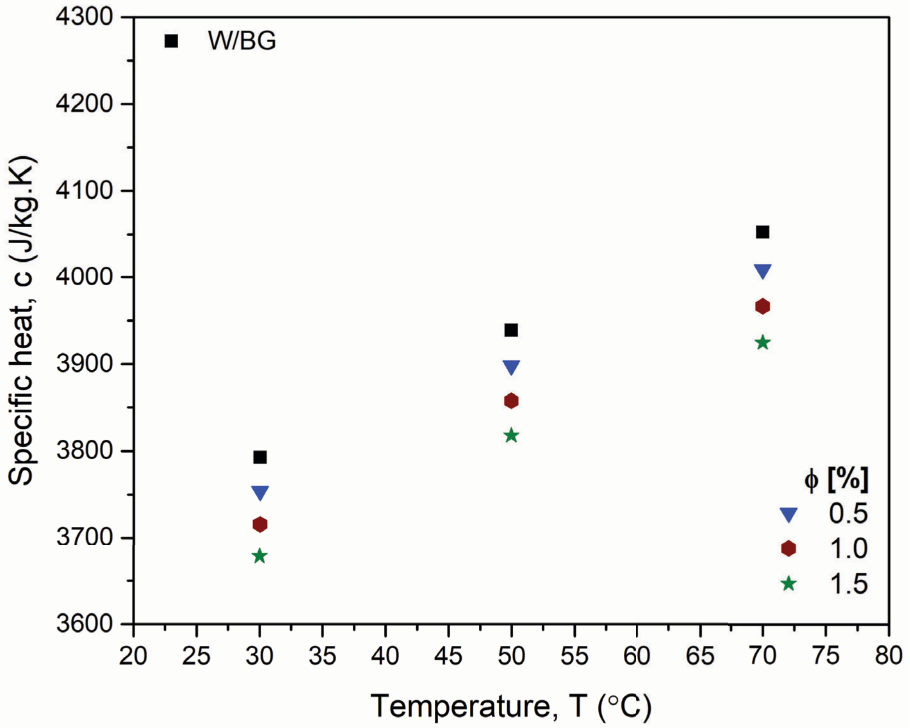


Figure 8. The specific heat of TiO_2-SiO_2 hybrid nanofluids at various concentrations

4. Conclusion

The present study explored the thermo-physical properties of W/BG-based TiO_2-SiO_2 hybrid nanofluids at volume concentrations between 0.5 and 1.5% in the temperature range between 30 and 70 °C. The hybrid nanofluid is confirmed stable with little sedimentation that appeared within a month. The improvement in thermal conductivity was found maximum at 1.5% volume concentration and temperature of 70°C, which is 6.83%. The viscosity was increased by up to 45% at 70 °C for 1.5% volume concentration. The results indicated that the thermal conductivity, viscosity, density increase as the particle concentration increase, but the specific heat decreased with the increase of particle concentrations. The thermophysical properties of TiO_2-SiO_2 hybrid nanofluids are temperature-dependent. Both thermal conductivity and specific heat are seen to increase with temperature. In contrast, the viscosity and density decreased when the temperature increase. Based on these findings, the TiO_2-SiO_2 hybrid nanofluids at the recommended volume concentration of 1.5% can be utilized to replace conventional heat transfer fluids.

Acknowledgments

The authors are grateful to the Ministry of Education Malaysia and Universiti Malaysia Pahang (www.ump.edu.my) for financial supports given under FRGS/1/2018/TK10/UMP/02/10 RDU190146, and PGRS1903110. The authors also thank the research team from the Automotive Engineering Centre (AEC), Centre of Excellence for Advanced Research in Fluid Flow (CARDIFF), and Advanced Automotive Liquids Laboratory (AALL). They provided insight and expertise that greatly assisted in the present research work.

References

[1] Marion and Norman 2011 Energy crisis 2050?: global scenario and way forward for Malaysia

[2] Masuda H, Ebata A and Teramae K 1993 Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Dispersion of Al2O3, SiO2, and TiO2 ultra-fine particles

[3] Ali N, Teixeira J A, and Addali A 2018 A Review on Nanofluids: Fabrication, Stability, and Thermophysical Properties *Journal of Nanomaterials* **2018** 33

[4] Azmi W H, Abdul Hamid K, Mamat R, Sharma K V and Mohamad M S 2016 Effects of working temperature on thermo-physical properties and forced convection heat transfer of TiO2 nanofluids in water – Ethylene glycol mixture *Applied Thermal Engineering* **106** 1190-9

[5] Li X and Zou C 2016 Thermo-physical properties of water and ethylene glycol mixture based SiC nanofluids: An experimental investigation *International Journal of Heat and Mass Transfer* **101** 412-7

[6] Abdolbaqi M K, Azmi W, Mamat R, Sharma K and Najafi G 2016 Experimental investigation of thermal conductivity and electrical conductivity of BioGlycol–water mixture based Al2O3 nanofluid *Applied Thermal Engineering* **102** 932-41

[7] Akilu S, Baheta A T, Kadirgama K, Padmanabhan E and Sharma K V 2019 Viscosity, electrical, and thermal conductivities of glycols (ethylene and propylene) β-SiC nanofluids *Journal of Molecular Liquids*

[8] Hamid K A, Azmi W H, Mamat R and Sharma K V 2019 Heat transfer performance of TiO_2–SiO_2 nanofluids in a tube with wire coil inserts *Applied Thermal Engineering* **152** 275-86

