Volume 16 No. 2
July 2024
ISSN : 2085 – 1669
e-ISSN : 2460 – 0288
Website : jurnal.umj.ac.id/index.php/jurtek
Email : jurnalteknologi@umj.ac.id

Jurnal Teknologi
UNIVERSITAS MUHAMMADIYAH JAKARTA

Investigation of Thermal Conductivity and Dynamics Viscosity of Green Nanofluids (ZrO_2-SiO_2)

Anwar Ilmar Ramadhan[1,*], Kushendarsyah Saptaji[2], Tri Yuni Hendrawati[3], Alvika Meta Sari[4], Efrizon Umar[5], Azmairit Aziz[6], Rifqi Putra Semendo[7], Hanif Rama Yuda Setiawan[8], Firmansyah[9]

[1,7,8,9]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, 10510 Jakarta, Indonesia*
[2]*Department of Mechanical Engineering, Faculty of Engineering Technology, Sampoerna University, 2780 Jakarta, Indonesia*
[3,4]*Department of Chemical Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, 10510 Jakarta, Indonesia*
[5,6]*National Research and Innovation Agency, 40132 Bandung, Indonesia*

*Corresponding author email: anwar.ilmar@umj.ac.id

Jurnal Teknologi use only:
Received 30 June 2024; Revised 14 July 2024; Accepted 31 July 2024

ABSTRACT

In recent years, research has been directed towards improving the thermophysical properties of single-component nanofluids. Therefore, hybrid or composite nanofluids are developed to improve heat transfer performance. The thermophysical properties of ZrO_2-SiO_2 nanoparticles suspended in a mixture of water (W) and ethylene glycol (EG) with vol 60:40 or Green Nanofluids for various volume concentrations were investigated. Experiments were performed for volume concentrations of 0.1, 0.2, and 0.3% of green nanofluids at 50, 60, 70, and 80°C. Measurements of thermal conductivity and dynamic viscosity are performed at temperatures ranging from 50-80°C. The highest thermal conductivity of the green nanofluids is obtained at a concentration of 0.3%, and the maximum increase is up to 37.5% higher than the base fluid (EG/W). Meanwhile, evidence from the dynamic viscosity of green nanofluids is affected by concentration and temperature. Furthermore, the green nanofluids behave as a Newtonian fluid in a volume concentration of 0.1-0.3%. In conclusion, the combination of increased thermal conductivity and dynamic viscosity at a concentration of 0.3% has optimal conditions, which has more advantages for heat transfer than at other concentrations.

Keywords: Dynamics viscosity, Green nanofluids, Hybrid, Thermal conductivity, Temperature.

Introduction

Nanofluids are liquid suspensions containing metal or non-metal nanoparticles with a typical size of 1-100 nm that are dispersed in a base liquid that was first introduced by Choi, et al. [1]. Nanofluids have been shown to improve heat transfer by improving their thermophysical properties. Nanofluids are known for their use in heating and cooling processes. The primary cooling process is an integral part of industrial applications such as power plants, chemical processes, microelectronics, transportation, and automotive cooling systems [2-6]. The presence of dense particles causes interesting characteristics in the basic thermophysical

DOI: https://dx.doi.org/10.24853/jurtek.16.2.301-312

properties of nanofluids. Many researchers have investigated thermal conductivity, viscosity, density, and stability in the last few years [7-9].

The nanofluid preparation method is very important, which minimizes nanoparticle agglomeration and increases stability. The most common procedures used in the preparation of nanofluids are one-step and two-step methods. A one-step method is a nanofluid synthesis process with simultaneous particle dispersion in the base fluid. However, this method is not practical in industry, which only applies to low vapor pressure liquids. Another method of nanofluid preparation is a two-step method. There are two processes involved, namely (i) synthesis of nanoparticles in powder form (ii) dispersion of nanoparticles in the base liquid to form a stable and homogeneous solution [10-13]. Most nanofluids use oxide particles, and the preparation of carbon nanotubes through a two-step method [14-17]. The two-step method is preferred for the large-scale production of nanofluids required for industrial applications. The challenge in using the two-step method lies in the prevention of agglomeration that results in rapid sedimentation of nanoparticles [18]. The two-step method is the most dominant method compared to the one-step method in the preparation of nanofluids.

