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Thermal-properties correlation of Al_2O_3-TiO_2-SiO_2 Nanofluids in Water-Ethylene Glycol Mixture for Application Radiator Cooling System

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ABSTRACT

In recent years, research focused on enhancing the thermo-physical properties of a single component nanofluid. Therefore, hybrid or composite nanofluids are developed to improve heat transfer performance. The thermo-physical properties of the Al_2O_3-TiO_2-SiO_2 nanoparticles suspended in the base of water (W) and ethylene glycol (EG) blends with vol 60:40, many volume concentrations are investigated. The experiment was conducted for the concentration volume of 0.05, 0.1, 0.2 and 0.3% of Al_2O_3-TiO_2-SiO_2 nanofluids with temperature conditions of 30, 40, 50, 60 and 70 °C. The development of new correlation for thermal conductivity and dynamic viscosity of tri-hybrid nanofluids have been found to be precise. As a conclusion, the combination of enhancement in thermal conductivity and a dynamic viscosity at a concentration of 0.3% has optimum conditions, which have more advantages for heat transfer than other concentrations.

1. Introduction

Nanofluid is a suspension of liquid containing metal or non-metallic nanoparticles of typical size (1-100 nm) dispersed into the base liquid. In 1995, the concept of nanofluids was first introduced by Choi *et al.,* [1]. This new method was proven to increase the heat transfer by improving the thermo-physical properties of the nanofluids. Nanofluids are known for the application in the heating and cooling process. The main cooling process is an important part of industrial applications such as power plants, chemical processes, microelectronics, transportation, and automotive cooling systems [2-6]. The existence of solid particles leads to interesting characteristics in the fundamental thermo-physical properties of nanofluids. Thermal conductivity, viscosity, density and stability have been investigated in recent years by many researchers [7-10].

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The method of nanofluids preparation is important to minimize the agglomeration of the nanoparticles, hence improve the stability. The most common process used in nanofluids preparation is one-step and two-step methods. The one-step method is the process of synthesizing nanoparticles and simultaneously dispersing them in a base liquid. However, this method is not practical for industry, which only applies to low vapor pressure liquids. Another method of nanofluid preparation known as the two-step method. There are two processes in this method, namely (i) the synthesis of nanoparticles in powder form (ii) spreading the nanoparticles into the base liquid to form a stable and homogeneous solution [11-14]. Most nanofluids that used oxide particles and carbon nanotubes were produced through a two-step method [15-20]. The two-step method is preferable for production of nanofluids in a large scale and thus applicable for the industry. However, the challenge of using the two-step method is that agglomeration and nanoparticles tend to settle quickly [21-25]. The two-step method is the most dominant method compared to the one-step method for nanofluid preparation.

Several recent studies discuss the topic of hybrid or composite nanofluids [26,27]. Hybrid or composite nanofluids is considered an extension of research work for single nanofluids, which can be carried out through a combination of two or more different nanoparticles - either in mixed or dispersed composites in liquids [28]. Composite or hybrid materials are elements that combine chemical and physical properties. The aim of synthesizing hybrids or nanofluid composites is to improve the properties of single nanoparticles in which a better increase in thermal properties or rheological properties can be achieved. Hybrid nanofluid is expected to achieve good thermal performance when compared to a single of nanofluid [29].

Recently, some papers regarding nanofluid hybrids have been reviewed by HamzaH *et al.,* [30] and Sidik *et al.,* [31]. Both papers were presented on hybrid nanofluids preparation, performance and application methods. Therefore, investigations on thermal conductivity and viscosity are important in understanding hybrid nanofluids behavior for further implementation in heat transfer applications. Thermal conductivity is an important factor affecting the increase in heat transfer [32]. There are several factors that influence thermal conductivity such as: concentration, temperature, particle size, surface ratio to nanoparticle volume, and stability of nanofluids [33-38]. Azmi *et al.,* [39] the thermo-physical properties of TiO_2-SiO_2 nanoparticles suspended in a base fluid of water (W) and ethylene glycol (EG) mixture with 60:40 volume ratio is investigated. They are finding of highest thermal conductivity for TiO_2-SiO_2 nanofluids was obtained with a ratio of 20:80 and the maximum enhancement exceeded up to 16% higher than the base fluids.

