Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi
Terakreditasi "**Peringkat 3**" berdasarkan SK Dirjendiktiristek, Nomor: 225/E/KPT/2022
Volume 6 Nomor 1 Tahun 2024, Januari 2024, Halaman 143-152
Website : http://journal.univpancasila.ac.id/index.php/asiimetrik/

p-ISSN 2655-1861
e-ISSN 2716-2923

Qualitative Stability and Thermal Properties Investigation of TiO2-EG/W Nanofluids Through Experimental Validation

Investigasi Stabilitas Kualitatif dan Sifat Termal Nanofluida TiO2-EG/W Melalui Validasi Eksperimental

Muhamad Taufik Ulhakim[1,2], Sukarman[1,2*], Khoirudin[1,2], Nazar Fazrin[1], Tomas Irfani[1], Amri Abdulah[3]
[1]Departmen of mechanical engineering, Faculty of engineering, Universitas Buana Perjuangan Karawang, Indonesia
[2]Centre of Research and Innovation in Energy Conversion and Nanoparticle Technology, Universitas Buana Perjuangan Karawang, Indonesia
[3]Departmen of mechanical engineering, Sekolah Tinggi Teknologi Wastukancana, Indonesia

Article information:

Received:
24/11/2023
Revised:
07/12/2023
Accepted:
11/12/2023

Abstract

Over the past two decades, researchers have been extremely interested in developing TiO_2 nanofluids for heat exchanger applications. Therefore, this study evaluates the performance of employing TiO_2 nanofluids, which were prepared using ethylene glycol (EG) and distilled water as the base fluid, then called TiO_2-EG/W. The qualitative stability and thermal conductivity properties were measured through the experimental investigation. XRD and SEM analyses were also carried out to investigate the structures of TiO_2 nanoparticles used in terms of their crystalline and morphological structures. The results showed a positive impact of stability even for 15 days, and after that, the nanoparticles dropped to the sedimentation by about 58%. Then, the highest thermal conductivity at the temperature of 80 °C was increased by about 17.08% compared to the base fluid. Supported by the results of XRD and SEM analysis, respectively, highlight that TiO_2 nanoparticles have a rutile phase with an average crystallite size of 20.23 nm and are small spherical in morphology. This paper also provided the challenge and future perspective of TiO_2 nanofluid to appear as an innovation for the development of TiO_2 nanofluid in the further studies of heat exchanger applications.

Keywords: stability, thermal conductivity, nanofluids, TiO2-EG/W.

***SDGs*:**

Abstrak

Selama dua dekade terakhir, para peneliti sangat tertarik untuk mengembangkan nanofluida TiO_2 untuk aplikasi penukar panas. Oleh karena itu, penelitian ini mengevaluasi kinerja penggunaan nanofluida TiO_2 yang dibuat menggunakan etilen glikol (EG) dan air suling sebagai cairan dasar, yang kemudian disebut TiO_2-EG/W. Stabilitas kualitatif dan sifat konduktivitas termal diukur melalui penyelidikan eksperimental. Analisis XRD dan SEM juga dilakukan untuk menyelidiki struktur nanopartikel TiO_2 yang digunakan ditinjau dari struktur kristal dan morfologinya. Hasilnya menunjukkan dampak positif stabilitas bahkan selama 15 hari, dan setelah itu nanopartikel turun ke sedimentasi sekitar 58%. Kemudian konduktivitas termal tertinggi pada suhu 80 °C meningkat sekitar 17,08% dibandingkan dengan fluida dasar. Didukung oleh hasil analisis XRD dan SEM, masing-masing menyoroti bahwa nanopartikel TiO_2 memiliki fase rutil dengan ukuran kristal rata-rata 20,23 nm dan morfologinya berbentuk bola kecil. Tulisan ini juga memberikan tantangan dan perspektif masa depan nanofluida TiO_2 untuk tampil sebagai inovasi pengembangan nanofluida TiO_2 pada penelitian lebih lanjut pada aplikasi penukar panas di masa depan.

Kata Kunci: stabilitas, termal konduktivitas, nanofluida, TiO2-EG/W.

