International Journal of Engineering & Technology, 7 (3.17) (2018) 137-140

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Evaluation on Thermo-Electrical Characteristics of Sio_2 Nanofluids for Fuel Cell Cooling Application in Automobiles

Suleiman Akilu[1], Aklilu Tesfamichael Baheta[1]* and K. V. Sharma[2]

[1]*Mechanical Engineering Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia*
[2]*Centre for Energy, Mechanical Engineering, JNTUH College of Engineering, Kukatpally, Hyderabad 500085, India*
**Corresponding author Email: aklilu.baheta@utp.edu.my*

Abstract

Effective thermal management is critical requirement in fuel cell technologies to avoid the performance degradation during operation. Nanofluids offer the potential to address this cooling challenge in fuel cells better than pure fluids. However, due to the electrochemical changes associated with the proton exchange membrane system, a strict limit on thermal and electrical properties of coolant needs to comply. In this study, the thermal and electrical conductivities of silicon dioxide (SiO_2) dispersion of ethylene glycol (EG), glycerol (G), and 40:60 by mass ethylene glycol-glycerol (EG/G) was investigated experimentally. Measurements were carried for particle volume concentrations of 0.25–2.0% at a temperature of 30 °C. The thermal and electrical conductivity of the nanofluids significantly increases with SiO_2 loading. Maximum enhancements of ~4.0% and ~198% at a volume concentration of 2.0% were obtained with SiO_2-EG/G, respectively. Further, analysis of the results reveals that SiO_2/G exhibited the greatest thermo-electrical performance, followed by SiO_2-EG/G and EG. Therefore, SiO_2-EG/G nanofluid is best-suited coolant for PEM fuel cell thermal applications.

Keywords: *SiO_2; nanofluid; electrical conductivity; thermal conductivity, PEM fuel cell*

1. Introduction

Enhancing the thermophysical properties of single-phase fluids offers a smarter and sustainable means to achieve improved thermal transport efficiency, save energy consumption, and cost with less environmental impacts. A proton exchange membrane fuel cell (PEMFC) is a power source like batteries which combines hydrogen and oxygen into usable electric power through an electrochemical reaction. A typical operation of the device for low power application occurs at high power densities with temperatures ranging from 30℃ to 100℃. Due to exothermic nature of the electrochemical process, heat generated needs to be managed effectively to keep the fuel cell operating efficiently. Water is typically used as a medium for cooling closed-cathode fuel cell technologies. For a highly compact stack design fuel cells, a new improved cooling system is required. Thus, nanofluids have been proposed as alternative cooling fluid to water [1]

Nanofluid is a new heat transfer fluid engineered by dispersing solid particles of less than 100 nm dispersed in conventional fluids such as water, ethylene glycol, and glycerol [2]. Nanofluids are proven for enhanced thermal conductivity, electrical conductivity, and heat transfer performance [3]. It has been proposed as next-generation cooling fluids for electronics devices, automotive engine, fuel cells exchange membrane, etc.

The electrical conductivity is an important property of a suspension involving electric-active fluid flow applications. It depends upon the nature of suspended particles, base fluid, volume fraction, particle size and surface charge. Nanofluids utilizing metallic oxides dispersion would exhibit high electric conductivity than pure base liquids. This is because of very well structured and larger electrical double layer (EDL) of high ionic conductivity, resulting from strong interactions between the ions/molecules in solution and charges on the surface of nanoparticles [4]. So far, efforts to measure the electrical conductivity of nanofluids have been relatively few.

Angayarkanni and Philip [5] reported the electrical conductivity Al_2O_3 (~15 nm)/water nanofluids for volume concentration up to 4.0% at room temperature of (25 ^oC). Adio et al. [6] have examined the electrical conductivity of glycerol-based γ-Al_2O_3 (17 nm) at 0.1–2.0% volume and temperatures between 20 and 70 ^oC. Sharifpur et al. [7] investigated the electrical behavior of SiO_2 (13.4 nm)/ethylene glycol nanofluids. Recently, Zyła and Jacek [8] studied ethylene glycol-based nanofluid of SiO_2 (7–14 nm) nanoparticles at a temperature of 25 ^oC and volume concentrations of 0.5–2.6%.

In light of the above discussion, therefore, present work aimed to investigate the electrical and thermal conductivity properties of SiO_2 nanofluids for potential cooling applications in Proton Exchange Membrane (PEM) fuel cells systems. Different SiO_2 dispersions in ethylene glycol, glycerol, and ethylene glycol-glycerol for particle volume concentrations of 0.25–2.0% and at temperatures of 30 ^oC were considered for the present study.

