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Thermal Characteristic of Nanofluids Containing Titanium Dioxide Nanoparticles in Ethylene Glycol

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Rapid development of technology requires high-performance of cooling devices especially in heat transfer industries. In these recent years, there has been a lot of researchers show some interest in nanofluids because nanofluids is believed to be a very good coolant that exhibit some attractive characteristics as a coolant due to its high thermal properties. This research was conducted to formulate stable nanofluids containing titanium dioxide (TiO_2) nanoparticles in ethylene glycol (EG) base fluid with the aid of gum arabic (GA) as the surfactant. The thermal conductivity of nanofluids were measured. Two-step method was employed for nanofluids preparation. The results showed that in the presence of surfactant, the stability of nanofluids samples was increased because of modification of TiO_2 nanoparticles surface area. The nanoparticles tend to repulse each other and decrease the agglomeration in the nanofluids. The thermal conductivity was enhanced by increasing the concentration of nanoparticles and temperature due to effect of Brownian motion. The research showed that TiO_2 in EG nanofluids has the potential to be employed as a heat transfer fluids compared to the conventional fluids.

1. Introduction

In current globalised world, customers are demanding high technology especially in electronic devices has been increased. Electronic devices such as laptop and desktop basically have problems with their cooling system when generate large quantities of heat. Normal fluids that have been used previously for heat transfer application have a lower thermal conductivity. Due to demands of modern technology, many development for new type of fluids for efficient heat transfer has been made. Choi and his team had introduced the ability of this new breed of fluids, known as nanofluids (Anoop et al., 2013). Nanofluids contain very small particles of size (5 - 100 nm) suspended in saturated liquids such as water, ethylene glycol (EG), engine oil and others (Hussein et al., 2016). By introducing small size solid particles into fluids seems to increase the thermal conductivity of that fluid. TiO_2 nanoparticles usually was used for nanofluids preparation due to the high thermal conductivity value (4 - 11.8 W/m.K), safe material, easily obtained (they are produced in very large industrial scales) and metal oxides such as TiO_2 are chemically more stable than their metallic counterparts (Bozorgan, 2012). Due to their significantly improved thermal properties, nanofluids could have applications in many field such as electronic cooling systems, solar collectors, heat exchanger and nuclear reactor (Solangi et al., 2015).

According to Singh (2008), there is not any standard method for preparation of nanofluids. There are two basic methods to obtain stable nanofluids which are single-step and two-step methods. In a single-step method, nanofluids can be prepared using by wet technology. Meanwhile in two-step method, nanofluids are prepared by producing nanoparticles first and then dispersed into a base fluid. While for measuring the thermal characteristic, many methods are available as transient hot wire (THW) method, 3ω method and others (Bashirnezhad et al., 2015).

The dispersion of micro- and millimetre- sized particles is prone to sedimentation and clogging in micro-channels. This will affect the production of nanofluids because the stability is the main key factor of successful nanofluids production. Several methods need to be done which is addition of surfactant, mechanical mixing and ultrasonic vibration to improve the stability of nanofluids which has been produced by two-step method.

This because all the method can increase the repulsive force between the nanoparticles and lead to increase the stability of nanofluids.
This study was conducted to meet the following objectives: i) to formulate stable nanofluids that contain titanium dioxide nanoparticles (TiO_2) in ethylene glycol (EG) base fluid with the aid of gum arabic (GA) as the surfactant, ii) to conduct stability analysis of nanofluids, and iii) to measure thermal conductivity of nanofluids at different temperature and concentration of nanoparticles.

2. Experimental

The chemical substances were used to prepare nanofluids are TiO_2 nanoparticle and EG as the base fluid. Gum arabic (GA) was used as surfactant to enhance the nanofluids stability. The stability was observed visually while KD2 Pro Thermal Properties Analyzer was used to measure the thermal conductivity of nanofluids.