*Correspondence Author
email : sukarman@ubpkarawang.ac.id

1. INTRODUCTION

All the industrial sectors in the world use heat exchanger tools for their operation, such as the automotive industry, petroleum industry, electronics, renewable energy, and so on (Gupta, Verma and Yadav, 2022). Therefore, heat exchanger plays an important role in the industrial sector to run an operating system and influence the effectiveness of its conversion energy systems (Tuncer *et al.*, 2023). Heat exchangers have utilized the heat transfer concept in their principal work to provide the thermal energy flow using the fluid at a certain range of temperatures (Pordanjani *et al.*, 2019). However, the evolution of technology caused the performance of heat exchangers to decrease due to the need for devices that can work more optimally. Some recent findings confirmed that the heat exchanger device is undesirable due to its limited thermal properties. Thermal properties is play an important role for heat transfer performance (Kristiawan, Kamal and Yanuar, 2016). For now, the researchers have tried to develop this study to obtain a higher coefficient heat transfer to improve performance (Zhong, Zhong and Wen, 2020). Muneeshwaran et al., introduced an alternative solution to this problem by improving the thermal properties of fluids in the heat exchanger system and no doubt conducted due to its simple, low cost, and easy preparation (Muneeshwaran *et al.*, 2021). Then, in 2022, Louis et al. stated that nanofluids are the best fluids for improving the heat exchanger (Louis *et al.*, 2022).

A long time ago, Choi and Eastman (1995) introduced nanofluid as a promising fluid for heat exchanger application (Pavía *et al.*, 2021). Nanofluid is a homogeneous mixture of nanoparticles and conventional fluid (base fluid). These conventional fluids include water, oil, or ethylene glycol (EG) (Okonkwo *et al.*, 2021). The nanofluid offers more advantages, such as a higher heat transfer rate and greater stability, to enhance the performance of heat exchanger devices (Kumar and Sarviya, 2021). Nanofluids also have a large potential to applied in electronic devices, automotive, and other sectors which coexist with the human life (Kristiawan *et al.*, 2022). For that reason, the study of nanofluids under different conditions and modifications has become a new trend among researchers. Those studies are focused on determining the right compilers of nanofluids that have a positive impact on the performances of heat exchanger devices. In other words, the nanoparticles and base fluid used in the nanofluids fabrication should be selected appropriately. Nfawa et al., in 2021., claim that metal oxide is a promising nanoparticle for nanofluid due to the low prices and their abundance (Nfawa *et al.*, 2021). Another advantage of metal oxide nanoparticles for nanofluid applications is that there is no clogging in the heat exchanger and better homogeneity (Dharmakkan *et al.*, 2023). Several metal oxides that have been fabricated to the nanofluid are MgO (Dehaj and Mohiabadi, 2019), CuO (Shang *et al.*, 2022), ZrO_2 (Yushuang Huang *et al.*, 2022), ZnO (Sharma *et al.*, 2022), Al_2O_3 (Bai *et al.*, 2023), SiO2 (Zou *et al.*, 2022), and TiO_2 (Arifin *et al.*, 2022). Among these nanoparticles, TiO_2 has attracted more attention due to its characteristics. TiO_2 has good thermal properties and is easily dissolved. It is difficult to descend to the sedimentation (Arsana *et al.*, 2022). Up to now, several studies about the utilization of TiO_2 nanofluid for heat exchanger applications have been reported. In 2022, Thianpong et al. revealed that the TiO_2 working fluid significantly improved the heat transfer properties and their device's overall performance by up to 5.0% (Thianpong *et al.*, 2022). Then, the right choice of base fluid also plays an important role in the nanofluid performance. According to Dosodia et al., base fluids used in the fabrication of nanofluid should be controlled to obtain high performance, e.g., a mixture of several base fluids such as EG-water (Dosodia *et al.*, 2022). A mixture of EG-water is believed to increase the performance of the heat exchanger device by up to 70% compared to the other base fluids (Zheng *et al.*, 2020). Rashidi et al. also reported that study in 2023. their work varied the sample of EG-water base fluid in several ratios. Then, it was found that all EG-water ratios positively impacted the heat transfer properties and proposed a great potential to study further the significant increase in the performance of heat exchanger applications (Rashidi *et al.*, 2023). The similar studies have reported by Thiyana that found EG-water mixture has significantly improved the heat transfer performance (Thiyana *et al.*, 2023).

Based on these explanations, this study brings up the motivation, innovation, and aim to contribute to increasing the performance of the heat exchanger device through the preliminary study on the development of nanofluids. The main focus of this present study is to evaluate the characteristics of TiO_2 nanofluid with a volume fraction of 3.0%. The higher concentration than 3.0% is not studied due to the disadvantage to obtain the high viscosity of nanofluid (Kristiawan *et al.*, 2020). Then, these nanofluid was successfully fabricated with the base fluid prepared from the mixture of EG and water in the 25:75 (1:3) ratio. The characteristics that evaluated are stability and thermal conductivity. These two are the fundamental characteristics that the nanofluids should achieve. For heat exchanger device performance, the nanofluid should have long-term stability and high thermal conductivity (Adun, Kavaz and Dagbasi, 2021). The crystal and morphological structure are also analyzed using X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) to support the characterization results. Then, the review of the heat exchanger application using the TiO2 nanofluid is also provided to show the challenge and opportunity of this study in future work. This research will have a significant impact on the development of heat exchanger devices and can be applied in a variety of industries.

