Experimental Study of Thermophysical Properties of TiO₂ Nanofluid

Majid I. Abdulwahab*, S.M.Thahab** and Asmaa H.Dhiaa***

*Chemical Engineering Department, University of Baghdad, Baghdad, Iraq, e-mail: majid58jc@yahoo.co.uk

**Nanotechnology and Advanced Materials Research Unit (NAMRU), College of Engineering – University of Kufa – 21 Najaf- IRAQ; e-mail: sabah.alabboodi@uokufa.edu.iq

***Materials Engineering Department College of Engineering – University of Kufa – 21 Najaf- IRAQ ce_asmaa@yahoo.com

Abstract

Titanium-dioxide (TiO₂) nanoparticles suspended in water, and ethanol based fluids have been prepared using one step method and characterized by scanning electron microscopy (SEM), and UV–visible spectrophotometer. The TiO₂ nanoparticles were added to base fluids with different volume concentrations from 0.1% to1.5% by dispersing the synthesized nanoparticles in deionized water and ethanol solutions. The effective thermal conductivity, viscosity and pH of prepared nanofluids at different temperatures from 15 to 30 °C were carried out and investigated. It was observed that the thermal conductivity, pH, and viscosity of nanofluids increases with the increase in TiO₂ nanoparticle volume fraction. The thermal conductivity of TiO₂ nanofluids significantly increases linearly with increasing particle vol. fraction at different temperature values and also it was found that the viscosity increases with increasing particle vol. fraction and decreases with the increase in temperature.

Key Words: Nanofluids, Thermal conductivity, Viscosity, TiO₂ nanoparticles.

Introduction

Nanofluids are engineered by suspending nanoparticles with common sizes below 100 nm in conventional heat transfer fluids such as water, oil, and ethylene glycol. Improvements in the thermal properties of base fluids, was indicated when an extremely small amount of nanoparticles dispersed regularly and suspended stably in base fluids. Nanofluid is the term introduced by Choi [1] to express this novel class of nanotechnology-based heat transfer fluids that exhibit thermal properties better than those of their host fluids or conventional particle fluid suspensions.

Titanium-dioxide (TiO₂) is one of the most paying attention materials in nanoscience and nanotechnology because of having a lot of attractive properties from fundamental and practical point of view by Castillo et al. [2]. Titanium-dioxide is present in three crystal forms: rutile, anatase and brookite; where the rutile and anatase phases have higher practical utility.
Yoo et al. [3] showed that the presence of nanoparticles of TiO$_2$, Al$_2$O$_3$, and Fe in base fluid caused a large enhancement in thermal conductivity compared to their base fluid. Kim et al. [4] have calculated the thermal conductivity of ZnO and TiO$_2$ nanoparticles in base fluid (water and ethylene glycol). The experimental data showed the effects of both particle size and volume concentration on thermal conductivity.

In the present study the thermophysical properties of TiO$_2$ nanoparticles in base fluids of deionized water and ethanol in the temperature ranges of 15-30°C at different volume concentrations of nanoparticles (0.1, 0.5, 1 and 1.5%) was investigated.

**Experimental**

1- Preparation of Nanofluids

Titanium dioxide nanoparticles, anatase, with an average diameter of 13 nm were used in the present work (ordered from USA nanomaterials co.) [5]. TiO$_2$ nanoparticles with different volume concentrations (0.1%, 0.5%, 1%, 1.5%) were dispersed in DDW (denoized water) and ethanol based fluids. The suspensions of nanofluids were then stirred and agitated thoroughly for 15 min with an ultrasonic homogenizer. This ensures uniform dispersion of nanoparticles in the base fluid. Table 1 shows the physical properties of TiO$_2$ nanoparticles.

<table>
<thead>
<tr>
<th>Average particle diameter, nm</th>
<th>13</th>
</tr>
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<tbody>
<tr>
<td>Purity, %</td>
<td>99.99</td>
</tr>
<tr>
<td>Density, kg/m$^3$</td>
<td>3900</td>
</tr>
<tr>
<td>Color</td>
<td>White</td>
</tr>
</tbody>
</table>

The energy dispersive X-ray analysis (EDX) image of the TiO$_2$ nanoparticles was recorded in the binding energy region of 0–20 keV as shown in Fig. (2).

2- Thermophysical Properties and Characterization of TiO$_2$ Based Nanofluids

Thermal conductivity was measured using a thermal conductivity meter (KD2 Pro, Decagon device, USA). A viscometer (Fungilab) was used for viscosity measurement. pH was measured using a pocket-sized pH meter with replaceable electrode (Inolab pH7110), TiO$_2$ nanoparticles were characterized by using SEM model (FEI), UV-visible (model UVWIN5 Spectrophotometer) was used to show the absorption spectroscopy or reflectance spectroscopy in the ultraviolet-visible spectral region.

Fig. (1) shows the SEM micrograph of the TiO$_2$ nanoparticles. The micrograph shows that the particles have nearly spherical shape and uniformly distributed. Larger particles may be aggregates of the smaller ones.
The peak from the spectrum reveals the presence of Ti and O at 4.5 and 0.6 keV respectively.