The thermo-physical properties of different types of hybrid nanofluids are very important to study. It aims to understand the behaviors and factors that influence the properties that can improve heat transfer performance. Based on the information obtained by the authors, studies on the influence of the mixture ratio for the three nanoparticles in the form of hybrid nanofluids are limited in the literature. Furthermore, the use of hybrid nanofluids with two different nanoparticles will result in an increase in viscosity relative to a single nanofluids component [40,41]. Some literature on the development of thermal properties correlations of hybrid nanofluids is still limited and not much has been researches.

Based on these problems, this study aims to determine the influence of the ratio of three nanoparticles on the thermal-physical properties of Al_2O_3-TiO_2-SiO_2 nanofluids. In addition, the development of new correlations is proposed to determine the thermal conductivity and dynamic viscosity of Al_2O_3-TiO_2-SiO_2 nanofluids or tri-hybrid nanofluids for radiator cooling system applications.

2. Methodology
2.1 Materials

Tri-hybrid nanofluids were developed by merging three different types of single nanofluids, namely Al_2O_3, TiO_2, and SiO_2, and then distributing them in a water/EG combination as a base fluid. All of the single nanofluids were given by US Research Nanomaterials, Inc. Al_2O_3, TiO_2, and SiO_2 nanoparticles had diameters of 13, 50, and 22 nm, respectively, and purity levels of 99.8%, 99.9%, and 99.99%. The features of each nanoparticle are listed in Table 1. The basic fluid in the current study was a 60:40 mixture of water and EG (volume %). The characteristics of Ethylene Glycol are shown in Table 2.

Table 1
Properties of Al_2O_3, TiO_2 and SiO_2 nanoparticles [42]

Properties	Al_2O_3	TiO_2	SiO_2
Molecular mass, g mol^{-1}	101.96	79.86	60.08
Average particle diameter, nm	13	50	22
Density, kg m^{-3}	4000	4230	2220
Thermal conductivity, W m^{-1} K^{-1}	40	8.4	1.4
Specific heat, J kg^{-1} K^{-1}	773	692	745

Table 2
Properties of Ethylene Glycol (EG) [42]

Properties	Ethylene Glycol
Vapour pressure, mmHg at 20 °C	0.08
Boiling point, °C	195–198
Melting point, °C	-13
Density, g ml^{-1} at 25 °C	1.113

2.2 Preparation of Tri-Hybrid Nanofluids

In two processes, tri-hybrid nanofluids are created. By merging three nanofluids, Ramadhan *et al.,* [42] create tri-hybrid nanofluids (Al_2O_3, TiO_2, and SiO_2). The volume calculations necessary in accordance with concentration are the first step in the preparation of nanofluids. Tri-hybrid nanofluides were created in this work at volume concentrations of 0.3% for various composition ratios with (1/3:1/3:1/3) of three nanoparticles (Figure 1).

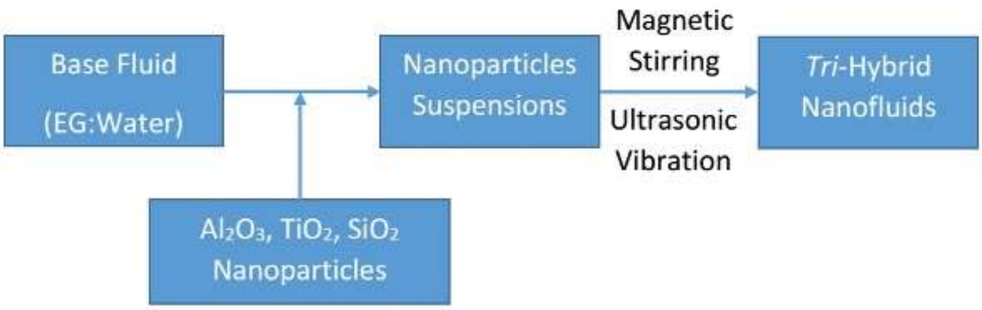

Fig. 1. The preparation of *tri*-hybrid nanofluids [42]