2. METHODOLOGY

2.1. Chemicals and Equipment's

This work uses several chemicals consisting of titanium oxide (TiO_2) with the white powder in visual characteristics as illustrated in Figure 1 and the other properties shown in Table 1, ethylene glycol (EG), and distilled water. Then, the equipment consists of digital scales, beaker glass, magnetic stirrer, and ultrasonication, respectively, for measuring the chemical with accurate composition, measuring the volume of based fluid, making the homogeneous nanofluid, and dispersing nanofluids. The thermal properties validation uses a Portable KS-3 Tempos Thermal Properties Analyzer Instrument (METER Group, Inc., USA). All chemicals used in this research were purchase from Brataco Chemical, its analytical grade without any purification process.

Figure 1. White powder visualization of TiO_2 nanoparticles.

Table 1. The properties of TiO_2 nanoparticles.

Properties	Specifications
Molecular formula	TiO_2
Shape	Spherical
Average size (nm)	30
Purity (%)	>99.95
Appearance	White
density	4.23 g/cm^3

2.2. Preparation of Nanofluids

This stage begins with a chemical preparation consisting of 63.5 g of TiO_2, 25 ml of EG, and 75 ml of distilled water in a 25:75 (1:3) ratio for EG-distilled water. This mixture is a 3.0% volume fraction of TiO_2 nanofluids with 25% EG on the base fluid (TiO_2-EG/W). The number of volume fractions is calculated using equation (1) (Krishnakumar *et al.*, 2019).

$$\phi = \frac{\left(\frac{m}{\rho}\right)_{TiO_2}}{\left(\frac{m}{\rho}\right)_{TiO_2} + \left(\frac{m}{\rho}\right)_{Base\ fluid}} \text{ x } 100\% \qquad (1)$$

where, ϕ represents the percentage volume fraction of the nanofluid, m refers to the mass of the TiO_2 and base fluid. Then, ρ is the density for TiO_2 and base fluid, respectively.

The nanofluid is then prepared using a two-step method, as shown in Figure 2. This method is preferred for dispersing nanoparticles in different base fluids (Elsaid *et al.*, 2021).

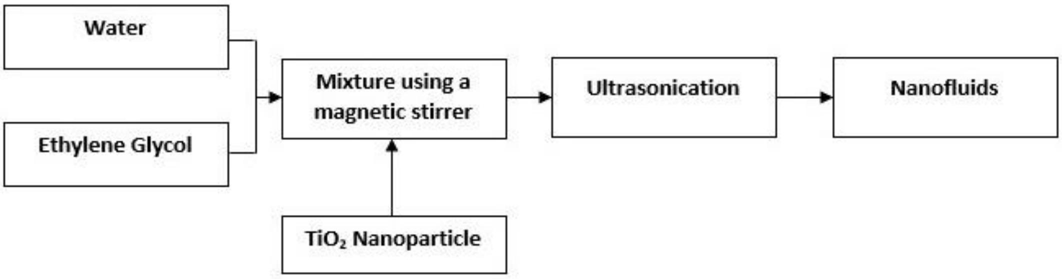

Figure 2. Illustration of TiO_2-EG/W preparation.

The first step involves mixing EG and distilled water with a magnetic stirrer for about one hour in 600 rpm. This solution is then known as the base fluid.

TiO_2 was then gradually introduced into the base fluid while stirring. Once all mixed, the stirring was subsequently continued until a homogeneous nanofluid was obtained. Afterwards, the homogeneous TiO_2 nanofluid is dispersed by ultrasonication for approximately one hour in deionized water. According to Poloju et al., ultrasonication caused the breaking of nanofluid aggregation and its change in the thermophysical properties with a long-term nanofluid stability (Poloju *et al.*, 2022). Several characterizations are then carried out to investigate the properties of the nanofluids, i.e. crystal structure using an XRD Benchtop Miniflex 600 and morphological structure using an SEM SU3500. The XRD characterization operates in scan mode between 0 to 90°. The characterization is carried out using Cu-Kα radiation at a wavelength of 1.5046 Å. Furthermore, this characterization also estimated the crystallite size of the nanoparticle using the Debye-Scherrer equation, as shown in equation 2 (Sundar, 2023). Meanwhile, SEM operates at 4.0 kV to produce a high-quality image. XRD and SEM characterizations are carried out on the dry of TiO_2-EG/W.

$$D = \frac{0.9\lambda}{\beta \cos\theta} \tag{2}$$

where, D is the crystallite size (nm), λ is the wavelenght of the X-ray source used for characterization, β is the full width at half maximum intensity peak, and θ is the angle of the diffraction process.