Recent research discusses the topic of hybrid or composite nanofluids [19-21]. Hybrid or composite nanofluids are considered to be an extension of the research work for single nanofluids, which can be done by combining two or more different nanoparticles - either in the form of a mixed composite or dispersed in a liquid [22]. Composite or hybrid materials are elements that combine chemical and physical properties. Synthesis of hybrid or composite nanofluids aims to improve the properties of single nanoparticles through which thermal properties or rheological properties are achieved. Hybrid nanofluids are expected to achieve good thermal performance compared to single nanofluids [23]. Recently, Hamzah, et al. [24], Sidik, et al. [25], specialized journals [23], [24] present detailed presentations on the preparation, performance, and applications of hybrid nanofluids. Therefore, research on thermal conductivity and viscosity is very important in understanding the behavior of hybrid nanofluids for further implementation in heat transfer applications. Thermal conductivity is an important factor that affects the increase of heat transfer [26]. Several factors affect thermal conductivity: concentration, temperature, particle size, surface to volume ratio of nanoparticles, and nanofluid stability [27-31]. Turgut, et al. [32] showed that the thermal conductivity increased by 7.4% above the alkaline liquid. Experimental investigations with Al_2O_3-Cu composite nanofluids with water as the base fluid were carried out by Suresh, et al. [33], who reported an increase of up to 12% with increasing volume concentration. In another paper, Hamid, et al. [34] the thermo-physical properties of TiO_2-SiO_2 nanoparticles suspended in a mixture of water (W) and ethylene glycol (EG) with a volume ratio of 60:40 have been reported. They found that the highest thermal conductivity for TiO_2-SiO_2 nanofluid was obtained with a ratio of 20:80 and the maximum increase was up to 16% higher than the base fluid.

Several researchers have conducted research on the thermal conductivity, dynamic viscosity and stability of the produced nanofluids [28-33, 43-51]. Green nanofluids or bio-nanofluids, or environmentally friendly nanofluids are derived from several sources of natural materials [34, 35]. Colloidally very stable green nanofluids as alternative working fluids are very important for their effective use in different thermal systems [36]. Based on previous research, research on the development of green nanofluids in the world is still very little.

Based on the problem, the research was conducted by focusing on the comparative influence of two nanoparticles (ZrO_2-SiO_2)/EG-Water or green nanofluids on the thermal-physical properties for heat transfer applications.

Methods

Preparation of green nanofluids from ZrO_2 and SiO_2 Nanoparticles

The production of green nanofluids involves mono nanofluids, namely ZrO_2 nanoparticles or Nano-Zircon and SiO_2 nanoparticles or Nano-Silicate, each of which comes from local natural materials found in Indonesia. Both are mixed and dispersed in a base fluid mixed with EG/Water (40:60) ratio. Nano-Zircon is made through the Caustic Fusion method and Nano-Silicate is obtained from Empty Palm Oil Shell (EPS) which is made using the Ultra-Sonication Method. The sizes of Nano-Zircon and Nano-Silicate nanoparticles are 32 nm and 44 nm, respectively. The characteristics of Nano-Zircon and Nano-Silicate are given in **Table 1**.

Table 1. Properties of ZrO_2 and SiO_2 nanoparticles from synthesis process

Properties	ZrO_2	SiO_2
Molecular mass, g mol^{-1}	231.891	60.08
Average particle diameter, nm	32	44
Density, kg m^{-3}	5680	2220
Thermal conductivity, W m^{-1} K^{-1}	2.8	1.4
Specific heat, J kg^{-1} K^{-1}	418	745

The base fluid mixture of water and EG is used in the present study in a 60:40 ratio by volume. The ethylene glycol properties are presented in **Table 2**.

Table 2. Properties of Ethylene Glycol (EG) [41]

Properties	EG
Vapour pressure, mmHg at 20 °C	0.08
Boiling point, °C	195–198
Melting point, °C	-13
Density, g ml^{-1} at 25 °C	1.113

A two-step method is used for the preparation of green nanofluids. Green nanofluids is prepared by mixing Nano-Zircon and Nano-Silicate (50:50) ratio with EG/Water mixture (40:60), and sonication. The production of green nanofluids begins with the calculation of the required volume according to its concentration. In this research, green nanofluids were made with volume concentrations of 0.1, 0.2, and 0.3%. The nanofluid was first prepared at the highest concentration, 0.3% and then diluted to a lower concentration. Green nanofluids preparation process based on **Figure 1**.

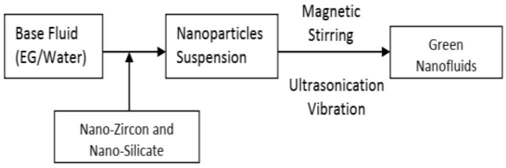


Figure 1. The preparation of green nanofluids with ZrO_2 and SiO_2 Nanoparticles

ZrO_2 Nanoparticles or Nano-Zircon and SiO_2 Nanoparticles or Nano-Silicate are available in powder form with a weight concentration of 22% for ZrO_2 and 25% for SiO_2. Eq. (1) [35, 51] is used to convert weight concentration into volume concentration. Dilution from a higher volume concentration to a lower volume concentration using Eq. (2) [50, 51] by adding the base fluid (ΔV).

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

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

Nano-Zircon and Nano-Silica are mixed (50:50) with a mixture of EG/Water with a ratio of 40:60 to become green nanofluids. A total volume of 100 mL was prepared for nanofluids concentration. The nanofluids solution was mixed using a magnetic stirrer for 15 minutes. The solution is then sonicated for 2 hours using ultrasonic immersion to increase stability.

