Improved thermal conductivity of TiO$_2$-SiO$_2$ hybrid nanofluid in ethylene glycol and water mixture

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Abstract. The need to study hybrid nanofluid properties such as thermal conductivity has increased recently in order to provide better understanding on nanofluid thermal properties and behaviour. Due to its ability to improve heat transfer compared to conventional heat transfer fluids, nanofluids as a new coolant fluid are widely investigated. This paper presents the thermal conductivity of TiO$_2$-SiO$_2$ nanoparticles dispersed in ethylene glycol (EG)-water. The TiO$_2$-SiO$_2$ hybrid nanofluids is measured for its thermal conductivity using KD2 Pro Thermal Properties Analyzer for concentration ranging from 0.5% to 3.0% and temperature of 30, 50 and 70°C. The results show that the increasing in concentration and temperature lead to enhancement in thermal conductivity at range of concentration studied. The maximum enhancement is found to be 22.1% at concentration 3.0% and temperature 70°C. A new equation is proposed based on the experiment data and found to be in good agreement where the average deviation (AD), standard deviation (SD) and maximum deviation (MD) are 1.67%, 1.66% and 5.13%, respectively.

1. Introduction

The nanofluids are proven to be one of the suitable heat transfer fluid as its thermal properties are improved compared to conventional fluid such as water, ethylene glycol (EG) and oil based fluid [1, 2]. Recently, hybrid nanofluid gain attention among researcher due to its augmentation in thermal properties compared to single nanofluid. Hybrid nanofluid can be defined as combination of two or more different types of nanoparticles dispersed in a base fluid [3, 4].

A lot of studies conducted on investigation of thermal conductivity where several factors mention affected the properties. Han et al. [5] studied on hybrid carbon nanotubes (CNT) attached to alumina/iron oxide sphere and dispersed in poly-alpha-olefin. The measurement was taken for temperature range from 10 to 90°C. They obtained an enhancement of 21% for volume fraction of 0.2%. The diffusive heat conduction and CNT’s thermal conductivity contribute to the enhancement. A study by Suresh et al. [6] used Al$_2$O$_3$–Cu/water hybrid nanofluids with volume concentrations from 0.1% to 2%. The two nanoparticles Al$_2$O$_3$ and Cu were mixed at weight ratio of 90:10. At 2% concentration, the maximum enhancement of thermal conductivity observed was 12.11% compared to single Al$_2$O$_3$-water nanofluid. The study also obtained a significant increase in thermal conductivity ratio with the increasing in concentration where formation of larger particle-free regions in the liquid offer greater thermal resistances by the agglomerated particles. For that reason, the thermal
conductivity of Al₂O₃–Cu/water hybrid nanofluids is improved. Another study by Madhesh and Kalaiselvam [7] used Cu-TiO₂ in water based as a coolant. The thermal conductivity of the coolant is improved resulting in enhancement of conductive heat transfer at about 48.4% for concentration 0.7%. The surface functionalized and highly crystalline nature of the hybrid nanofluid is said to be the factor that contributed to the enhancement of thermal conductivity. Baghbanzadeh et al. [8] investigated thermal conductivity of silica (SiO₂₃) nanosphere/multiwall carbon nanotube (MWCNT). Two ratios of SiO₂ to MWCNT were used in the investigation which were 80:20 and 50:50. The enhancement in thermal conductivity were 16.7% for SiO₂:MWCNT at ratio 50:50, and 12.3% at ratio 80:20. The structure of the CNT that have high aspect ratio and its high thermal conductivity influence the thermal conductivity. The hybrid nanofluid with more percentage of CNT showed higher thermal conductivity.

From the literature survey, there were very few investigations concern on hybrid nanofluid mixed at ratio other than 50:50. Hence, the purpose of the present study is to investigate the thermal conductivity of TiO₂-SiO₂ hybrid nanofluid at ratio 40:60 (vol.%), dispersed in EG/water (40:60, vol.%). The measurement of thermal conductivity is carried out at three temperatures 30, 50 and 70°C for nanofluid concentration ranging from 0.5% to 3.0%.

2. Materials and solutions
Two types of nanoparticles used in the present study to prepare hybrid nanofluid are TiO₂ and SiO₂, procured from US Research Nanomaterials, Inc. (USA) with weight concentration of 40 wt.% and 25 wt.%, respectively. The average size of TiO₂ and SiO₂ are 50 nm and 30 nm, respectively. A solution of EG and water is mixed at volume ratio of 40:60, used as the base fluid. Properties of nanoparticles TiO₂ and SiO₂, and EG are presented in Table 1 and Table 2.

| Property                  | TiO₂ | SiO₂ |
|---------------------------|------|------|
| Average Particle diameter, nm | 50   | 30   |
| Density, kg m⁻³           | 4230 | 2220 |
| Thermal Conductivity, W m⁻¹ k⁻¹ | 8.4  | 1.4  |
| Specific heat, J kg⁻¹ K⁻¹  | 692  | 745  |

| Property                  | EG   |
|---------------------------|------|
| Formula                   | C₃H₂O₂|
| Molecular mass, gmol⁻¹     | 62.07 |
| Freezing point, °C         | -12.7 |
| Boiling point, °C at 101.3 kPa | 198  |
| Viscosity, mPas at 20°C    | 20.9  |
| Density, kgm⁻³ at 20°C     | 1113  |
| Specific heat, Jkg⁻¹K⁻¹ at 20°C | 2347 |

3. Methodology
This section elaborates on the preparation of TiO₂-SiO₂ hybrid nanofluid samples at six volume concentrations. The measurement of the thermal conductivity is also included covering the measurement technique and the description of the instrument related.