2.1 Sample preparation

Two-step method was used for this study since it is a simple and less costly compared to the single-step method. Raw TiO_2 nanoparticle (Degussa) in the range of 20 - 30 nm diameter was dispersed in EG. The nanofluids samples were prepared and consist of different concentration of nanoparticles which are 0.25 wt%, 0.50 wt%, 0.75 wt % and 1.00 wt %. All samples were dispersed in 50 mL EG and was sonicated in ultrasonic homogeniser for 2 h. This is to reduce the particles from agglomeration. After that, 0.50 wt % of GA was added to the nanofluids and sonicated for another 2 h.

2.2 Thermal conductivity measurement

In this study, KD2 Pro Thermal Properties Analyzer (Decagon Devices, Inc.) was used to measure the thermal conductivity of nanofluids. First, the nanofluids samples were transferred into the small bottle that has the 7 cm long. Since the sample is in liquid form; therefore, KS-1 sensor was used. The sensor was immersed into the sample for a few minutes and records the thermal conductivity. In order to minimise the errors during measurement, an average reading from 3 measurements was taken from each the samples. The samples of nanofluids were analysed at different temperature of 30 °C, 40 °C, 50 °C, and 60 °C. Hot water bath and heating plate was used in order to increase the temperature of nanofluids.

2.3 Data analysis

Stability of nanofluids can be identified by using visual observation. Nanofluids that was well dispersed and without visible sedimentation for 2 weeks were considered as stable nanofluids. For the thermal conductivity, all those values were recorded and analysed by plotting a graph according to the manipulated variable such as concentration of TiO_2 nanoparticle and temperature of nanofluids

3. Results and discussion

For results and discussion, it can be divided into 2 sections which are stability of nanofluids and thermal conductivity analysis of nanofluids.

3.1 Stability of nanofluids

From visual observation, nanofluids with GA as surfactant showed better dispersion and longer time stability than the one without surfactant. Figure 1 and Figure 2 show the nanofluids condition after 2 weeks.
As shown in Figure 1 and Figure 2, particle in suspension without any surfactant agglomerated and deposited after 2 weeks, while particle in suspension with GA surfactant are still in well dispersed and with less agglomeration after 2 weeks. This because addition of surfactant may slower the surface tension of host fluids and increases the immersion of particles (Mukherjee and Paria, 2013). Other than that, the inclusions of surfactants in the nanoparticles sample were modifying the TiO_2 nanoparticles surface to hydrophilic from hydrophobic (Ilyas et al., 2014). TiO_2 nanoparticles will tend to repulse each other due to the surface modification. Garg et al. (2009) stated that reiterated surfactant is able to change the wetting and adhesion behaviours of nanoparticles, thus reducing the tendency of these particles to agglomerate. The addition of surfactants give significantly improves the stability of nanofluids.

3.2 Conductivity analysis

The enhancement in thermal conductivity becomes important parameter for nanofluids when used as effective heat transfer fluids. Concentration of nanoparticles is one of the factors that can affect the thermal conductivity of nanofluids. Figure 3 shows the relationship between thermal conductivity and concentration of nanoparticle at room temperature.