Thermal conductivity measurement of Green Nanofluids

The thermal conductivity measurement method follows the ASTM D5334 and IEEE 442-1981 standards, using the TEMPOS Thermal Property Analyzer shown in **Figure 2**. Thermal sample conductivity test section, KS-1 sensor to read k [W/m K], measuring bottle to enter the sample to be tested, and the TEMPOS controller is an important part of the thermal conductivity measuring device. The TEMPOS

ISSN : 2085 – 1669
e-ISSN : 2460 – 0288

Thermal Property Analyzer instrument uses a transient line heat source to measure thermal properties. Thermal conductivity measurements were performed for temperatures varying from 50 to 80 °C. A water bath is used to keep the sample temperature constant. Previously, the thermal conductivity value from the thermal conductivity sensor was validated using liquid glycerine standards supplied by Meter Group. The measured K is 0.286 W/m K with an accuracy of ± 0.35%. The measurement of thermal conductivity was done several times and the average was taken, the measurement time was 15 minutes for each set of data at different temperatures. This is important to minimize the occurrence of errors in measurements with free convection due to temperature variations along the sensor that is in direct contact with the liquid sample.

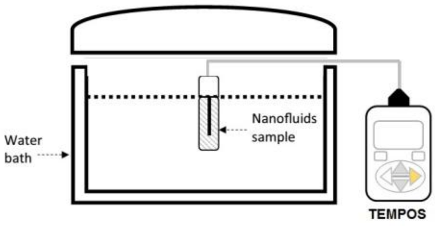


Figure 2. TEMPOS Thermal Properties Analyzer to the measurement of thermal conductivity

Dynamic viscosity measurement of Green Nanofluids

Viscosity measurement used water bath circulation at Brookfield LVDV III Ultra Rheometer. Operating conditions of Rheometer for viscosity measurement from 1 to 6×10^6 mPa.s. The sample of 16 mL was added to the cylinder jacket and pasted into a Rheometer. The RheoCal program is used for determining the VST at various spindle velocities. Dynamic viscosity measurements were performed in the temperature range of 50~80°C. The use of a circulating water bath is made to control the sample temperature. The VST measurements are repeated five times, and the average value reported. Dynamic viscosity measurements used the apparatus shown in **Figure 3**. Water: EG in 60:40 mixture ratio at different temperatures is validated by the values reported in the literature. Furthermore, dynamic viscosity measurements are performed for ZrO_2-SiO_2 or green nanofluids.

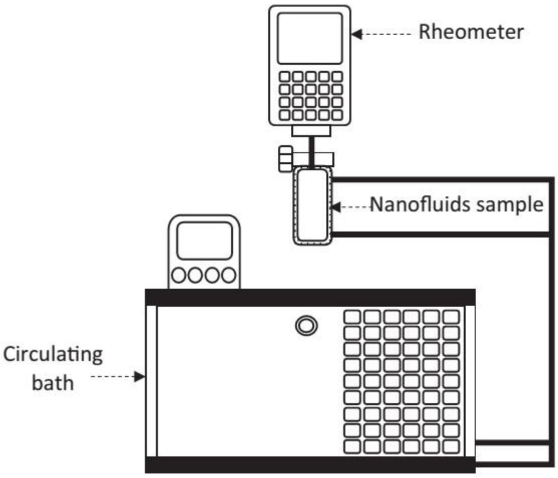


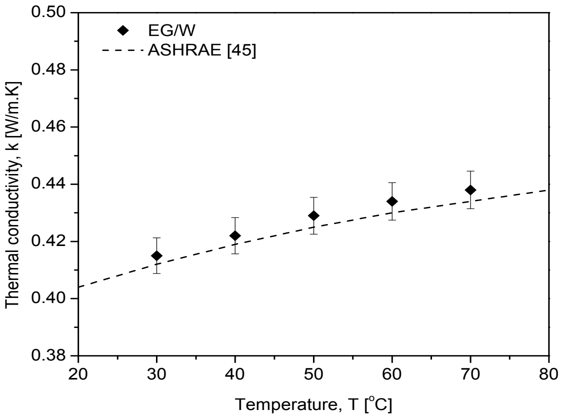
Figure 3. Brookfield LVDV III Ultra Rheometer to the measurement of dynamic viscosity

Results and Discussions

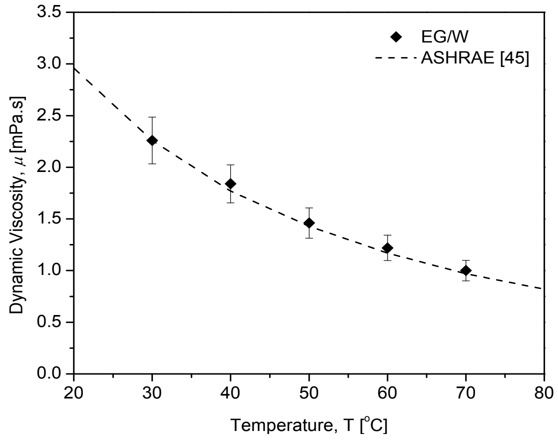
Properties measurement validations with ASHRAE