3.1. Preparation of hybrid nanofluid
The TiO₂-SiO₂ hybrid nanofluid is prepared by mixing the single nanofluids of TiO₂ and SiO₂, undergo mixing process and sonication. For both single nanofluid TiO₂ and SiO₂, the weight
concentration is converted to volume concentration using equation (1) [14, 15] where \( \phi \), \( \omega \), and \( \rho \) are volume concentration, weight concentration and density, respectively. The subscript \( p \) and \( bf \) correspond to nanoparticles and base fluid. Equation (2) [14, 16] is used to dilute the volume concentration at higher concentration to lower concentration by adding the EG/water base fluid. \( \Delta V \) is the volume of the base fluid required to dilute the nanofluid at higher concentration \( (\phi_1) \) to the lower concentration \( (\phi_2) \), prior to \( V_i \) is known. \( \text{TiO}_2 \) nanofluid is then mixed with \( \text{SiO}_2 \) nanofluid at volume ratio 40:60 with magnetic stirrer for 15 minutes; and subjected to sonication with ultrasonic bath for 2 hours. Six samples with 100 mL volume each is prepared at concentration 0.5\%, 1.0\%, 1.5\%, 2.0\%, 2.5\% and 3.0\%. The stability of the sample is determined by Transmission Electron Microscopy (TEM) observation as shown in Figure 1. The \( \text{TiO}_2 \) and \( \text{SiO}_2 \) nanoparticles are well dispersed in the base fluid.

\[
\phi = \frac{\omega \rho_{bf}}{1 - \frac{\omega}{100} \rho_p + \frac{\omega}{100} \rho_{bf}} \tag{1}
\]

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

**Figure 1.** TEM image (100 nm scales) for \( \text{TiO}_2 \)-\( \text{SiO}_2 \) hybrid nanofluids at \( \phi = 1.0\% \).

3.2. Measurement of thermal conductivity

The measurement of thermal conductivity is conducted using KD2 Pro Thermal Properties Analyzer. The device measures the thermal conductivity by evaluating the time and temperature response of the sudden electric signals. The device is equipped with handheld controller and needle sensor KS-1. The range of thermal conductivity measured is 0.02 to 2.00 W/m.K with an accuracy of ±0.01\%. The glycerine solution is provided for calibration/verification of the sensor, where the thermal conductivity for glycerin at 25°C is 0.285 W/m.K (±5\%). A water bath is used to control the temperature of the sample along the measurement. A nanofluid sample with 70 mL is inserted in a bottle, immersed in the water bath until the temperature reach the desired temperature (30, 50 and 70°C). The arrangement of the measurement is shown in Figure 2. The interval of each measurement is set at 15 minutes. A
minimum of five readings were taken and the mean value was considered in the analysis for accuracy within 5%. Previous study by Abdolbaqi et al. [17] and Zakaria et al. [18] also used the same device.

![Nanofluid sample](image)

**Figure 2.** Measurement of thermal conductivity with KD2 Pro and water bath.

### 4. Results and discussion

Figure 3 shows the effect of concentration to the thermal conductivity of TiO$_2$-SiO$_2$ hybrid nanofluid for three temperatures; 30, 50 and 70°C. The thermal conductivity at all concentrations of the nanofluids are higher than the base fluid ($\phi=0\%$). As the concentration increased, the thermal conductivity of the nanofluid is also increased. The maximum thermal conductivity is occurred at highest concentration 3.0%. The range of enhancement compared to base fluid are from 3.9-17.4%, 5.8-18.9%, and 8.7-22.1%, respectively for temperature at 30, 50 and 70°C. The effect of concentration is noticeable due to the addition of the nanoparticles. The rate of collision between the nanoparticles is increased hence affect the thermal conductivity of the nanofluid [19].

The effect of temperature to the thermal conductivity of TiO$_2$-SiO$_2$ nanofluid is shown in Figure 4. The figure clearly shown that the thermal conductivity is increased with the increasing of the temperature. It can be observed that all concentrations at temperature measured have higher thermal conductivity than the base fluid, which follow the trend in Figure 3. The temperature mainly affected the thermal conductivity because of the Brownian motion which is strong function of temperature [20]. When the temperature in the nanofluid is raised, the contribution to micro-convection is greater resulting to the enhancement in effective conductivity [21]. The similar behaviour is also found in previous studies by Usri et al. [22] and Megatif et al. [23].
Figure 3. Effect of concentration to thermal conductivity.