2.3. Qualitative Stability Analysis and Thermal Conductivity Measurement

The qualitative stability is investigated by observing TiO_2-EG/W visualization day by day until the nanofluid's stability is down. This observation confirms the stability level of the nanofluid. The stability is observed by the sedimentation that formed from nanofluid. The fastest sedimentation formed indicates a low stability of nanofluids. Then, the thermal conductivity of TiO_2-EG/W nanofluid was measured using a Portable KS-3 Tempos Thermal Properties Analyzer Instrument (METER Group, Inc., USA) with a schematic illustrated in Figure 3.

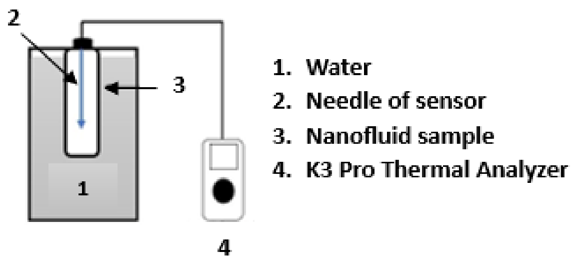

Figure 3. Illustration of thermal conductivity measurement.

The KS-3 type employed is the needle with an embedded temperature sensor. This instrument is claimed to be the best tool for measuring the thermal conductivity of fluids and has been used by several researchers, including Sundaram (Sundaram *et al.*, 2023). In this work, the measurement is performed in the temperature range between 30° to 80° with the data collected at each 5° increase in temperature. These range of temperature was choosen due to the average of optimal working temperature of heat transfer devices (Yicheng Huang *et al.*, 2022). Initially, the nanofluid sample was stored in a heat-resistant tube. The KS-3 needle was then inserted into the tube vertically without touching the tube's wall surface. This condition was maintained to ensure the accuracy of the measuring results. Measurements with repeatability are performed to improve the precision with which the thermal conductivity of nanofluids is determined. In addition, the results are validated by comparison to the ASHRAE standard.

3. RESULTS AND DISCUSSION

XRD and SEM characterization are carried out to validate the structure of TiO_2-EG/W for crystal and morphological structures, respectively. The XRD analysis is presented in a graphical intensity pattern to Bragg's angle as shown in Figure 4. The Bragg angles observed at 27.60° (101), 36.24° (200), 39.37° (111), 41.42° (120), 44.21° (211), 54.49° (220), 56.77° (002), 63.23° (130), 64.19° (221), 69.16° (301), 69.97° (112), 82.53° (202) belong to the rutile phase of TiO_2.

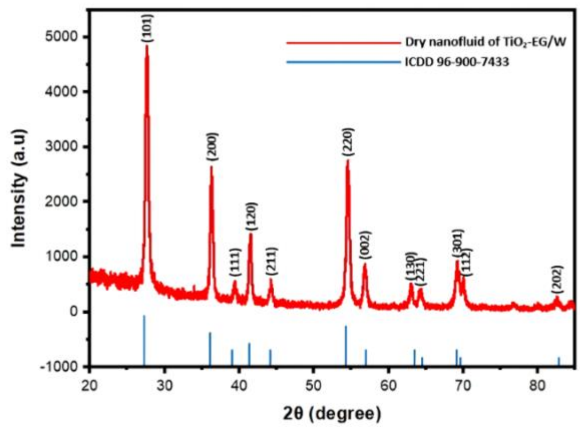

Figure 4. XRD pattern for dry nanofluid of TiO_2 nanoparticle.

According to Ali in 2018, the rutile phase of TiO_2 shows a good performance for nanofluids (Ali *et al.*, 2018). Then, the pattern is matched to the ICDD 96-900-7433 in Match! 3 software, this analysis indicates that the nanofluid is pure TiO_2 without any impurity. The XRD analysis confirms that the TiO_2 nanoparticle has an average crystallite size of 20.23 nm. This number is obtained from the analysis using the Debye Scherrer formula, as shown in equation 2. In addition, SEM analysis was performed to confirm the structure of TiO_2 nanoparticles in nanofluid. It was observed that the morphological structure of the TiO_2 nanoparticle appeared to be a spherical shape, as illustrated in Figure 5. The SEM analysis also confirms that TiO_2 nanoparticles are predicted to be easily agglomerated. This finding will be a drawback for nanofluid applications. However, this condition needs further observation in the stability of TiO_2-EG/W nanofluid. The stability of the TiO_2 nanofluid was then evaluated. In this work, the evaluation was carried out by qualitative experiment. This method was reported by Shi et al. in 2023 (Shi *et al.*, 2023).