Thermal conductivity and viscosity measurement data should be validated using ASHRAE [45] for EG/Water (60:40). Measurement of thermal conductivity using TEMPOS, data validation results with an error bar of 1.5% are presented in **Figure 4 (a)**. The deviation for measured data is less than 1.0% compared to ASHRAE [45]. Reddy, et al. [46] performed a validation test for deviations from the base fluid up to 2.5% compared to ASHRAE [45]. Furthermore, for the same temperature range and water/EG ratio in the current viscosity measurement validation as stated by other papers [47-49].

Figure 4 (b) shows that the viscosity data is in accordance with ASHRAE [45]. Additionally, the data for the base fluid consisting of a mixture of water and EG is very accurate with the ASHRAE data trending decreasing viscosity with temperature. Therefore, further measurements and research for the thermal conductivity and dynamic viscosity of the green nanofluids were carried out.



(a) Thermal Conductivity



(b) Dynamic Viscosity

Figure 4. Validation of EG/Water (40:60) with ASHRAE

The thermal conductivity of green nanofluids

Figure 5 presented the relationship between the thermal conductivity of green nanofluids and temperature for a volume concentration of 0.1~0.3%. The thermal conductivity of green nanofluids for volume concentration variations can increase along with temperature and is higher than the base fluid. Furthermore, the highest thermal conductivity was obtained for a volume concentration of 0.3% at a temperature of 80 °C with 37.5% higher than the base fluid. Meanwhile, a volume concentration of 0.1% gave the lowest thermal conductivity among the temperatures studied.

In this research, the relationship between the comparison of the composition of ZrO_2-SiO_2 nanoparticles (50:50) in the green nanofluids to the increase in thermal conductivity is influenced by two nanoparticles that have different sizes. The diameters of ZrO_2 and SiO_2 nanoparticles are 32 nm and 44 nm respectively, where the ZrO_2 nanoparticles are smaller than the SiO_2 nanoparticles which measure 44 nm. ZrO_2 nanoparticles play a role in conduction by filling the space of larger SiO_2 nanoparticles. Increasing the contact area for intermolecular conduction, resulting in a higher heat transfer rate when there is a collision by Brownian motion [50], requires a specific arrangement of the two nanoparticles.

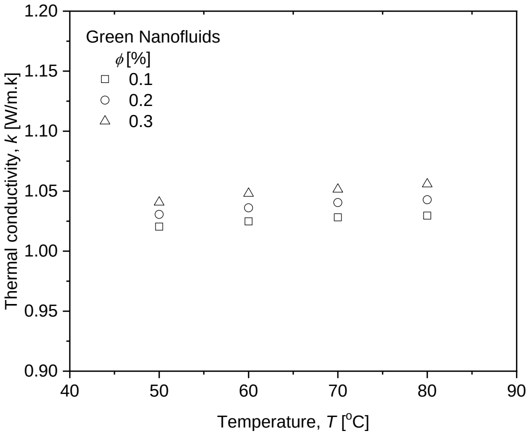


Figure 5. The experimental thermal conductivity of green nanofluids

Dynamic viscosity of green nanofluids

Figure 6 illustrates the dynamic viscosity against the shear rate in the range $920 \leq \gamma \leq 4320\ s^{-1}$ for a green nanofluids volume concentration of 0.1%. The results show that dynamic viscosity remains constant with an increase in shear rate of 0.1% vol. The shear-independent viscosity dyamics shows that the green nanofluids behaves as a Newtonian fluid in the studied temperature. The dynamic viscosity of green nanofluids for different temperatures has a significant effect on the volume concentration of 0.1%. A temperature of 80°C gives a higher dynamic viscosity than a temperature of 50, 60, and 70°C as shown in **Figure 6**. This is likely due to the difference in intensity of ZrO_2 and SiO_2 nanoparticles at both composition ratios (50:50) in the green nanofluids.

Figure 7 shows the dynamic viscosity for various volume concentrations of green nanofluids in the temperature range of

50~80°C. Dynamics viscosity at all volume concentrations follows the base fluid trend whereby it decreases exponentially with temperature. The volume concentration viscosity of 0.3 is higher than the value of 0.1 and 0.2% A volume concentration of 0.3% showed the highest value for dynamic viscosity at all temperatures. Dynamic viscosity of green nanofluids slightly decreased. The Dynamic viscosity of the green nanofluids varies with the mixture composition ratio of ZrO_2 and SiO_2 nanoparticles, which may be caused by the difference in the interaction of these particles with the base fluid. However, the influence of temperature on the viscosity of ZrO_2-SiO_2 nanofluids for all mixture ratios decreases with increasing temperature, proven by Asadi, et al. [51].