2. Theory

Maxwell [9] firstly introduced a model for the electrical conductivity of suspensions of ceramic particles which holds for the homogeneous medium of low volume fraction liquid-solid system with uniformly sized, randomly dispersed, and non-interacting spherical particles given as:

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

$$\frac{\sigma_{nf}}{\sigma_{bf}} = \frac{3(\alpha-1)\varphi}{3(\alpha-2)-3(\alpha-1)\varphi} \quad (1)$$

The Maxwell's model (1) was later generalized by Cruz et al. [10] which resulted in the following conditions:

$$\frac{\sigma_p}{\sigma_{bf}} = 1-3\varphi, \text{ for } \sigma_p << \sigma_{bf} \text{ (insulating particles)} \quad (i)$$

$$\frac{\sigma_p}{\sigma_{bf}} = 1, \text{ for } \sigma_p = \sigma_{bf} \text{ (equal conductivity)} \quad (ii)$$

$$\frac{\sigma_p}{\sigma_{bf}} = 1+3\varphi, \text{ for } \sigma_p >> \sigma_{bf} \text{ (conducting particles)} \quad (iii)$$

Where, ϕ is the particle concentration, σ_{nf}, σ_{bf}, and σ_p are the electrical conductivities of the nanofluid base liquid and nanoparticle, α is the conductivity ratio of the two phases given by σ_p/σ_{bf} and obtained from Maxwellian approximation.

2.1. Thermo-Electrical Ratio

Thermo-electric (TEC) ratio is a figure of merit defined as the ratio of thermal to electrical conductivity. It is used as a benchmark for assessing the suitability of the nanofluids in proton exchange membrane fuel cell (PEMFC) cooling as represented in Eq. (2):

$$\text{TEC} = \frac{5k_{nf}}{\sigma_{nf}k_{bf}} \quad (2)$$

The variables k_{nf} and k_{bf} describe thermal conductivity of nanofluid and base liquid, respectively. Higher values of TEC indicate better cooling capacity of the fluid medium.

3. Experiments

Materials and Methods: Silicon oxide nanopowder (SiO_2, 15-20 nm, S-type, spherical, non-porous and amorphous) was procured from US Research Nanomaterials, Inc. while analytical grades of ethylene glycol (EG) and glycerol (G) were obtained from R&M Chemicals.

Nanofluids were prepared in two steps by dispersing the procured SiO_2 powder in the three base fluids namely, ethylene glycol, glycerol, and ethylene glycol glycerol mixture (40:60) at 0.25, 0.5, 0.75, 1.0 and 2.0% volume concentrations, respectively. About 100 ml of nanofluid solution was ultrasonicated for 2 hours to break down the agglomerates.

The structure and size of the as-received powder were examined by field emission gun assisted scanning electron microscopy analysis (FE-SEM) on LEO 1525, GEMINI).

The electrical conductivity was measured using a portable dual-channel conductivity/pH meter (SG23-SevenGo, Mettler Toledo) with an accuracy of ±0.01 µS/cm. The thermal conductivity was measured using KD2 Pro device within ±5% uncertainty. All data were recorded at steady-state temperature of 30 ^oC.

4. Results and Discussion

The SEM image of the silica powder is shown in Figure 1. From this image, the SiO_2 particles appear to be nearly uniform in size and are closely packed spheres. The average size of the nanoparticles was estimated as 21 nm.

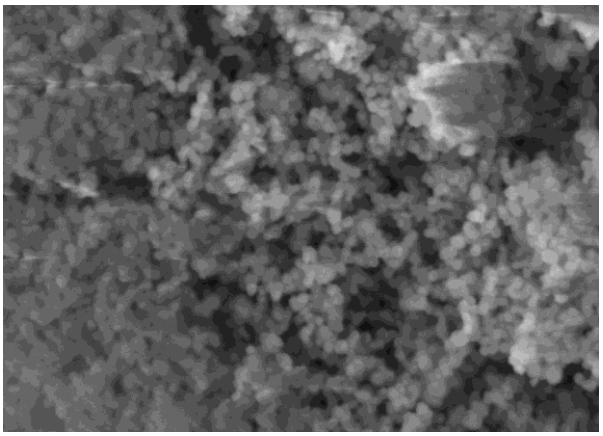


Fig. 1: SEM image of silicon dioxide nanoparticles.

The measured data for electrical conductivity of base liquids; EG, G and EG/G base liquids is presented in Table 1. The obtained values for EG and G were compared with reference values [11,12]. It must be mentioned that comparison data were unavailable for EG/G. As can be observed from this table, the electrical conductivity values strongly deviated from reference values. The reason for these discrepancies are unclear but the differences in purity levels or ionic species could be a probable cause [13].