Qualitative stability is investigated using observation day by day. This evaluation produces the stability information of nanofluid from the visual image of nanofluid taken at different time intervals. In this work, the TiO2-EG/W is observed at 0 days (after preparation), 15 days, and 30 days, as shown in Figure 6a. From that information, it was found that the decreasing of TiO_2-EG/W nanofluid stability is 58% for 15 days as shown in Figure 6b. It informed that sedimentation occurred on this condition; however, it cannot predict the reaction behind the sedimentation process. It might occur due to the strong van der Waals forces and gravity of TiO_2 nanoparticles (Rehman *et al.*, 2023). Nevertheless, several studies report the same condition regarding the sedimentation formed in TiO_2 nanoparticles, as shown in Table 2. It concludes that the sedimentation formed on the 15^{th} day from the preparation process is still better than others.

Table 2. Several studies about the sedimentation of TiO_2 nanofluid investigation.

Materials	Sedimentation investigation	Ref.
TiO_2/Water	7 days	(Zhang *et al.*, 2022)
$CuO/TiO_2/SiO_2$	10 days	(Muzaidi *et al.*, 2021)
TiO_2-EG/W	15 days	This work

Figure 7a shows the plot of the thermal conductivity of TiO2-EG/W nanofluid prepared by a two-step method at a temperature range of

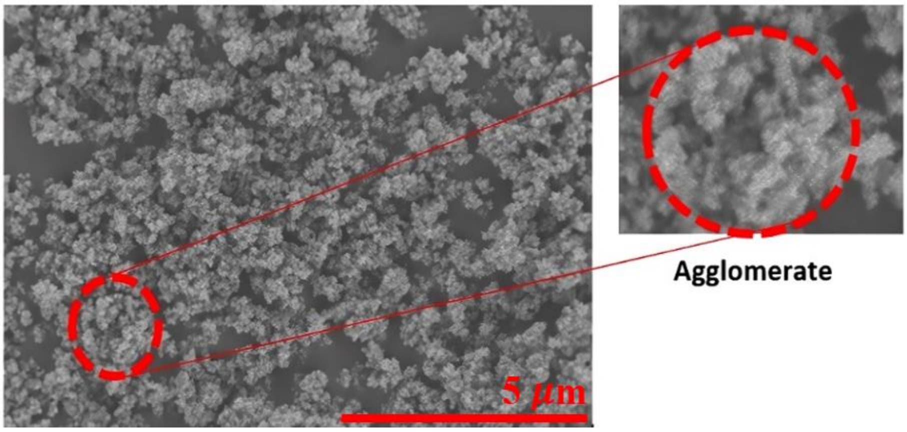

Figure 5. Nanoparticle morphological investigation using SEM.

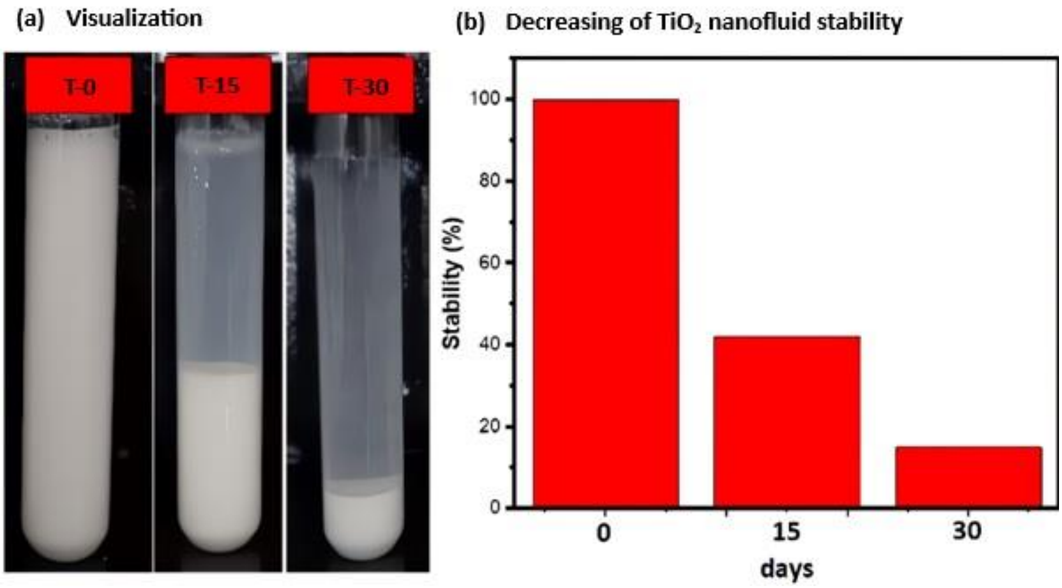

Figure 6. (a) Qualitative stability observation of TiO2-EG/W nanofluid at 0 day/after preparation (T-0), 15 days (T-15), and 30 days (T-30), (b) Decreasing of TiO2-EG/W nanofluid stability.