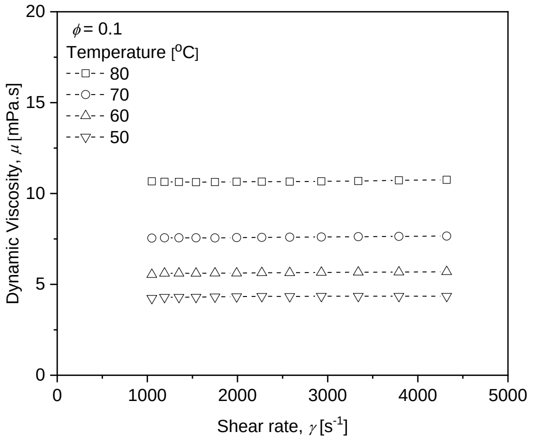


Figure 6. Variation of dynamic viscosity with shear rate

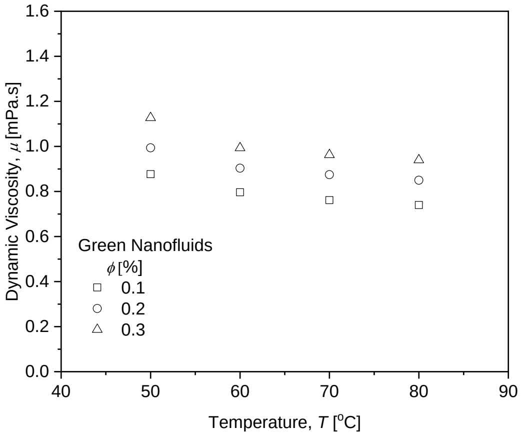
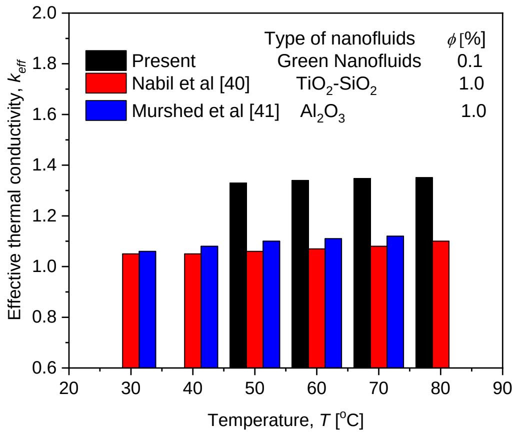


Figure 7. Variation of dynamic viscosity with temperature

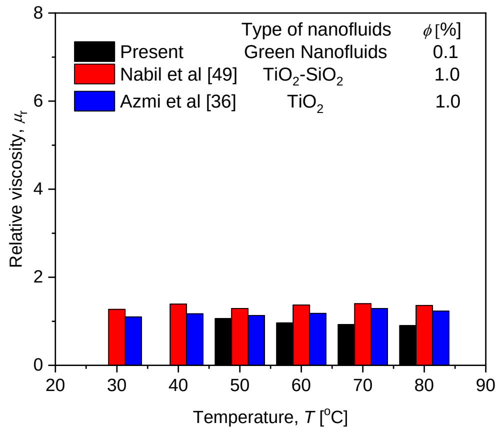
Comparison with literature

Figure 8 (a) and (b) shows a comparison of the effective thermal conductivity and relative viscosity from this study with data from Nabil, et al. [52], Murshed, et al. [53], and Azmi, et al. [47]. In this research, the thermal conductivity of the green nanofluids increased 1.25-1.37 times compared to the base fluid for a concentration of 0.1%. Murshed, et al. [53], using Al_2O_3 nanoparticles with a volume concentration of 1.0% of the base fluid used by the EG-Water mixture. They proved that the experimental values of the thermal conductivity of different nanofluids increased significantly with fluid temperature, which increased the Brownian motion of nanoparticles and decreased the viscosity of the base fluid. With the strong influence of Brownian action, the contribution of micro-connectivity to heat transfer increases, resulting in an increase in the thermal conductivity of the nanofluids.

Research by Nabil, et al. [52] used TiO_2-SiO_2 with EG/Water as the base fluid. They present the results of the thermal conductivity of TiO_2-SiO_2 nanofluids increasing with increasing concentration and temperature. However, the relative viscosity in their study is almost identical compared to this study for a temperature of 50°C. In another paper, Azmi, et al. [47] performed a relative viscosity measurement for TiO_2 nanoparticles in an EG/Water-based fluid with a concentration of 0.5%. The results of the research proved that the relative viscosity in the studied range increased by about 1.03-1.15 times compared to the water/EG mixture. Reasons for fluctuations in relative viscosity in an unspecified temperature range. Their relative viscosity is the lowest value compared to the others, as shown in **Figure 8 (b)**. According to Sundar, et al. [37] The magnitude of the increase in thermal conductivity or relative viscosity depends on the type of nanoparticles and base fluid, so observed and illustrated in **Figure 8 (a) and (b)**.