Figure 4. Effect of temperature to thermal conductivity.
Equation (3) is proposed based from experimental data where $k_r$, $k_{nf}$ and $k_{bf}$ represent the ratio of thermal conductivity, thermal conductivity of nanofluid and thermal conductivity of base fluid; while $\phi$ and $T$ are volume concentration and temperature. This equation valid for range of concentration $0 \leq \phi \leq 3.0\%$ and range of temperature $30 \leq T \leq 70^\circ C$. The average deviation (AD) and standard deviation (SD) are 1.67% and 1.66%. Maximum deviation (MD) is found to be 5.13%. The tabulation of thermal conductivity from the experiment and from equation (3) is presented in Figure 5. The figure shows that the experiment data is in good agreement with the equation proposed.

$$k_r = \frac{k_{nf}}{k_{bf}} = \left(1 + \frac{\phi}{100}\right)^{5.25} \left(1 + \frac{T}{70}\right)^{0.076}$$

Figure 5. Comparison between experimental thermal conductivity and Equation (3).

5. Conclusions
The TiO$_2$-SiO$_2$ hybrid nanofluid is prepared with single nanofluid TiO$_2$ and SiO$_2$, mixed and sonicated until the stable solution formed. TiO$_2$ and SiO$_2$ is mixed at ratio of 40:60 (vol.%) and dispersed in base fluid of EG/water at ratio 40:60 (vol.%); for volume concentration of 0.5% to 3.0%. The measurement of thermal conductivity is conducted at 30, 50 and 70$^\circ C$. From the findings discussed in the previous section, in can be conclude that the thermal conductivity of TiO$_2$-SiO$_2$ hybrid nanofluid dispersed in EG/water is affected by the concentration and temperature. The thermal conductivity of the hybrid nanofluid is enhanced up to 22.1%, observed at concentration 3.0% and temperature 70$^\circ C$. The proposed equation as in Equation (3) valid for volume concentration range of $0 \leq \phi \leq 3.0\%$ and temperature range of $30 \leq T \leq 70^\circ C$. 

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References
[1] Azmi W H, Sharma K V, Mamat R, Najafi G and Mohamad M S 2016 Renew. Sust. Energ. Rev. 53 1046-58
[2] Devendiran D K and Amirtham V A 2016 Renew. Sust. Energ. Rev. 60 21-40
[3] Sundar L S, Sharma K V, Singh M K and Sousa A C M 2017 Renew. Sust. Energ. Rev. 68, Part 1 185-98
[4] Leong K Y, Ku Ahmad K Z, Ong H C, Ghazali M J and Baharum A 2017 Renew. Sust. Energ. Rev. 75 868-78
[5] Han Z H, Yang B, Kim S H and Zachariah M R 2007 Nanotechnology 18 105701
[6] Suresh S, Venkitaraj K P, Selvakumar P and Chandrasekar M 2011 Colloids Surf. A 388 41-8
[7] Madhesh D and Kalaiselvam S 2014 Procedia Eng. 97 1667-75
[8] Baghbanzadeh M, Rashidi A, Rashtchian D, Lotfi R and Amrollahi A 2012 Thermochim. Acta 549 87-94
[9] He Y, Jin Y, Chen H, Ding Y, Cang D and Lu H 2007 Int. J. Heat Mass Transf. 50 2272-81
[10] Heris S Z, Etemad S G and Nasr Esfahany M 2006 Int. Commun. Heat Mass 33 529-35
[11] Vajjha R S, Das D K and Kulkarni D P 2010 Int. J. Heat Mass Transf. 53 4607-18
[12] Pak B C and Cho Y I 1998 Exp. Heat Transfer 11 151-70
[13] ASHRAE 2009 ASHRAE Handbook-Fundamentals SI Edition, ed M S Owen and H E Kennedy (Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.) p.31.4
[14] Hamid K A, Azmi W H, Mamat R and Sharma K V 2016 Int. Commun. Heat Mass 73 16-24
[15] Azmi W H, Sharma K V, Sarma P K, Mamat R, Anuar S and Dharma Rao V 2013 Exp. Therm. Fluid Sci. 51 103-11
[16] Azmi W H, Sharma K V, Sarma P K, Mamat R and Najafi G 2014 Int. Commun. Heat Mass 59 30-8
[17] Abdolbaqi M K, Azmi W H, Mamat R, Sharma K V and Najafi G 2016 Appl. Therm. Eng. 102 932-41
[18] Zakaria I, Azmi W H, Mamet A M I, Mamet R, Saidur R, Abu Talib S F and Mohamed W A N 2016 Int. J. Hydrogen Energ. 41 5096-112
[19] Charab A A, Movahedirad S and Norouzei R 2017 Appl. Therm. Eng. 119 42-51
[20] Akilu S, Sharma K V, Baheta A T and Mamat R 2016 Renew. Sust. Energ. Rev. 66 654-78
[21] Murshed S M S, Leong K C and Yang C 2008 Int. J. Therm. Sci. 47 560-8
[22] Usri N A, Azmi W H, Mamat R, Hamid K A and Najafi G 2015 Energy Procedia 79 397-402
[23] Megatif L, Ghozatloo A, Arimi A and Shariati-Niasar M 2016 Exp. Heat Transfer 29 124-38