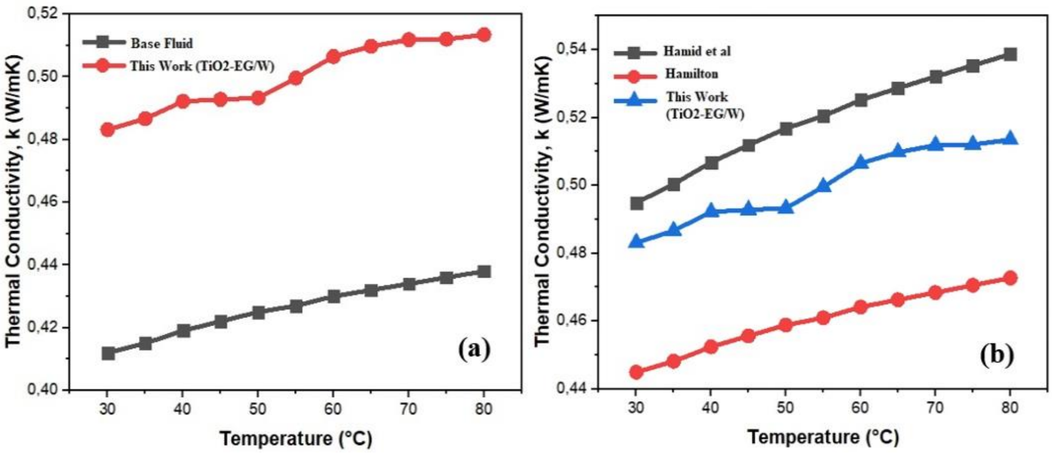

Figure 7. (a) Thermal conductivity of TiO2-EG/W compared to base fluid, (b) compared to other studies (Hamid *et al.*, 2015).

30°C to 80 °C compared to the base fluid of ASHRAE. It informs that the highest thermal conductivity is reached at 80 °C, about 17.08% higher than the base fluid. This finding is an advantage for TiO_2-EG/W that is applied to heat exchanger application. Then, thermal conductivity was also compared to the Hamid et al. (Hamid *et al.*, 2016) and Hamilton model Figure 7b shows that the thermal conductivity of TiO_2-EG/W in this present study is higher than Hamilton and lower than Hamid. However, overall characteristics found in this work are still within the normal limits of TiO_2 for heat exchanger application.

This study then findings several characteristics of TiO_2 nanofluid properties that might be useful and helpful for the innovation of upcoming work. To obtain improved performance of TiO_2-EG/W, it is suggested to vary several factors, i.e., volume fraction or EG-water ratio. Another suggestion is to develop a calculation model to determine the thermal conductivity. In addition, TiO_2 nanofluid still has great potential to be developed in future work due to their abundance in nature. Then, it can be developed to apply the TiO_2 nanoparticles from nature as nanofluid in heat exchanger applications and compare their performances with the analytical grade of TiO_2 nanoparticles. However, there are several challenges to developing the TiO_2 nanofluid; one is challenging to control the heat transfer properties due to the technological increase. It follows the fulfilment of nanofluid properties from time to time, customized to heat exchanger devices.

4. CONCLUSION

This study reported the investigation of nanofluid-based TiO2-EG/W with the ratio of EG: water is 40:60 (2:3) and the volume fraction of nanofluid equal to 3.0%. The nanofluid-based TiO2-EG/W was successfully prepared by a two-step method. It was confirmed by an XRD analysis, which showed the rutile phase of TiO2 and, following the aim of this study, indicated good properties for nanofluid application. It is supported by SEM analysis that confirms the morphological structure of TiO2 in nanofluid is approached to be spherical shape. However, the disadvantage was that TiO2 nanoparticles easily agglomerate in a nanofluid. These findings follow the stability characteristics, which showed the decrease of TiO2 nanoparticles in nanofluid and formed the sedimentations after 15 days.

The stability is observed using qualitative method and informed the stability decrease of about 58% from the initial or after the preparation. This investigation confirmed that TiO2-EG/W nanofluid in this present study has good stability even for 15 days, and then the evaluation of TiO2-EG/W nanofluid properties is ready to be conducted for further investigation. The thermal conductivity of TiO2-EG/W was investigated at the range temperatures of 30 °C to 80 °C. The maximum value of thermal conductivity was obtained at 80 °C of temperature. That value has enhanced up to 17.08% relative to the base fluid. These findings also confirmed the good characteristics of TiO_2-EG/W nanofluid for heat transfer or other applications related to this topic.

