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EXPERIMENTAL MEASUREMENT OF NANOFLUIDS THERMAL PROPERTIES

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ABSTRACT

Solid particles dispersed in a liquid with sizes no larger than 100nm, known as nanofluids, are used to enhance Thermophysical properties compared to the base fluid. Preparations of alumina (Al_2O_3), titania (TiO_2) and silica (SiO_2) in water have been experimentally conducted in volume concentrations ranging between 1 and 2.5%. Thermal conductivity is measured by the hot wire method and viscosity with viscometer equipment. The results of thermal conductivity and viscosity showed an enhancement (0.5–20% and 0.5–60% respectively) compared with the base fluid. The data measured agreed with experimental data of other researchers with deviation of less than 5%. The study showed that alumina has the highest thermal conductivity, followed silica and titania, on the other hand silica has the highest viscosity followed alumina and titania.

Keywords: Nanofluid; thermal conductivity; viscosity.

INTRODUCTION

The increasing need in many applications for fluids with more efficient heat transfer has been led to enhance heat transfer to meet the cooling challenge necessary, such as in the electronics, photonics, transportation and energy supply industries (Das et al., 2008). The experimental study of copper suspended in water to enhance the heat transfer and reduce pumping power in a heat exchanger was carried out by Choi and Eastman (1995). The thermal conductivity of nanofluids has been calculated theoretically, and the results showed a high thermal conductivity compared with the base fluid. Metals have higher thermal conductivities than fluids at room temperature, as shown in Table 1 (Touloukian and DeWitt, 1970). The thermal conductivity of metallic liquids is much greater than that of non-metallic liquids. Therefore the thermal conductivities of fluids that contain suspended solid metallic particles could be expected to be significantly higher than those of conventional heat transfer fluids. Sen Gupta et al. (2011) carried out an experimental study to measure the thermal conductivity in graphene nanofluids using the transient hot wire method. They also studied carbon nanotube (CNT) and graphene oxide nanofluids. The magnitude of enhancement was between CNT and metallic/metal oxide nanofluids. The multicurrent hot-wire technique was used by Peñas et al. (2008) to measure the thermal conductivity of SiO_2 and CuO in water and ethylene glycol nanofluids with concentrations of up to 5% in mass fraction. They found good agreement, within 2%, with the published thermal conductivities of the pure fluids. The optimisation of the thermal conductivity of nanofluids has been proposed by Xie et al. (2011), various nanoparticles involving Al_2O_3 of different sizes, SiC with different shapes, MgO , ZnO , SiO_2 , Fe_3O_4 , TiO_2, diamond and carbon nanotubes. The base fluids used have been deionised water (DW), ethylene glycol (EG), glycerol, silicone oil, and a binary mixture of DW and EG. Results showed that the thermal conductivity enhancements of nanofluids could be influenced by multi-faceted factors, including the volume fraction of the nanoparticles, the tested temperature, thermal conductivity of the base fluid, size of the nanoparticles, the pre-treatment process, and the additives of the fluids. The viscosity and specific heat of silicon dioxide (SiO_2) nanoparticles with various diameters (20, 50 and 100 nm) suspended in a 60:40 (by weight) ethylene glycol and water mixture were investigated experimentally by Namburu et al. (2007). The results showed a new correlation of the experimental data, which related viscosity with particle volume percent and nanofluid temperature. Also the specific heats of the SiO_2 nanofluids for various particle volume concentrations were reviewed. Murshed et al. (2006) examined the effect of temperature and volume fraction on viscosity for a TiO_2-water nanofluid. Results were recorded and analysed within a temperature range of 25 to 70^oC and volume fractions of 0.1, 0.4, 0.7 and 1%. The viscosity measured using a rheometer has been studied by Bobbo et al. (2012). It was obtained as a function of the nanoparticle's mass fraction and shear rate. Water was used as the base fluid with two different materials: single wall carbon nanohorn (SWCNH) and titanium dioxide (TiO_2). The results proposed an empirical correlation to the equations of viscosity. In this study three types of nanoparticle (Al_2O_3, TiO_2 and SiO_2) are suspended in water prepared in a laboratory. The thermal conductivity and viscosity of these nanofluids are measured experimentally. The results for the thermal conductivity and viscosity are compared with standard values and other available studies.

Table 1. Thermophysical properties of various materials at 25^oC (Han and Rhi, 2011).

Material	**Density (kg / m^3)**	**Thermal Conductivity (W/m.k)**	**Specific heat (J / kg.k)**
Silver	10490	429	710
Copper	8954	380	390
Aluminium	2700	237	910
Diamond	3510	3300	425
Carbon nanotubes	2250	3000	410
Silicon	2330	148	710
Alumina(Al_2O_3)	3880	36	773
Silica (SiO_2)	2220	1.4	745
Titanium dioxide (TiO_2)	4175	8.4	692
Water	998.9	0.613	4181
Ethylene glycol	1110	0.253	2200
Engine oil	890	0.145	1800

PREPARATION OF NANOFLUIDS

Nanofluids have been prepared in the thermal laboratory of the Mechanical Engineering Faculty of the University Malaysia Pahang. Nanopowders were purchased from US Research Nanomaterials, Inc. (NovaScientific Resources (M) Sdn. Bhd. They represent three types of commercial nanoparticle (Al_2O_3, TiO_2 and SiO_2), as shown in Figure 1, and are dispersed in water as the base fluid.

