Thermal conductivity enhancement of TiO₂ nanofluid in water and ethylene glycol (EG) mixture

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The need to study nanofluid properties has increased over these past centuries 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 have widely been investigated. This study presents the thermal conductivity enhancement of titanium dioxide (TiO₂) nanoparticles dispersed in mixture of water and ethylene glycol (EG). The nanofluids have been prepared for volume concentrations from 0.5 to 1.5%. The thermal conductivity measurement of the nanofluid has been performed using KD2 Pro Thermal Properties Analyzer at working temperatures of 30 to 80 °C. The measurement gives 15.35% maximum enhancement of thermal conductivity at 1.5% volume concentration and temperature of 60 °C. The results show that the thermal conductivity increases with the increase of nanofluid concentration and temperature. Also, the nanofluids provide enhancement in thermal conductivity compared to their base fluid of a water/EG mixture in 60:40 ratio. Therefore, the addition of TiO₂ nanoparticles dispersed in the base fluid of a water and EG mixture will enhance the effective thermal conductivity of the nanofluid. The new thermal conductivity correlation of TiO₂ nanofluids is developed for a wide range of temperatures and concentrations with maximum deviation of 4.65% and average deviation of 1.37%.

Keywords: Nanofluid, Titanium dioxide, Thermal conductivity enhancement, Ethylene glycol

1 Introduction

Nanofluid is prepared by dispersing nanoparticles in based fluids such as water, EG and engine oil. This new class of fluid provides higher enhancement in the thermal performance compared to their based fluids. In terms of their stability, nanofluid has better stability than those fluids as it contains macro or mili-sized particles, which is the advantage of using nanofluids. Besides that, it possesses a higher thermal conductivity than the based fluids themselves which offers potential benefits in the engineering field that involves the cooling process. The study on the thermal conductivity of a fluid plays a vital role in the improvement of energy-efficient heat transfer equipment. Numerous theoretical and experimental studies on the thermal ability of liquids to suspend nano-sized particles have been conducted since the early 90’s through the determination of thermal conductivity and viscosity of the nanofluids such as Al₂O₃, SiO₂ and TiO₂ in water based. Later, many researchers used different types of nanoparticles to investigate the rheological behaviour of the nanofluids. A study on thermal properties using Fe₃O₄ nanoparticles dispersed in a mixture of EG and water found that the thermal conductivity of nanofluids increased as concentration and temperature of the nanofluids increased. Apart from these two outstanding factors, the types of nanoparticles used also contribute to the thermal conductivity enhancement as well as particle size and stability of the nanofluid.

The previous work to study the EG based nanofluids was done using nanoparticles such as copper (Cu), zinc oxide (ZnO), alumina (Al₂O₃) and aluminium nitride (AlN). In EG based γ-Al₂O₃ nanofluid, it was proven that the nanofluid provides better heat transfer enhancement than water based γ-Al₂O₃ in a study of heat transfer behaviour in a uniformly heated tube. A study where the investigation is focused on thermal conductivity, leads to the findings that the thermal conductivity of nanofluid follows the behaviour of based fluid (EG) where the maximum thermal conductivity is at approximately the same temperature in pure based fluids. Other factors that affect the thermal conductivity are particle shape and aggregation.

A study on TiO₂ nanofluids in EG based found that the nanofluid exhibits higher thermal conductivity, behave as Newtonian fluid and at low Reynolds number, the convective heat transfer deteriorates. The enhancement of thermal conductivity will
contribute to heat transfer coefficient as shown in a study on pool boiling using ZnO in EG based nanofluids. With the enhancement in thermal conductivity, the heat transfer coefficient shows enhancement about 22% at 1.6% volume concentration.

Most of the research work related, as mentioned previously was conducted at limited volume concentration and temperature ranges. Also, limited study related to TiO$_2$ nanofluids for water and ethylene glycol based mixture is available in the literature. Therefore, it is important to study the thermal conductivity of TiO$_2$ nanofluids and useful for further investigation of nanofluids heat transfer by experimentally and numerically. Accordingly, the present research aims to study the enhancement of thermal conductivity of TiO$_2$ nanoparticles dispersed in a mixture of water and EG for a wider range of volume concentration and working temperature.