Table 1: Font Specifications for A4 Papers

T(°C)	Exp (EG), µS·cm-1	Theo. (EG), µS·cm-1
20	0.18	1.07 [11]
20	0.26	-
T(°C)	**Exp (G), µS·cm-1**	**Theo. (G), µS·cm-1**
25	0.0	-
25	0.0	0.064 [12]
T(°C)	**Exp (G), µS·cm-1**	**Theo. (G), µS·cm-1**
20	0.0	NA
25	0.08	NA

*NA – not available

The variation in electrical conductivity with loadings of SiO_2 nanoparticles in EG, G, and EG/G, respectively at 30 ^oC are presented in Figure 2. As can be seen, the electrical conductivity of the nanofluid increase linearly with increase in particle volume

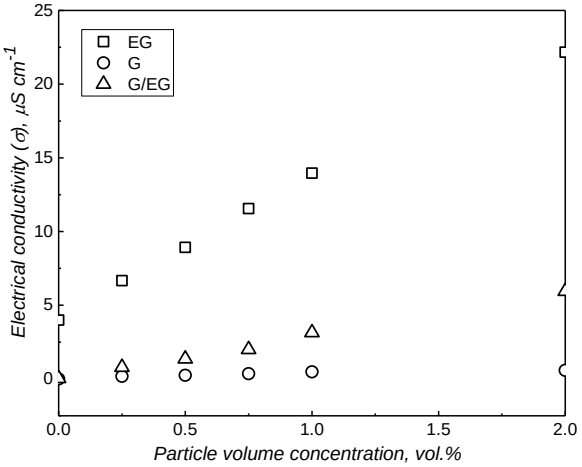


Fig. 2: SEM image of silicon dioxide nanoparticles versus particle volume fraction.

concentration. The EG based SiO_2 nanofluids exhibits higher electrical conductivity increase than SiO_2 dispersions in G and EG/G. The maximum values observed for EG, G, and EG/G at 2.0% volume fraction were 22.2 µScm^{-1}, 0.58 µScm^{-1}, and 5.94 µScm^{-1}, respectively. The main cause for electrical conductivity increase can be attributed to the net charge effect of the suspended particle and the consequent EDL interactions in the nanofluid [14].

Figure 3 compares electrical conductivity ratio of SiO_2-EG and SiO_2-EG/G nanofluids at different volume fractions. The data of

SiO_2 G-nanofluids is not presented since glycerol (G) had a very negligible electrical conductivity value at 30 °C. From the plot, higher electrical conductivity enhancement values are found at 2.0% volume concentrations of nanofluids. The conductivity enhancement ratio was up to 63% for SiO_2/EG and 198% for SiO_2-EG/G as compared to their respective base liquids EG and EG/G. This enhancement may be caused by polarization effects due to surface charges around nanoparticles in a polar medium [15].

The comparison between the electrical conductivity enhancements of SiO_2 nanofluids and theory is depicted in Figure 4. It is apparent that the Maxwell model (case 1) failed to predict the electrical conductivity values. According to Maxwell theory SiO_2 nanoparticles will decrease the electrical conductivity of the base fluids due to their insulating characteristics. This is consistent with the results of Khdher et al. [4].

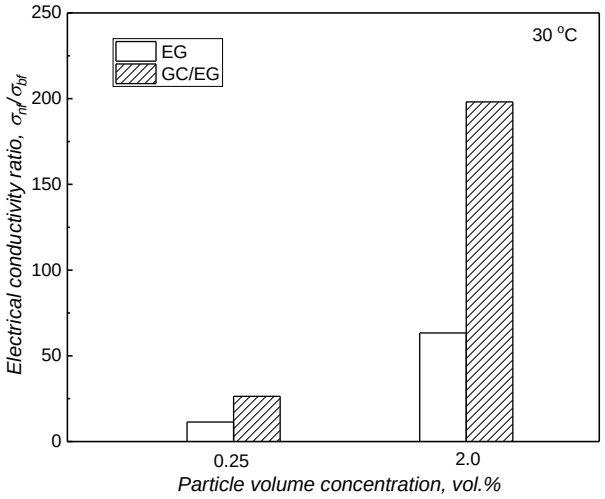


Fig. 3: Electrical conductivity ratio of SiO_2 nanofluids versus particle volume fraction.