(a) Comparison of thermal conductivity



(b) Comparison of dynamic viscosity

Figure 8. Comparison of green nanofluids properties with the data from the literature

Conclusions

In this research, the thermal conductivity and dynamic viscosity of green nanofluids were examined for three concentration volumes and temperatures from 50 to 80°C. Experimental results show that the concentration volume of 0.3% obtains the best effective thermal conductivity and relative viscosity compared to 0.1 and 0.2%. Therefore, in this research, different concentration volumes become control and performance parameters studied. In terms of thermal conductivity increase, the volume of 0.3% gave a maximum increase of up to 37.5% while 0.1% was observed to have the most negligible increase in dynamic viscosity, which is about 1.03 times on average compared to the other ratios.

Acknowledgment

The authors would like to thank the Universitas Muhammadiyah Jakarta, LLDIKTI Wilayah III, Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi Republik Indonesia have funding and supported implementation grant of Penelitian Fundamental Reguler on year 2024 with contract number: 105/E5/PG.02.00.PL/2024.

Funding

This research was funded by the 2024 research grant scheme of Penelitian Fundamental Reguler with contract number: 105/E5/PG.02.00.PL/2024.

Author Contributions

AIR, KS, TYH: Conceptualization, method, writing, analyses, supervision, review, AMS, EU, AA, F: editing review, EU, MHBAH: methodology, analyses, drafting, RPS, HRYS: experiment, data experiment.

Conflict of interest

The authors declare no conflict of interest in this paper.

References

[1] S. Choi, J. Eastman, Argonne National Lab, IL (United States), (1995).

[2] A. Nuntaphan, S. Vithayasai, N. Vorayos, N. Vorayos, T. Kiatsiriroat, Use of oscillating heat pipe technique as extended surface in wire-on-tube heat exchanger for heat transfer enhancement, International communications in heat and mass transfer, 37(3) (2010) 287-292.

[3] R. Saidur, K. Leong, H. Mohammad, A review on applications and challenges of nanofluids, Renewable and sustainable energy reviews, 15(3) (2011) 1646-1668.

[4] A.I. Ramadhan, W.H. Azmi, R. Mamat, Heat Transfer Characteristics of Car Radiator using Tri-Hybrid Nanocoolant, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2020.

[5] M.A. Fikri, W.M. Faizal, H.K. Adli, Z. Bo, X.X. Jiang, A.I. Ramadhan, Experimental Determination of Water, Water/Ethylene Glycol and TiO2-SiO2 Nanofluids mixture with Water/Ethylene Glycol to Three Square Multilayer Absorber Collector on Solar Water Heating System: A Comparative Investigation, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, pp. 012019.

[6] A.I. Ramadhan, E. Diniardi, E. Dermawan, Numerical study of effect parameter fluid flow nanofluid Al2O3-water on heat transfer in corrugated tube, in: AIP Conference Proceedings, AIP Publishing LLC, 2016, pp. 050003.

[7] M. Chandrasekar, S. Suresh, A review on the mechanisms of heat transport in nanofluids, Heat Transfer Engineering, 30(14) (2009) 1136-1150.

[8] S. Lee, S.-S. Choi, S. Li, and, J. Eastman, Measuring thermal conductivity of fluids containing oxide nanoparticles, Journal of Heat transfer, 121(2) (1999) 280-289.

[9] A.I. Ramadhan, W.H. Azmi, R. Mamat, Experimental investigation of thermo-physical properties of tri-hybrid nanoparticles in water-ethylene glycol mixture, Walailak Journal of Science and Technology (WJST), 18(8) (2021) 9335 (9315 pages)-9335 (9315 pages).

[10] A.S. Hatwar, V. Kriplani, A review on heat transfer enhancement with nanofluid, Int. J. Adv. Res. Sci. Eng, 3(3) (2014) 175-183.

[11] K.A. Hamid, W. Azmi, R. Mamat, N. Usri, G. Najafi, Effect of temperature on heat transfer coefficient of titanium dioxide in ethylene glycol-based nanofluid, Journal of Mechanical Engineering and Sciences (JMES) Volume, 8 (2015) 1367-1375.

[12] A.I. Ramadhan, W.H. Azmi, R. Mamat, K.A. Hamid, Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids, Case Studies in Thermal Engineering, 22 (2020) 100782.

[13] A.I. Ramadhan, W.H. Azmi, R. Mamat, Stability and Thermal Conductivity of Tri-hybrid Nanofluids for High Concentration in Water-ethylene Glycol (60:40), Nanoscience & Nanotechnology-Asia, 11(4) (2021) 11-21.

[14] W. Azmi, K. Sharma, R. Mamat, A. Alias, I.I. Misnon, Correlations for thermal conductivity and viscosity of water based nanofluids, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2012, pp. 012029.