Single nanofluids Al_2O_3, TiO_2, and SiO_2 are provided in water suspensions at weight concentrations of 20%, 40%, and 25%, respectively. To convert from weight concentration to volume concentration, used Eq. (1) [42].

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

ϕ = volume concentration, %, ρ_{bf} = density of base fluid, kg/m^3, ρ_p = density of nanoparticle, kg/m^3, ω = weight concentration, %. All single nanofluids were blended together in a tri-hybrid nanofluids composition ratio (Table 3). A total volume of 100 mL was formed with a volume concentration of 0.3% for tri-hybrid nanofluids. A magnetic stirrer was used to mix a solution of three single nanofluids, Al_2O_3, TiO_2, and SiO_2, for 120 minutes. The solution is sonicated in an ultrasonic bath to increase stability.

2.3 Thermal Conductivity Measurement of Tri-Hybrid Nanofluids

The method of thermal conductivity measurement followed the ASTM D5334 and IEEE 442-1981 standards; using KD2 Pro Property Analyzer (Decagon Devices) is shown Figure 2. Part of the thermal test sample conductivity, KS-1 sensor to read of k [W/m K], measuring bottle to put samples to be tested, KD2 Pro controller is an important part of thermal conductivity measuring device. The KD2 Pro instrument uses a transient line heat source to measure thermal properties. Thermal conductivity measurements are performed for temperatures varying from 30 to 70 °C. To maintain a constant sample temperature is used water bath. Previously, validation of thermal conductivity values from thermal conductivity sensors using standardized liquid glycerin supplied by Decagon Devices. The KS-1 single needle sensor has a length of 60 mm and a diameter of 1.3 mm. The measured k is 0.286 W/m K with accuracy ± 0.35%. Thermal conductivity measurements are performed several times and taken average, the measurement time of 15 minutes for each set data at different temperatures. It is important to minimizing the occurrence of errors in measurements with free convection due to temperature variation along the sensor that directly touches with the liquid sample.

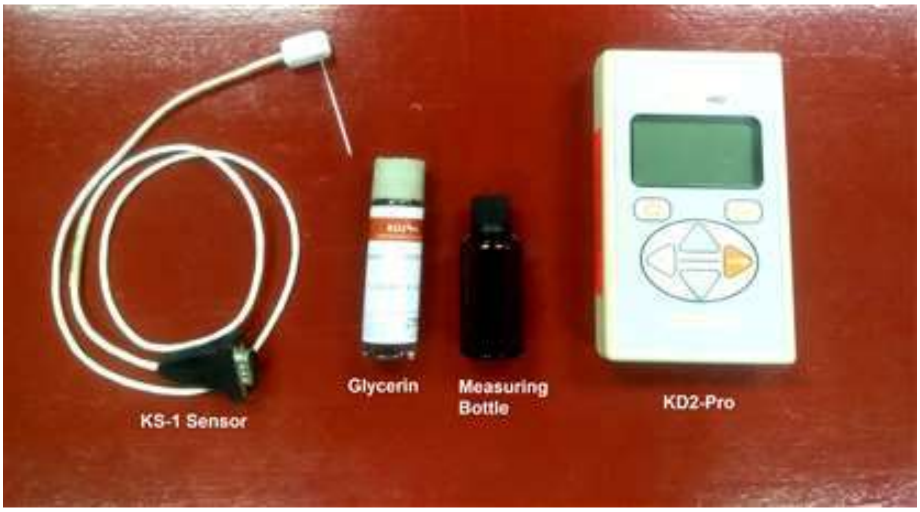

Fig. 2. KD2 Pro thermal properties to the measurement of thermal conductivity [14]