ACKNOWLEDGMENTS

Thanks to "The Ministry of Research, Technology, & Higher Education" who has fully funded this research through the "Penelitian Dosen Pemula" program with contract number 053/SPH2H/RT-MONO/LL42023/and 02/LPPM/PDP/VII/2023.

REFERENCES

Adun, H., Kavaz, D. and Dagbasi, M. (2021) 'Review of ternary hybrid nanofluid: Synthesis, stability, thermophysical properties, heat transfer applications, and environmental effects', *Journal of Cleaner Production*, 328, p. 129525.

Ali, H.M. *et al.* (2018) 'Preparation Techniques of TiO2 Nanofluids and Challenges: A Review', *Applied Sciences*, 8(4), p. 587.

Arifin, Z. *et al.* (2022) 'The application of TiO2 nanofluids in photovoltaic thermal collector systems', *Energy Reports*, 8, pp. 1371-1380.

Arsana, I.M. *et al.* (2022) 'Preparation and Characterization of TiO2 Nanoparticles as Nanofluid in Double Pipe Heat Exchanger', in.

International Joint Conference on Science and Engineering 2022 (IJCSE 2022), Atlantis Press, pp. 169-185.

Bai, X. *et al*. (2023) 'Tribological Performance of Different Concentrations of Al2O3 Nanofluids on Minimum Quantity Lubrication Milling', *Chinese Journal of Mechanical Engineering*, 36(1), p. 11.

Dehaj, M.S. and Mohiabadi, M.Z. (2019) 'Experimental investigation of heat pipe solar collector using MgO nanofluids', *Solar Energy Materials and Solar Cells*, 191, pp. 91-99.

Dharmakkan, N. *et al*. (2023) 'A case study on analyzing the performance of microplate heat exchanger using nanofluids at different flow rates and temperatures', *Case Studies in Thermal Engineering*, 44, p. 102805.

Dosodia, A. *et al*. (2022) 'Experimental Studies and Analytical Analysis of Thermophysical Properties of Ethylene Glycol-Water-Based Nanofluids Dispersed with Multi-walled Carbon Nanotubes', *International Journal of Thermophysics*, 43(12), p. 175.

Elsaid, K. *et al*. (2021) 'Thermophysical properties of graphene-based nanofluids', *International Journal of Thermofluids*, 10, p. 100073.

Gupta, S.K., Verma, H. and Yadav, N. (2022) 'A review on recent development of nanofluid utilization in shell & tube heat exchanger for saving of energy', *Materials Today: Proceedings*, 54, pp. 579-589.

Hamid, K.A. *et al*. (2015) 'Effect of temperature on heat transfer coefficient of titanium dioxide in ethylene glycol-based nanofluid', *Journal of Mechanical Engineering and Sciences*, 8, pp. 1367-1375.

Hamid, K.A. *et al*. (2016) 'Experimental investigation on heat transfer performance of TiO2 nanofluids in water-ethylene glycol mixture', *International Communications in Heat and Mass Transfer*, 73, pp. 16-24.

Huang, Yicheng *et al*. (2022) 'Thermal management of polymer electrolyte membrane fuel cells: A critical review of heat transfer mechanisms, cooling approaches, and advanced cooling techniques analysis', *Energy Conversion and Management*, 254, p. 115221.

Huang, Yushuang *et al*. (2022) 'Thermophysical property evaluation of β-cyclodextrin modified ZrO2 nanofluids for microchannel heat exchange', *Ceramics International*, 48(21), pp. 31728-31737.

Krishnakumar, T.S. *et al*. (2019) 'Heat transfer studies on ethylene glycol/water nanofluid containing TiO2 nanoparticles', *International Journal of Refrigeration*, 102, pp. 55-61.

Kristiawan, B. *et al*. (2020) 'Enhancing the thermal performance of TiO2/water nanofluids flowing in a helical microfin tube', *Powder Technology*, 376, pp. 254-262.

Kristiawan, B. *et al*. (2022) 'Simulation-based assessment of the thermal-hydraulic performance of titania-based nanofluids in a circular-mini-channel tube', *International Journal of Ambient Energy*, 43(1), pp. 8022-8035.

Kristiawan, B., Kamal, S. and Yanuar (2016) 'Thermo-Hydraulic Characteristics of Anatase Titania Nanofluids Flowing Through a Circular Conduit', *Journal of Nanoscience and Nanotechnology*, 16(6), pp. 6078-6085.

Kumar, P. and Sarviya, R.M. (2021) 'Recent developments in preparation of nanofluid for heat transfer enhancement in heat exchangers: A review', *Materials Today: Proceedings*, 44, pp. 2356-2361.

Louis, S.P. *et al*. (2022) 'Application of Nanofluids in Improving the Performance of Double-Pipe Heat Exchangers-A Critical Review', *Materials (Basel, Switzerland)*, 15(19), p. 6879.