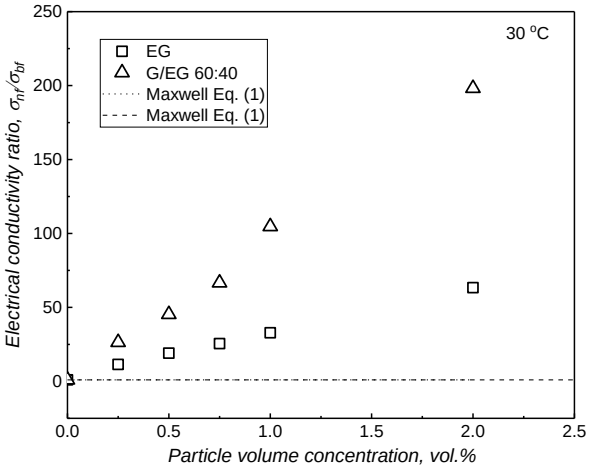


Fig. 4: Comparisons of electrical conductivity ratio of SiO_2 nanofluids with theory.

Figure 5 shows the variation of electrical conductivity with loadings of SiO_2 nanoparticles in EG, G, and EG/G, respectively at 30 °C. The thermal conductivity of nanofluid increased with increasing particle concentration. The enhancement is the highest for EG based SiO_2 nanofluids compared to G and EG/G nanofluids. Maximum enhancements for EG, G, and EG/G nanofluids, respectively were 9.4%, 1.3%, and 3.2% at 2.0% volume concentration compared to base liquids. The reason for this phenomenon may be explained by nature of layering of the base fluid molecules on the surface of the SiO_2 nanoparticles [4].

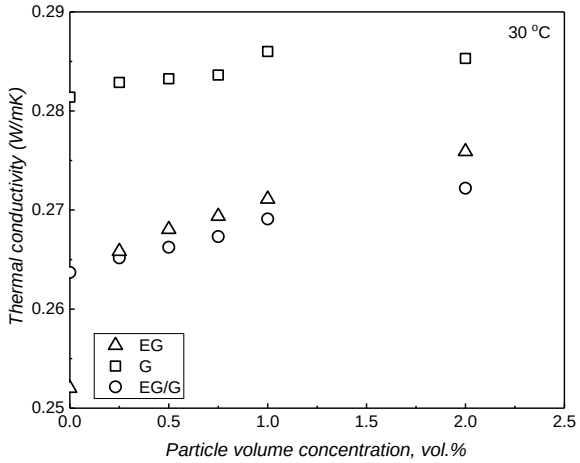


Fig. 5: Thermal conductivity of SiO_2 nanofluids versus particle volume fraction.

Figure 6 shows the thermo-electrical conductivity of SiO_2 nanofluids at 30 °C. As can be observed, as the particle volume concentration increases, the TEC ratio decreases. The SiO_2/G nanofluids exhibited the highest values compared to SiO_2-EG and SiO_2-EG/G. The maximum values for the nanofluids are 28.6, 1.26 and 6.3, respectively at 0.25% volume concentration. Therefore, the SiO_2-EG nanofluid in the present study had better TEC ratios for PEM fuel cell thermal applications that prioritized higher thermal conductivity enhancements than electrical conductivity.

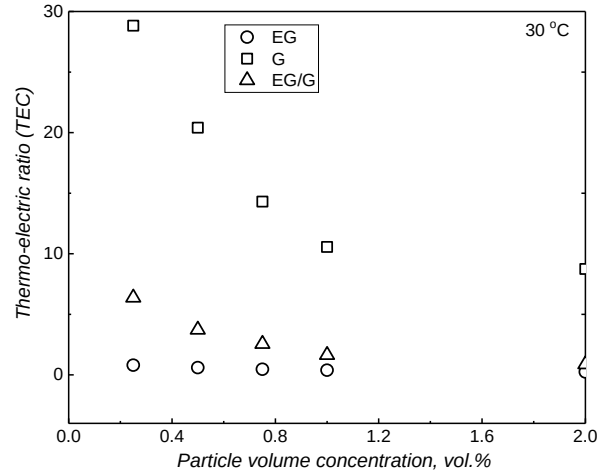


Fig. 6: Comparison of thermos-electric conductivity (TEC) of SiO_2 nanofluids.

5. Conclusions

In this work, the electrical and thermal conductivity of silica nanoparticles in different base liquids viz., ethylene glycol, glycerol and ethylene glycol-glycerol mixture (40:60) ratio by weight is investigated in the range of 0.25–2.0% vol. and at temperature of 30 °C. The following conclusions can be drawn from the experimental work:

(1) The effective electrical and thermal conductivities increased with concentration and SiO_2 exhibit larger increment values in EG compared to G and EG/G as base liquids.