2.4 Dynamic Viscosity Measurement of Tri-Hybrid Nanofluids

Viscosity measurement used water bath circulation at Brookfield LVDV III Ultra Rheometer. Operating conditions of Rheometer for viscosity measurement from 1 to 6 × 10^6 mPa.s. The sample of 16 mL was added to the cylinder jacket and pasted into a Rheometer. The RheoCal program is used for measuring the viscosity connected to the controller. Sample viscosity is evaluated by varying the velocity of the spindle. For the viscosity test, the spindle speed can be adjusted from 0.01 to 250 RPM. It has a 1.0% accuracy in measuring viscosity. Dynamic viscosity measurements were performed with a temperature variation of 30-70°C. The circulating water bath was used to control the sample temperature. The measurements are repeated five times and the average value is reported. Dynamic viscosity measurements used the apparatus shown Figure 3. Basic liquid 60:40 (water: EG) at different temperatures validated by the data contained in the literature. Furthermore, dynamic viscosity measurements are performed for Al_2O_3-TiO_2-SiO_2 or tri-hybrid nanofluids.

Fig. 3. Brookfield LVDV III Ultra Rheometer to the measurement of dynamic viscosity [14]

3. Results

3.1 Thermal Conductivity of Tri-Hybrid Nanofluids

The relationships between tri-hybrid nanofluids thermal conductivity with temperature for volume concentration of 0.05-0.3% at presented Figure 4. Thermal conductivity of the tri-hybrid nanofluids for volume concentration variations may increase in relation to temperature and higher than base fluid. Furthermore, the highest thermal conductivity was obtained for volume concentrations of 0.3%. Meanwhile the volume concentration of 0.05% provided the lowest thermal conductivity among temperatures investigated. In this study, the relationship between the composition ratio of nanoparticles (1/3: 1/3: 1/3) in the tri-hybrid nanofluids to increased thermal conductivity is influenced by three nanoparticles that have different sizes. The diameters of Al_2O_3 and SiO_2 nanoparticles are 13 nm and 22 nm, where in both nanoparticles are smaller than TiO_2 nanoparticles that have a size of 50 nm. Al_2O_3 and SiO_2 nanoparticles play a role in conduction by fulfilling larger TiO_2 nanoparticle spaces. To increase the contact area for conduction between molecules, resulting in a higher rate of heat transfer during a collision by the Brownian motion [15] requires a special arrangement of the three nanoparticles.