## 2 Materials and Methods

### 2.1 Preparation of nanofluid and characterization

The type of nanoparticles used in this study is titanium dioxide (TiO$_2$) of 99.8% purity which was supplied by the US Research Nanomaterials, Inc in water dispersion with weight concentration of 40 wt%. The physical appearance of the raw TiO$_2$ is in liquid form and white in colour. The average size of TiO$_2$ nanoparticles is 50 nm, determined from FESEM image as in Fig. 1. The base fluid used in the study is a mixture of distilled water and EG in a volume ratio of 60:40. The distilled water was prepared in the laboratory with distiller while EG with AR grade used was purchased from QRec Asia with purity of 99.5%. The physical appearance of EG is colourless and odourless. The chemical composition of the EG is listed in Table 1.

The TiO$_2$ nanofluid was then prepared by dilution method. The weight concentration was converted to volume concentration using Eq. (1) and diluted into a new concentration using Eq. (2). The range of volume concentrations used in the preparation of this study is 0.5 to 1.5%. The nanofluid samples were then immersed in ultrasonic bath (Fisherbrand, Germany) operated at ultrasound frequency and ultrasound power RMS of 37 kHz and 80 W, respectively. The samples were immersed in the ultrasonic bath for 2 h to ensure that all particles of TiO$_2$ are agitated thus to help the stability of the nanofluid. The TiO$_2$ nanofluid samples were found to be stable up to 3 month. Figure 2 shows the TiO$_2$ samples used in the study.

$$\phi = \frac{\omega \rho_{bf}}{100 \rho_{bf} + \rho_p \left(1 - \frac{\omega}{100}\right)} \quad \ldots (1)$$

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**Table 1 – Chemical composition of EG**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity</td>
<td>max. 0.0002 meq/g</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>max. 0.005 %</td>
</tr>
<tr>
<td>Chlorides (Cl)</td>
<td>max. 0.00002 %</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>max. 0.00002 %</td>
</tr>
<tr>
<td>KMnO$_4$ red. matter (as O)</td>
<td>max. 0.0003 %</td>
</tr>
<tr>
<td>Substances darkened by H$_2$SO$_4$</td>
<td>passes test</td>
</tr>
<tr>
<td>Sulfated ash</td>
<td>max. 0.005 %</td>
</tr>
<tr>
<td>Water</td>
<td>max. 0.1 %</td>
</tr>
</tbody>
</table>

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Fig. 1 – FESEM image of dry TiO$_2$ nanopowder at two magnifications

Fig. 2 – Nanofluid samples of TiO$_2$ in mixture water/EG (a) Nanofluid samples after preparation, (b) Nanofluid samples after three months
\[ \Delta V = (V_2 - V_1) = V_1 \left( \frac{\phi_1}{\phi_2} - 1 \right) \quad \ldots (2) \]

The precise characterization of the TiO\(_2\) dry nanoparticle sample is obtained by the field emission scanning electron microscopy (FESEM) technique\(^{11}\). The image from Fig. 1(a) shows that the nanopowder is in a cluster form under atmospheric condition. A magnification of these aggregates at magnification of 200,000 in nanoscale is shown in Fig. 1(b). This allows the size classification each individual particle in nanoscale at the agglomerate surface. The shape of TiO\(_2\) nanoparticles is nearly spherical.

2.2 Thermal conductivity measurement

The thermal conductivity of nanofluids was measured using KD2 Pro Thermal Properties Analyzer of Decagon Devices, Inc, USA. This device uses the transient line heat source to measure the thermal properties. It consists of a handheld controller and a sensor for measuring the thermal conductivity for liquids. A water bath (WNB7L1, Memmert) was used to maintain a constant temperature within 0.1 °C. The sensor was calibrated by determining the thermal conductivity of distilled water and glycerin. The measured values of thermal conductivity at room temperature are 0.610 and 0.280 W/mK, respectively for distilled water and glycerin, which are in agreement with standard values of 0.613 and 0.285 W/mK, within ± 5% accuracy. The nanofluid sample was immersed in the water bath for 10 min at a desired temperature; the nanofluid temperature is in equilibrium with the bath. Five sets of readings were taken at the average value in 15 min intervals between each measurement. The temperature was set in a range between 30 °C to 80 °C.

3 Results and Discussion

3.1 Thermal conductivity

The experimental procedure of the nanofluids started with testing in water, EG and the actual based used which is a mixture of water and EG in a volume ratio of 60:40. The thermal conductivity of water, EG and mixture of water/EG data are taken from ASHRAE Handbook\(^{12}\) and compared with base fluid used in the present experiment as shown in Fig. 3. From the measurement with KD2 Pro, the maximum deviation for data of mixture water/EG data are found to be 1.60% at 80 °C.