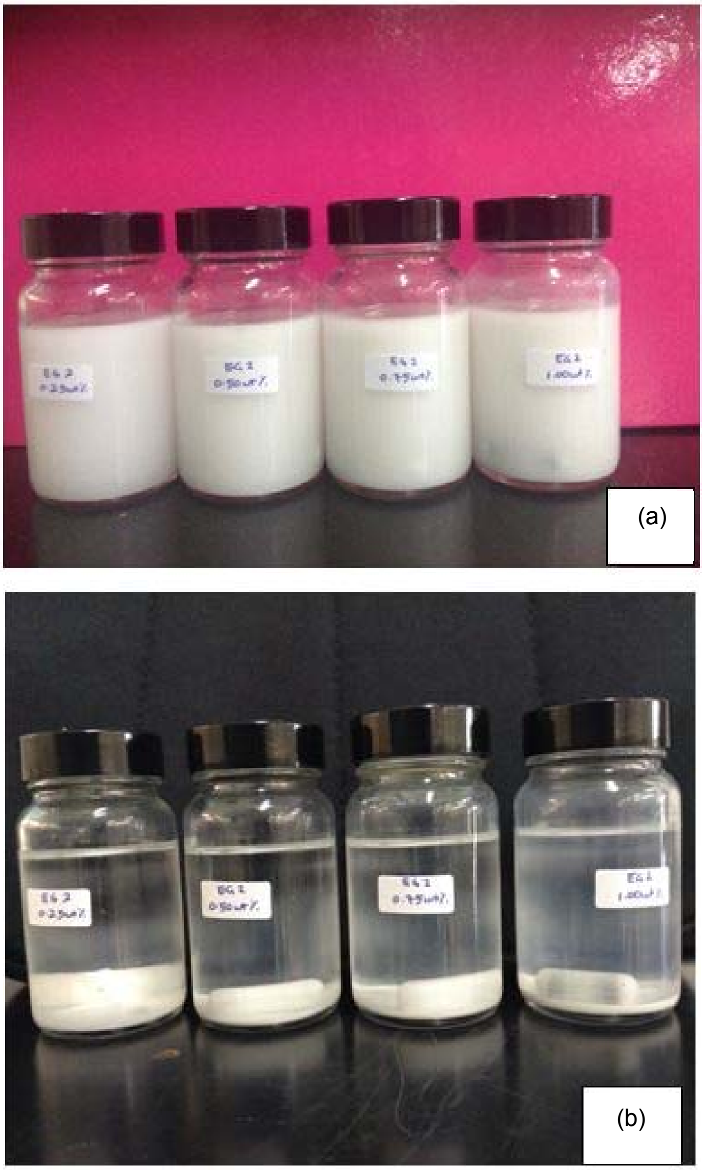

Figure 1: Nanofluids without surfactant: (a) Upon preparation without surfactant; (b) After 2 weeks without surfactant

From Figure 3, it can be seen that the thermal conductivity was enhanced by increasing the concentration of TiO_2. The reason is for ordinary solid-liquid mixture, the thermal conductivity increases due to higher thermal conductivity of solid particles. Nanofluids thermal conductivity is some kind of average thermal conductivity of the solid and liquid (Das et al., 2003). When the nanoparticle concentration increases, it means that more solid particles were present and will lead to more Brownian motion and increases the thermal conductivity. By increasing the concentration of nanoparticles, there is greater possibility of collision between particles and that makes energy transfer becoming faster. This condition also can be related to the clustering of nanoparticles in the base fluids. As heat transport in solid-fluid suspension occurs at the particle-liquid interface, interfacial area increases can lead to more efficient heat transport properties (Ali et al., 2010). This clustering will give a major effect on increasing the thermal conductivity.
Lastly, thermal conductivity seems to be significantly changed by changing the temperature of nanofluids. The effect of temperature on the enhancement of effective thermal conductivity of nanofluids was investigated by measuring the thermal conductivity of nanofluids for different temperatures ranging from 30 °C to 60 °C. Figure 4 illustrates the relationship between the temperature and effective thermal conductivity of nanofluids.

The thermal conductivity against temperature profile at different concentration are very closed to each other, thus only two results are shown here. The result shows that for 1 wt% TiO_2, the thermal conductivity was enhanced by 32 %, 113 %, and 231 % for temperature 40 °C, 50 °C and 60 °C. This can be said that by increasing the nanofluids temperature, the thermal conductivity will increase as well. Brownian motion has been thought as the main reason for the thermal conductivities change with temperature (Das et al., 2003). Hua et al. (2008) said besides Brownian motion, the effects of particle agglomeration and viscosity change with the temperature also contributes to the temperature dependence of nanofluids thermal conductivity. Brownian motion contributes to the thermal conductivity enhancement. It becomes more intensive when the nanofluids temperature increases. With an intensified Brownian motion, the contribution of micro convection in heat transport increases which results in increased enhancement of nanofluids thermal conductivity (Murshed et al., 2008). Temperature increase leads to the reduction of the particle surface energy and decreases the agglomeration of nanoparticles. The smaller size leads to the more intensive Brownian motion, then increase the thermal conductivity.