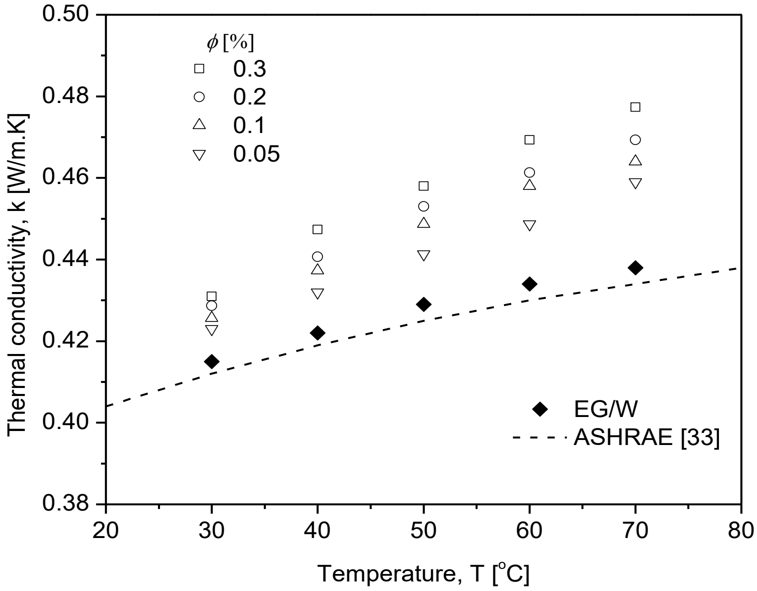

Fig. 4. The experimental thermal conductivity of *tri*-hybrid nanofluids

3.2 Dynamic Viscosity of Tri-Hybrid Nanofluids

Figure 5 presented the dynamic viscosity for various volume concentration of tri-hybrid nanofluids in the temperature range of 30~70^{o}C. The viscosity for all volume concentration follows the base fluid trend whereby it decreases exponentially with temperature. The viscosity of volume concentration of 0.3 is higher than the values of the 0.2, 0.1, and 0.05 %. The volume concentration of 0.3% shows the highest value for viscosity at all temperatures. The dynamic viscosity of the tri-hybrid nanofluids decreased slightly and varied by the differences in the composition ratio of Al_2O_3, TiO_2 and SiO_2 nanoparticles of 1/3:1/3:1/3 in the tri-hybrid nanofluids contributing to the difference in the interactions of those particles with a base fluid. However, the effect of temperature on the Al_2O_3-TiO_2-SiO_2 nanofluids viscosity for all mixed ratios decreases with increasing temperature and is evidenced by Azmi *et al.,* [38].

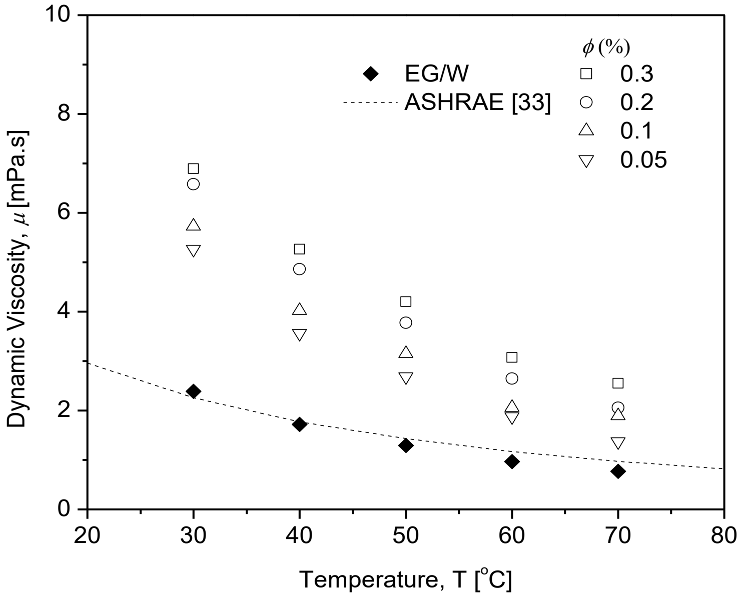

Fig. 5. Variation of dynamic viscosity with temperature

3.3. Regression Correlations for Thermal Conductivity and Dynamic Viscosity

The development of the property's regression equation of the Eq. (2) and (3) respectively can be analysed with experimental data from both thermal conductivity and dynamic viscosity. The equation is combined with the volume concentration of tri-hybrid nanofluids for the range 0.05-0.3%. This equation applies to the estimation of tri-hybrid nanofluids at 60:40 (Water/EG) and temperatures from 30 to 70°C. The average deviation (AD), and standard deviation (SD) for thermal conductivity were 0.5% and 0.7%, respectively. Where, for viscosity 1.4% and 1.9% respectively. Measurement data in good agreement with estimated values from Eq. (4) and (5) based on the statistical analysis shown in Figures 6 and 7.