The thermal conductivity of TiO\(_2\) nanofluid in base fluid of a water/EG mixture at different volume concentrations are shown in Fig. 4. As observed from the figure, thermal conductivity is increased with the increase of volume concentration and temperature, following the behaviour of base fluid (EG) thermal conductivity. The maximum value was found to be at the condition where temperature and concentration is at the maximum which were 80 °C and volume concentration 1.5%. All thermal conductivity of the nanofluids at this concentration range is found to be higher than its based fluid. The observation of this trend seems to be related to the Brownian motion where the addition of small

![Fig. 3 – Benchmark test cases for the thermal conductivity of water, EG and mixture water/EG](image)

![Fig. 4 – Variation of thermal conductivity of TiO\(_2\) nanofluid in mixture water/EG with temperature](image)
quantities of particle tend to increase the collision of particle with molecules of base liquid at high temperatures\cite{13,14}. However, there are other researchers that encounter with the same trends for based fluid in such a mixture by using nanofluids (\text{Al}_2\text{O}_3 and \text{CuO}) in a mixture of water and \text{EG}\textsuperscript{15}. Other researchers with the experimental investigation on thermal conductivity for nanofluid in base mixture also found the similar trend of thermal conductivity behaviour using \text{Fe}_3\text{O}_4 nanoparticles\textsuperscript{2}.

Figure 5 shows the thermal conductivity enhancement in percentage for ranges of temperature between 30 to 80 °C. The enhancement for all concentrations were not linear as the temperature increases. The thermal conductivity enhancement for this concentration range shows maximum enhancement of 15.35% at volume concentration of 1.5% when temperature is at 60 °C. However, at maximum temperature measured which is 80 °C, the enhancement decreased to 15.28% for the same concentration.

3.2 Empirical Equation
Equation (3) is developed for the estimation of thermal conductivity for mixture base nanofluids using the present experimental data. The equation is valid for particle concentrations from 0.5 to 1.5%, liquid temperature from 0 to 80 °C and particle diameter less and equal to 50 nm. From Fig. 6, it shows that the experimental data is in good agreement with the equation where the average deviation, standard deviation and maximum deviation are 1.37%, 1.74% and 4.65%, respectively.

\[
k_{nf} = k_f = \left(1 + \frac{\phi}{100}\right)^7 \times \left(\frac{T_{nf}}{80}\right)^{0.024}
\]… (3)

The empirical Eq. (3) is compared with other models in literature published by Vajjha and Das\textsuperscript{15}, Prasher \textit{et al}\textsuperscript{16} and Corcione\textsuperscript{17} as shown in Fig. 7. The graphs show the variation of thermal conductivity ratio with temperature for 1% volume concentration. It can be observed that the agreement between the values from the present equation with the models of Vajjha and Das\textsuperscript{15}, Prasher \textit{et al}\textsuperscript{16} and Corcione\textsuperscript{17} are satisfactory.

![Fig. 6 – Comparison of measured thermal conductivity with values from Eq. (3)](image)

![Fig. 7 – Comparison of Eq. (3) with the previously published model in literature](image)

![Fig. 5 – Variation of thermal conductivity enhancement with temperature](image)
4 Conclusions

The thermal conductivity of TiO$_2$ nanofluids in EG based is measured over a temperature range of 30 °C to 80 °C for various volume concentrations. The results show an increase in thermal conductivity of TiO$_2$ dispersed in mixture water/EG nanofluids with increase in temperature and concentration. Also, all nanofluid concentrations show enhancement compared to its base fluid. The TiO$_2$ nanofluid at 1.5% concentration shows the maximum enhancement of thermal conductivity which is 15.35%; achieved at 60 °C. The thermal conductivity of the TiO$_2$ nanofluid at range of 0 < φ < 1.5% and 0 < T < 80 °C can be predicted using Eq. (3).

Acknowledgment

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References

17 Corcione M, Energ Conver Manage, 52 (2011) 789.

Nomenclature

- $\Delta V$: additional volume (L)
- $k$: thermal conductivity (W/m.K)
- $k_{bf}$: thermal conductivity of base fluid (W/m.K)
- $k_{nf}$: thermal conductivity of nanofluid (W/m.K)
- $k_r$: thermal conductivity ratio
- $T_{nf}$: temperature of nanofluid (°C)
- $V_1$: initial volume (L)
- $V_2$: final volume (L)

Greek symbols

- $\varphi$: volume concentration (%)
- $\varphi_i$: initial volume concentration (%)
- $\varphi_f$: final volume concentration (%)
- $\omega$: weight concentration (%)
- $\rho_{bf}$: density of base fluid (kg/m$^3$)
- $\rho_p$: density of nanoparticle (kg/m$^3$)