[15] K. Abdul Hamid, W.H. Azmi, R. Mamat, N.A. Usri, Thermal conductivity enhancement of aluminium oxide nanofluid in ethylene glycol, in: Applied Mechanics and Materials, Trans Tech Publ, 2014, pp. 730-734.

[16] V. Kumaresan, S.M.A. Khader, S. Karthikeyan, R. Velraj, Convective heat transfer characteristics of CNT nanofluids in a tubular heat exchanger of various lengths for energy efficient cooling/heating system, International Journal of Heat and Mass Transfer, 60 (2013) 413-421.

[17] W.H. Azmi, K.A. Hamid, A.I. Ramadhan, A.I.M. Shaiful, Thermal hydraulic performance for hybrid composition ratio of TiO2–SiO2 nanofluids in a tube with wire coil inserts, Case Studies in Thermal Engineering, 25 (2021) 100899.

[18] W. Yu, H. Xie, Y. Li, L. Chen, Q. Wang, Experimental investigation on the heat transfer properties of Al2O3 nanofluids using the mixture of ethylene glycol and water as base fluid, Powder Technology, 230 (2012) 14-19.

[19] M.H. Esfe, A.A.A. Arani, M. Rezaie, W.-M. Yan, A. Karimipour, Experimental determination of thermal

conductivity and dynamic viscosity of Ag–MgO/water hybrid nanofluid, International Communications in Heat and Mass Transfer, 66 (2015) 189-195.

[20] A. Moghadassi, E. Ghomi, F. Parvizian, A numerical study of water based Al2O3 and Al2O3–Cu hybrid nanofluid effect on forced convective heat transfer, International Journal of Thermal Sciences, 92 (2015) 50-57.

[21] M.A. Fikri, W.M. Faizal, H.K. Adli, Z. Bo, X.X. Jiang, A.I. Ramadhan, Investigation on stability of TiO2-SiO2 nanofluids with ratio (70: 30) in W/EG mixture (60: 40), in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, pp. 012020.

[22] J. Sarkar, P. Ghosh, A. Adil, A review on hybrid nanofluids: recent research, development and applications, Renewable and Sustainable Energy Reviews, 43 (2015) 164-177.

[23] R. Sureshkumar, S.T. Mohideen, N. Nethaji, Heat transfer characteristics of nanofluids in heat pipes: a review, Renewable and Sustainable Energy Reviews, 20 (2013) 397-410.

[24] M.H. Hamzah, N.A.C. Sidik, T.L. Ken, R. Mamat, G. Najafi, Factors affecting the performance of hybrid nanofluids: A comprehensive review, International Journal of Heat and Mass Transfer, 115 (2017) 630-646.

[25] N.A.C. Sidik, M.M. Jamil, W.M.A.A. Japar, I.M. Adamu, A review on preparation methods, stability and applications of hybrid nanofluids, Renewable and Sustainable Energy Reviews, 80 (2017) 1112-1122.

[26] V. Trisaksri, S. Wongwises, Critical review of heat transfer characteristics of nanofluids, Renewable and sustainable energy reviews, 11(3) (2007) 512-523.

[27] L.S. Sundar, M.K. Singh, A.C.M. Sousa, Thermal conductivity of ethylene glycol and water mixture based Fe3O4 nanofluid, International communications in heat and mass transfer, 49 (2013) 17-24.

[28] G. Paul, J. Philip, B. Raj, P.K. Das, I. Manna, Synthesis, characterization, and thermal property measurement of nano-Al95Zn05 dispersed nanofluid prepared by a two-step process, International Journal of Heat and Mass Transfer, 54(15-16) (2011) 3783-3788.

[29] F.S. Javadi, S. Sadeghipour, R. Saidur, G. BoroumandJazi, B. Rahmati, M.M. Elias, M.R. Sohel, The effects of nanofluid on thermophysical properties and heat transfer characteristics of a plate heat exchanger, International Communications in Heat and Mass Transfer, 44 (2013) 58-63.

[30] D.H. Yoo, K.S. Hong, H.S. Yang, Study of thermal conductivity of nanofluids for the application of heat transfer fluids, Thermochimica Acta, 455(1-2) (2007) 66-69.

[31] M.A. Fikri, W.M. Faizal, H.K. Adli, R. Mamat, W.H. Azmi, Z.A.A. Majid, A.I. Ramadhan, Characteristic of TiO2-SiO2 Nanofluid With Water/Ethylene Glycol Mixture for Solar Application, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 81(2) (2021) 1-13.

[32] A. Turgut, I. Tavman, M. Chirtoc, H.P. Schuchmann, C. Sauter, S. Tavman, Thermal conductivity and viscosity measurements of water-based TiO2 nanofluids, International Journal of Thermophysics, 30(4) (2009) 1213-1226.