(2) The EG/G based SiO_2 nanofluids had superior electrical conductivity ratio (198%) than EG nanofluid (63.3%). Comparison was not possible for SiO_2/G due to zero values of electrical conductivity of G as base liquid. On the other hand, SiO_2-EG exhibited highest thermal conductivity enhancements of 9.4% followed by EG/G (3.2) and G nanofluid with 1.3% at 2.0% volume concentration.

(3) The classical Maxwell's model for electrical conductivity is not applicable to SiO_2 nanofluids.

(4) The highest TEC ratio was observed with SiO_2-G showing a maximum value of 28.6%, whereas SiO_2-EG/G and SiO_2-EG had lower values of 6.3% and 1.26%, respectively at a particle volume concentration of 0.25%. Hence, SiO_2-G nanofluid is more favourable for PEM fuel cell cooling benefit.

Acknowledgement

This work was supported by URIF Research Grant (URIF 0153AA-G01) by Universiti Teknologi PETRONAS (UTP) Malaysia. The first author also acknowledges the financial support towards PhD graduate assistantship.

References

[1] Talib S., Azmi W., Zakaria I., Mohamed W., Mamat A., Ismail H., 2015, "Thermophysical Properties of Silicon Dioxide (SiO2) in Ethylene Glycol/Water Mixture for Proton Exchange Membrane Fuel Cell Cooling Application," Energy Procedia, vol. 79, pp. 366–371, 2015.

[2] Choi S. U. S. and Eastman J. A. 1995. Enhancing thermal conductivity of fluids with nanoparticles, in developments and applications of non-Newtonian flows, in: D.A. Singer, H.P. Wang (Eds.), American Society of Mechanical Engineers, New York, FED–231/MD-66, 1995, pp. 99–105.

[3] Eastman J. A., Choi U. S., Li S., Thompson L. J., and Lee S. 1997. "Enhanced Thermal Conductivity through the Development of Nanofluids," in Proceedings of the Symposium on Nanophase and Nanocomposite Materials II", USA, pp. 3–11.

[4] Khdher A. M., Sidik N. A. C, Hamzah W. A. W., and Mamat R. 2016. "An experimental determination of thermal conductivity and electrical conductivity of bio glycol based Al2O3 nanofluids and development of new correlation," International Communications in Heat and Mass Transfer, vol. 73, pp. 75–83.

[5] R. Angayarkanni S. and Philip J. 2014. "Effect of Nanoparticles Aggregation on Thermal and Electrical Conductivities of Nanofluids," Journal of Nanofluids, vol. 3, pp. 17–25.

[6] Adio S. A., Sharifpur M., and Meyer J. P. 2015. "Investigation into Effective Viscosity, Electrical Conductivity, and pH of γ-Al2O3-Glycerol Nanofluids in Einstein Concentration Regime," Heat Transfer Engineering, vol. 36, pp. 1241–1251.

[7] Sharifpur M., Meyer J. P, and Adio S. 2015. "Experimental investigation on the viscosity, electrical conductivity and pH of SiO2-ethylene glycol nanofluids" International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics.

[8] Żyła G.and Fal, J. 2017. "Viscosity, thermal and electrical conductivity of silicon dioxide–ethylene glycol transparent nanofluids: An experimental study," Thermochimica Acta, vol. 650, pp. 106-113.

[9] Maxwell J. C. 1881. Treatise on Electricity and Magnetism, second ed. Oxford, UK: Clarendon Press.

[10] Cruz R. C., Reinshagen J., Oberacker R., Segadães A. M., and Hoffmann M. J. 2005. "Electrical conductivity and stability of concentrated aqueous alumina suspensions," Journal of colloid and interface science, vol. 286, pp. 579–588,

[11] Dow Chemical Company Inc., Physical properties of ethylene glycols. Available: http://www.dow.com/ethyleneglycol/about/properties.htm.

[12] Dean J. A. 1985. "Lange's handbook of chemistry,"

[13] Adio S. A., Sharifpur M., and Meyer J. P. 2015. "Factors affecting the pH and electrical conductivity of MgO–ethylene glycol nanofluids," Bull. Mater. Sci, vol. 38, pp. 1345–1357.

[14] Zawrah M. F., Khattab R. M., Girgis L. G., El Daidamony H., and Abdel Aziz R. E. 2014. "Stability and electrical conductivity of water-base Al2O3 nanofluids for different applications," HBRC Journal

[15] Zakaria I., Azmi W. H., Mohamed W. A. N. W., Mamat R., and Najafi G. 2015. "Experimental Investigation of Thermal Conductivity and Electrical Conductivity of Al2O3 Nanofluid in Water - Ethylene Glycol Mixture for Proton Exchange Membrane Fuel Cell Application," International Communications in Heat and Mass Transfer, vol. 61, pp. 61–68.