$$\frac{k_{nf}}{k_{bf}} = 0.968\left(1+\frac{\varphi}{100}\right)^{18.8276}\left(1+\frac{T}{70}\right)^{0.0866} \tag{2}$$

$$\frac{\mu_{nf}}{\mu_{bf}} = 3.52\left(1+\frac{\phi}{100}\right)^{147.268}\left(\frac{T}{70}\right)^{0.661} \tag{3}$$

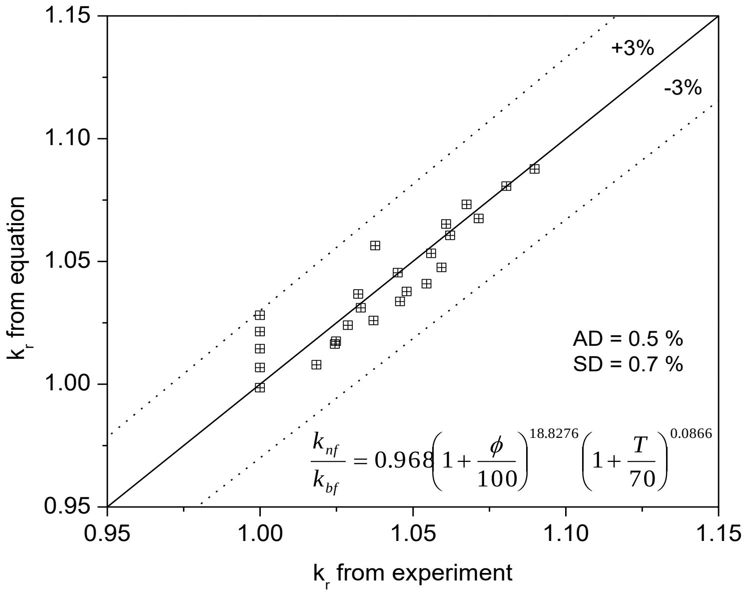

Fig. 6. Comparison of effective thermal conductivity with Eq. (2)

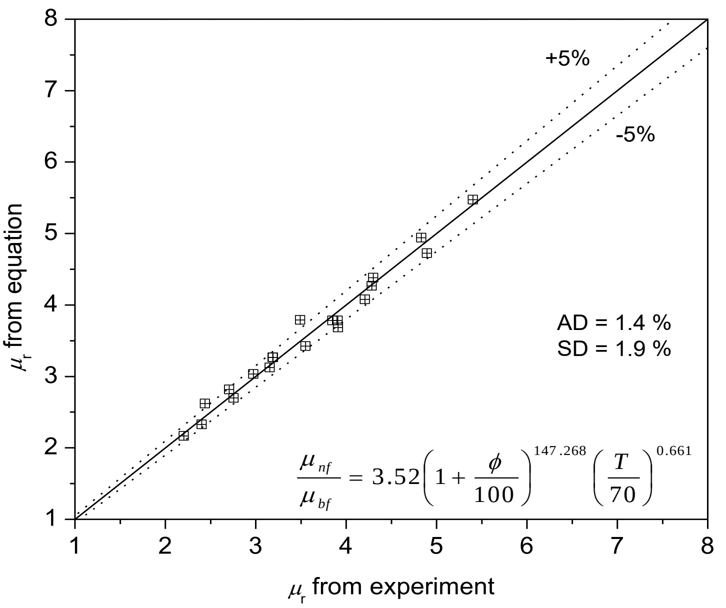

Fig. 7. Comparison of relative viscosity with Eq. (3)

4. Conclusions

In this study, thermal conductivity and dynamic viscosity of tri-hybrid nanofluids were investigated for four concentration volumes, and temperatures from 30 to 70°C. The experimental results showed that the concentration volume of 0.3% obtained the best according to the thermal conductivity and viscosity compared to 0.05~0.3%. The optimum of the concentration volume is 0.3%, where the increase in thermal conductivity and dynamic viscosity have more advantages than other concentration volumes. However, experimental investigations on heat transfer are required to determine the actual performance of this volume of concentration.

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