[33] S. Suresh, K.P. Venkitaraj, P. Selvakumar, M. Chandrasekar, Synthesis of Al2O3–Cu/water hybrid nanofluids using two step method and its thermo physical properties, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 388(1-3) (2011) 41-48.

[34] K.A. Hamid, W.H. Azmi, M.F. Nabil, R. Mamat, Experimental investigation

of nanoparticle mixture ratios on TiO2–SiO2 nanofluids heat transfer performance under turbulent flow, International Journal of Heat and Mass Transfer, 118 (2018) 617-627.

[35] C.J. Ho, J.B. Huang, P.S. Tsai, Y.M. Yang, Preparation and properties of hybrid water-based suspension of Al2O3 nanoparticles and MEPCM particles as functional forced convection fluid, International Communications in Heat and Mass Transfer, 37(5) (2010) 490-494.

[36] O. Soltani, M. Akbari, Effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluid: experimental study, Physica E: Low-dimensional Systems and Nanostructures, 84 (2016) 564-570.

[37] L.S. Sundar, K.V. Sharma, M.K. Singh, A.C.M. Sousa, Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor–A review, Renewable and Sustainable Energy Reviews, 68 (2017) 185-198.

[38] H. Setia, R. Gupta, R.K. Wanchoo, Stability of nanofluids, in: Materials Science Forum, Trans Tech Publ, 2013, pp. 139-149.

[39] W.H. Azmi, K.A. Hamid, N.A. Usri, R. Mamat, M.S. Mohamad, Heat transfer and friction factor of water and ethylene glycol mixture based TiO2 and Al2O3 nanofluids under turbulent flow, International Communications in Heat and Mass Transfer, 76 (2016) 24-32.

[40] K.A. Hamid, W.H. Azmi, M.F. Nabil, R. Mamat, K.V. Sharma, Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO2-SiO2 nanofluids, International Journal of Heat and Mass Transfer, 116 (2018) 1143-1152.

[41] A.I. Ramadhan, W.H. Azmi, R. Mamat, K.A. Hamid, S. Norsakinah, Investigation on stability of tri-hybrid nanofluids in water-ethylene glycol mixture, in: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2019, pp. 012068.

[42] C.-S. Jwo, L.-Y. Jeng, H. Chang, T.-P. Teng, Experimental study on thermal conductivity of lubricant containing nanoparticles, Rev. Adv. Mater. Sci, 18 (2008) 660-666.

[43] W. Yu, H. Xie, A review on nanofluids: preparation, stability mechanisms, and applications, Journal of nanomaterials, 2012 (2012) 1.

[44] A. Ghadimi, R. Saidur, H. Metselaar, A review of nanofluid stability properties and characterization in stationary conditions, International Journal of Heat and Mass Transfer, 54(17-18) (2011) 4051-4068.

[45] ASHRAE, Fundamentals (SI Edition), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, (2009).

[46] M.C.S. Reddy, V.V. Rao, Experimental studies on thermal conductivity of blends of ethylene glycol-water-based TiO2 nanofluids, International Communications in Heat and Mass Transfer, 46 (2013) 31-36.

[47] W.H. Azmi, K. Abdul Hamid, N.A. Usri, R. Mamat, M.S. Mohamad, Heat transfer and friction factor of water and ethylene glycol mixture based TiO2 and Al2O3 nanofluids under turbulent flow, International Communications in Heat and Mass Transfer, 76 (2016) 24-32.

[48] M. Bahrami, M. Akbari, A. Karimipour, M. Afrand, An experimental study on rheological behavior of hybrid nanofluids made of iron and copper oxide in a binary mixture of water and ethylene glycol: non-Newtonian behavior, Experimental Thermal and Fluid Science, 79 (2016) 231-237.

[49] A.A.M. Redhwan, W.H. Azmi, M.Z. Sharif, R. Mamat, Development of

nanorefrigerants for various types of refrigerant based: A comprehensive review on performance, International Communications in Heat and Mass Transfer, 76 (2016) 285-293.

[50] M.M. Ghosh, S. Ghosh, S.K. Pabi, Effects of particle shape and fluid temperature on heat-transfer characteristics of nanofluids, Journal of materials engineering and performance, 22(6) (2013) 1525-1529.

[51] M. Asadi, A. Asadi, Dynamic viscosity of MWCNT/ZnO–engine oil hybrid nanofluid: an experimental investigation and new correlation in different temperatures and solid concentrations, International Communications in Heat and Mass Transfer, 76 (2016) 41-45.

[52] M.F. Nabil, W.H. Azmi, K.A. Hamid, R. Mamat, F.Y. Hagos, An experimental study on the thermal conductivity and dynamic viscosity of TiO2-SiO2 nanofluids in water: ethylene glycol mixture, International Communications in Heat and Mass Transfer, 86 (2017) 181-189.

[53] S.M.S. Murshed, K.C. Leong, C. Yang, Investigations of thermal conductivity and viscosity of nanofluids, International Journal of Thermal Sciences, 47(5) (2008) 560-568.