[9] Azmi W H, Usui N A, Mamat R, Sharma K V, and Noor M M 2017 Force convection heat transfer of Al_2O_3 nanofluids for the different based ratio of water: Ethylene glycol mixture *Applied Thermal Engineering* **112** 707-19

[10] Taherialekouhi R, Rasouli S and Khosravi A 2019 An experimental study on stability and thermal conductivity of water-graphene oxide/aluminum oxide nanoparticles as a cooling hybrid nanofluid *International Journal of Heat and Mass Transfer* **145** 118751

[11] Kakavandi A and Akbari M 2018 Experimental investigation of thermal conductivity of nanofluids containing hybrid nanoparticles suspended in binary base fluids and propose a new correlation *International Journal of Heat and Mass Transfer* **124** 742-51

[12] Oliveira L Rd, Ribeiro SR F L, Reis M H M, Cardoso V L and Bandarra Filho E P 2019 Experimental study on the thermal conductivity and viscosity of ethylene glycol-based nanofluid containing diamond‑silver hybrid material *Diamond and Related Materials* **96** 216-30

[13] Hamid K A, Azmi W H, Nabil M F, Mamat R and Sharma K V 2018 Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO_2-SiO_2 nanofluids *International Journal of Heat and Mass Transfer* **116** 1143-52

[14] Wole-Osho I, Okonkwo E C, Kavaz D and Abbasoglu S 2020 An experimental investigation into the effect of particle mixture ratio on specific heat capacity and dynamic viscosity of Al2O3-ZnO hybrid nanofluids *Powder Technology*

[15] Dalkılıç A S, Açıkgöz Ö, Küçükyıldırım B O, Eker A A, Lüleci B, Jumpholkul C and Wongwises S 2018 Experimental investigation on the viscosity characteristics of water-based SiO_2-graphite hybrid nanofluids *International Communications in Heat and Mass Transfer* **97** 30-8

[16] Abdolbaqi M K, Sidik N A-C, Aziz A, Mamat R, Azmi W H, Yazid M N A W M and Najafi G 2016 An experimental determination of thermal conductivity and viscosity of BioGlycol/water-based TiO_2 nanofluids *International Communications in Heat and Mass Transfer* **77** 22-32

[17] Nabil M F, Azmi W H, Abdul Hamid K, Mamat R and Hagos F Y 2017 An experimental study on the thermal conductivity and dynamic viscosity of TiO_2 -SiO_2 nanofluids in water: Ethylene glycol mixture *International Communications in Heat and Mass Transfer* **86** 181-9

[18] Chiam H W, Azmi W H, Usri N A, Mamat R and Adam N M 2017 Thermal conductivity and viscosity of Al_2O_3 nanofluids for different based ratio of water and ethylene glycol mixture *Experimental Thermal and Fluid Science* **81** 420-9

[19] Teng T-P and Hung Y-H 2014 Estimation and experimental study of the density and specific heat

for alumina nanofluid *Journal of Experimental Nanoscience* **9** 707-18

[20] Raja R A, Sunil J and Maheswaran R 2018 Estimation of thermo-physical properties of nanofluids using theoretical correlations *Int. J. Appl. Eng. Res.* **13** 7950-3

[21] Ahammed N, Asirvatham L G and Wongwises S 2016 Entropy generation analysis of graphene–alumina hybrid nanofluid in multiport minichannel heat exchanger coupled with thermoelectric cooler *International Journal of Heat and Mass Transfer* **103** 1084-97

[22] Hormozi F, ZareNezhad B and Allahyar H R 2016 An experimental investigation on the effects of surfactants on the thermal performance of hybrid nanofluids in helical coil heat exchangers *International Communications in Heat and Mass Transfer* **78** 271-6

[23] Sundar LS, Sharma K V, Singh M K, and Sousa A C M 2017 Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor – A review *Renewable and Sustainable Energy Reviews* **68** 185-98

[24] Dynalene I 2014 Dynalene Technical Data Sheet

[25] Human A, Huminic G, Fleacă C, Dumitrache F, and Morjan I 2019 Thermo-physical properties of water based lanthanum oxide nanofluid. An experimental study *Journal of Molecular Liquids* **287** 111013

[26] Akilu S, Baheta A T and Sharma K V 2017 Experimental measurements of thermal conductivity and viscosity of ethylene glycol-based hybrid nanofluid with TiO_2-CuO/C inclusions *Journal of Molecular Liquids* **246** 396-405

[27] Vajjha R S and Das D K 2008 Measurements of Specific Heat and Density of Al2O3 Nanofluid. In: *AIP Conference Proceedings,* pp 361-70

[28] Kedzierski M A 2012 Viscosity and density of CuO nano-lubricant *international journal of refrigeration* **35** 1997-2002

[29] Mahbubul I M, Saidur R and Amalina M A 2013 Thermal conductivity, viscosity and density of R141b refrigerant-based nanofluid. In: *Procedia Engineering,* pp 310-5

[30] Nabati Shoghl S, Jamali J and Keshavarz Moraveji M 2016 Electrical conductivity, viscosity, and density of different nanofluids: An experimental study *Experimental Thermal and Fluid Science* **74** 339-46

[31] Raud R, Hosterman B, Diana A, Steinberg T A and Will G 2017 Experimental study of the interactivity, specific heat, and latent heat of fusion of water-based nanofluids *Applied Thermal Engineering* **117** 164-8