Figure 2: Nanofluids with surfactant: (a) Upon preparation with surfactant; (b) After 2 weeks with surfactant Thermal

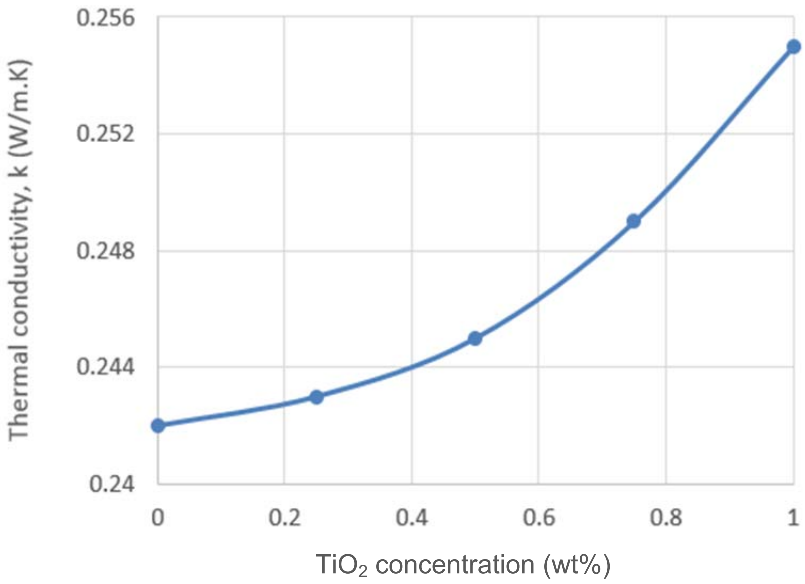

Figure 3: Thermal conductivity of nanofluids as a function of TiO_2 concentration at room temperature

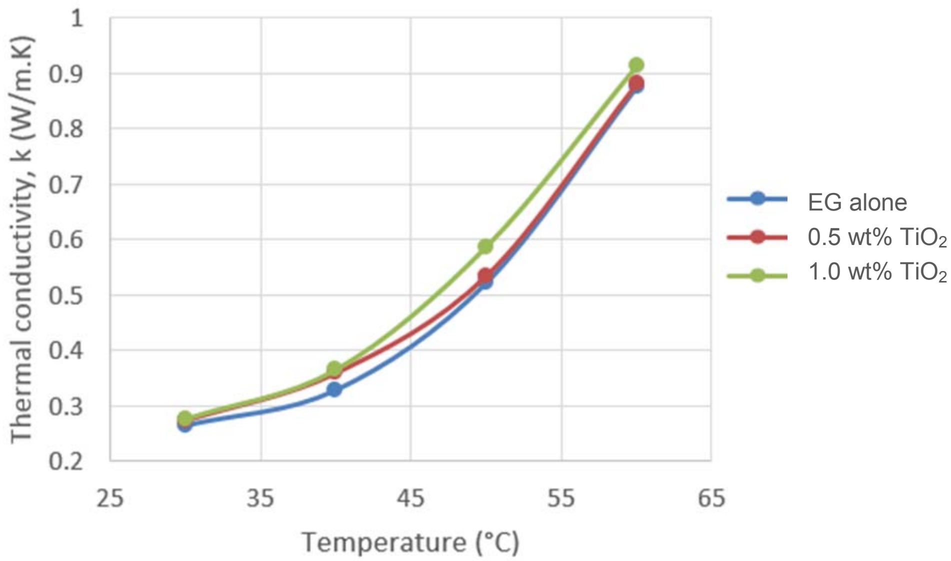

Figure 4: Thermal conductivity of nanofluids as a function of temperature and TiO_2 concentration

4. Conclusion

Formulation of stable nanofluids containing TiO_2 nanoparticles in EG base fluids was performed. The addition of GA as surfactant enhanced the dispersion and resulted in better stability over a period of time. This is because surfactant acts to slower the surface tension of host fluids and increases the immersion of particles and will give more stable nanofluids.

The thermal conductivity was enhanced by varying the amount of TiO_2 concentration, and temperature of the nanofluids. The enhancement of thermal conductivity is believed to be caused by the intensified Brownian motion of nanoparticles in increasing heat environment.

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