Muneeshwaran, M. *et al*. (2021) 'Role of hybrid-nanofluid in heat transfer enhancement - A review', *International Communications in Heat and Mass Transfer*, 125, p. 105341.

Muzaidi, N.A.S. *et al*. (2021) 'Heat absorption properties of CuO/TiO2/SiO2 trihybrid nanofluids and its potential future direction towards solar thermal applications', *Arabian Journal of Chemistry*, 14(4), p. 103059.

Nfawa, S.R. *et al*. (2021) 'Novel use of MgO nanoparticle additive for enhancing the thermal conductivity of CuO/water nanofluid', *Case Studies in Thermal Engineering*, 27, p. 101279.

Okonkwo, E.C. *et al.* (2021) 'An updated review of nanofluids in various heat transfer devices', *Journal of Thermal Analysis and Calorimetry*, 145(6), pp. 2817–2872.

Pavía, M. *et al.* (2021) 'A critical review on thermal conductivity enhancement of graphene-based nanofluids', *Advances in Colloid and Interface Science*, 294, p. 102452.

Poloju, V.K. *et al.* (2022) 'Thermal conductivity and dispersion properties of SDBS decorated ternary nanofluid: Impacts of surfactant inclusion, sonication time and ageing', *Journal of Molecular Liquids*, 368, p. 120832.

Pordanjani, A.H. *et al.* (2019) 'An updated review on application of nanofluids in heat exchangers for saving energy', *Energy Conversion and Management*, 198, p. 111886.

Rashidi, M.M. *et al.* (2023) 'Modeling and Sensitivity Analysis of Thermal Conductivity of Ethylene Glycol-Water Based Nanofluids with Alumina Nanoparticles', *Experimental Techniques*, 47(1), pp. 83-90.

Rehman, A. *et al.* (2023) 'Effect of surfactants on the stability and thermophysical properties of Al2O3+TiO2 hybrid nanofluids', *Journal of Molecular Liquids*, 391, p. 123350.

Shang, Y. *et al.* (2022) 'The computational study of microchannel thickness effects on H2O/CuO nanofluid flow with molecular dynamics simulations', *Journal of Molecular Liquids*, 345, p. 118240.

Sharma, R. *et al.* (2022) 'Characterization of ZnO/nanofluid for improving heat transfer in thermal systems', *Materials Today: Proceedings*, 62, pp. 1904–1908.

Shi, Z. *et al.* (2023) 'Thermal physical and magnetic properties of water-based yolk-shell Fe3O4@C nanofluids', *Inorganic Chemistry Communications*, 151, p. 110562.

Sundar, L.S. (2023) 'Experimental study on the thermophysical properties, heat transfer, thermal entropy generation and exergy efficiency of turbulent flow of ZrO2-water nanofluids', *Alexandria Engineering Journal*, 65, pp. 867–885.

Sundaram, P. *et al.* (2023) 'Synthesis, stability, and heat transfer behavior of water and graphene nanoplatelet-based nanofluid for cool thermal storage applications', *Journal of Energy Storage*, 64, p. 107219.

Thianpong, C. *et al.* (2022) 'Multi objective optimization of TiO2/water nanofluid flow within a heat exchanger enhanced with loose-fit delta-wing twisted tape inserts', *International Journal of Thermal Sciences*, 172, p. 107318.

Thiyana, T. *et al.* (2023) 'The Heat Transfer Coefficient in a Copper Pipe Flow System Using a 40/60 Volume Ratio Ethylene Glycol/Water (EG/H2O) Blended Fluid', *Jurnal Teknik Mesin Mechanical Xplore*, 4(1), pp. 37–46.

Tuncer, A.D. *et al.* (2023) 'Upgrading the performance of shell and helically coiled heat exchangers with new flow path by using TiO2/water and CuO-TiO2/water nanofluids', *International Journal of Thermal Sciences*, 183, p. 107831.

Zhang, H. *et al.* (2022) 'Stability and thermal conductivity of TiO2/water nanofluids: A comparison of the effects of surfactants and surface modification', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 641, p. 128492.

Zheng, D. *et al.* (2020) 'Performance analysis of a plate heat exchanger using various nanofluids', *International Journal of Heat and Mass Transfer*, 158, p. 119993.

Zhong, D., Zhong, H. and Wen, T. (2020) 'Investigation on the thermal properties, heat transfer and flow performance of a highly self-dispersion TiO2 nanofluid in a multiport mini channel', *International Communications in Heat and Mass Transfer*, 117, p. 104783.

Zou, Q. *et al.* (2022) 'Effect of water-based SiO2 nanofluid on surface wettability of raw coal', *Energy*, 254, p. 124228.