The absorption band edges were estimated around 340 nm (about 3.6 eV).

Fig. (4) shows the measured thermal conductivity of TiO$_2$/DDW nanofluid as a function of TiO$_2$ nanoparticles volume concentrations at different temperature values. It is observed that the thermal conductivity increases with increasing both TiO$_2$ volume concentrations and temperature range from 15 to 30 °C. In addition, the thermal conductivity of nanofluids is nearly constant at low particle concentrations (less than 1% by volume), for example the increase in the thermal conductivity of a 1.5% nanofluids at 20°C is about 39 % whereas it is about 44 % at 30 ºC in case of nanofluids, Brownian motion of nanoparticles causes change of temperature and clustering of nanoparticles, which results in remarkable changes of thermal conductivity of nanofluids with temperature.
Since water has a higher thermal conductivity than ethanol, any presence of water in ethanol would lead to an increase in the effective thermal conductivity. Therefore, presence of water in ethanol based nanofluids could lead to an erroneous conclusion about the enhancement, which is due to the presence of nanoparticles by Sunder [6]. Differences in the improvement of performance can be attributable to variations of the resistance of thermal boundary about the nanoparticles happening for diverse base fluids [7].

Fig. (6) shows the experimental thermal conductivity results of TiO$_2$ nanofluids obtained in the experiment in comparison with the three conductivity models by Maxwell, Hamilton and Brugeman show in table (2) below:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Correlation</th>
</tr>
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<tbody>
<tr>
<td>Maxwell’s</td>
<td>$K_{nf} = K_f + 3\varphi \frac{K_p - k_f}{2k_f + K_p}$ Spherical, low volume fractions, random distributed particles</td>
</tr>
<tr>
<td>Hamilton and Crosser</td>
<td>$K_{nf} = \frac{K_p + (n-1)K_f - (n-1)(K_p - K_f)\varphi}{K_p + (n-1)K_f + (K_f - K_p)\varphi}$ Spherical, low volume fractions, random distributed particles, for non-spherical n=6</td>
</tr>
<tr>
<td>Bruggeman</td>
<td>$\varphi\left(\frac{K_p - K_{nf}}{K_p + 2K_{nf}}\right) + (1 - \varphi)\left(\frac{K_f - K_{nf}}{K_f + 2K_{nf}}\right)$ Binary mixture, homogeneous, no limitations on the concentration, random distributed particles</td>
</tr>
</tbody>
</table>

The probable parameters which promote thermal conductivity enhancement are stochastic and Brownian motion of nanoparticles in the base fluid. The temperature is another factor which is responsible for particle random movements which in turn results in enhanced thermal conductivity.
At higher temperatures, the forces between the TiO₂ nanoparticles and the base fluid are weakened, causing a decrease in value of viscosity. For example at 1.5% viscosity is 5.49 at 15°C and decrease to 3.97 at 30°C.

Fig. (9) show the variation of pH value of nano-fluids as a function of TiO₂ volume concentration. It was observed that at 1.5% volume concentration of TiO₂ nanoparticles, the pH value decreased to 7.13 in the case of TiO₂/DDW and to 8.2 in the case of TiO₂/ethanol nanofluids. It can be observed that for TiO₂/DDW nanofluid, the pH value decreased from 7.7 at 1% to 7.13 at 1.5% volume concentration of TiO₂ nanoparticles. In the same trend, the pH value decreased from 8.56 to 8.2 accordingly in the case of TiO₂/ethanol nanofluid. This is ascribed to the effects of nanoparticles, which are identified to appearance clusters; this clustering can effect in quick transfer of heat over comparatively great ranges ago heat can be conducted extremely faster before particles of solid when compared to matrix of liquid, by Ravi Babu [8].
Conclusions
In this paper the effective thermal conductivities, viscosities and pH of water and ethanol based nanofluids containing TiO$_2$ nanoparticles are investigated experimental. The presence of TiO$_2$ nanoparticle in base fluid is capable of enhancement the thermal conductivity of base fluid. The level of the base fluid enhancement depends on the amount of nanoparticle added to base fluid at the concentration of 1.5 vol.%; the thermal conductivity enhancement of 51.1% at 30°C compared to base fluid was recorded. Also thermal conductivity of nanofluids increases with the increase in temperature. The viscosity of nanofluids was significantly higher as compared to the base fluid for two the nanofluids tested. The viscosity of TiO$_2$/DDW was found to be 5.49*10$^{-3}$ kg.m/s at 15°C and it decreased to 3.97*10$^{-3}$ kg.m/s at 30°C at a 1.5% TiO$_2$ nanoparticles.

Reference
5- US Research Nanomaterials, Inc. The Advanced Nanomaterials Provider 3302 Twig Leaf Lane, Houston, TX 77084, USA Phone: 832-460-3661, Fax: 281-492-8628 E-mail: Service@us-nano.com; Tech@us-nano.com Website: www.us-nano.com