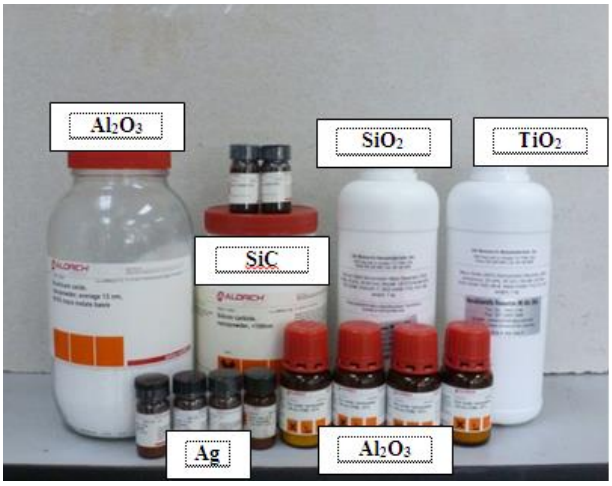


Figure 1. Commercial nanoparticles.

Water was prepared in a laboratory by double distillation as shown in Figure 2, before use in the experiments.

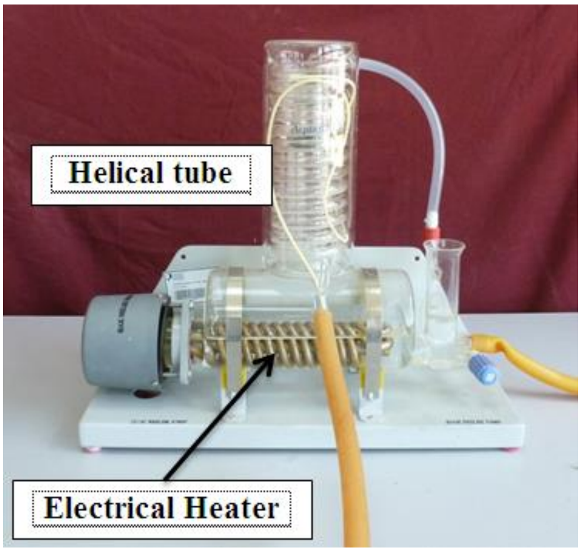
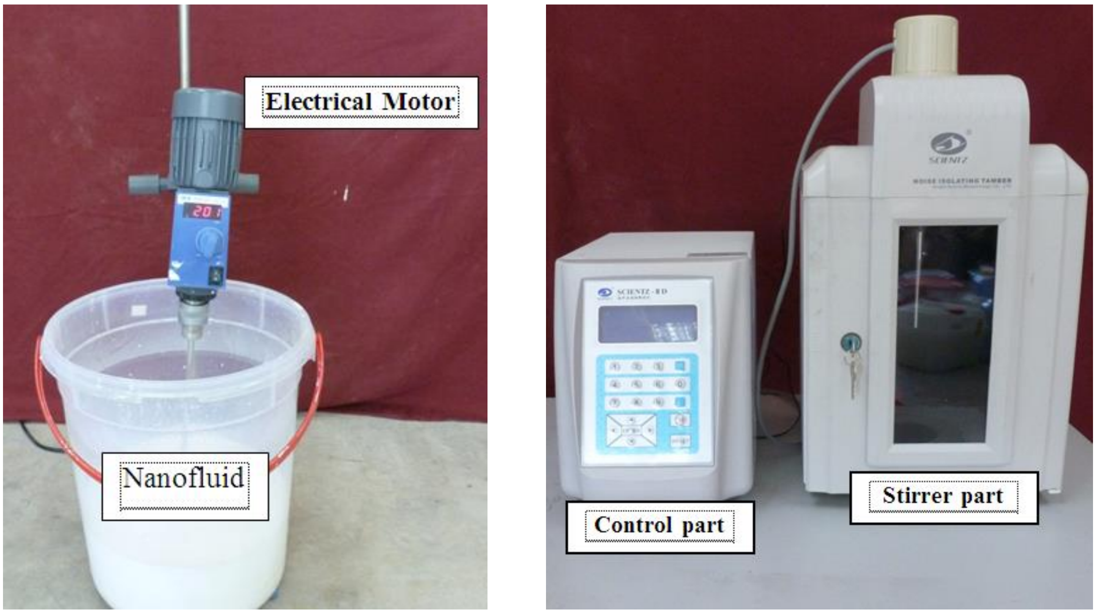


Figure 2. Water distillation equipment.

The diameters of the nanoparticles are 13, 30 and 30 nm. Measured quantities of nanoparticles are dispersed in distilled water to obtain mass concentration ϕ nanofluids. A mechanical stirrer is used to achieve a homogenously dispersed solution, as shown in

Figure 3(a). This method was based on Das et al. (2008), Mahendran et al., 2012, Han and Rhi (2011) and Lee et al. (1999). After that it has been subjected to ultrasonics as shown in Figure 3(b) for at least 3 hrs to break up any residual agglomerations.



(a) mechanical stirrer (b) ultrasonic device

Figure 3. Nanofluid stirrer equipment.

The mass of nanoparticles (m_p) and water (m_f) are measured with an accuracy of 0.001 g, to estimate the weight percentage (φ) using Eq. (1) (Das et al., 2007; Namburu et al., 2007).

$$\varphi = \left(\frac{m_p}{(m_p + m_f)} \right) \times 100 \tag{1}$$

Equation (2) is used to estimate the volume concentration of the nanofluid ϕ depending on the nanoparticle density (ρ_p) and base fluid density (ρ_f) at 25^{o}C.

$$\phi = \frac{\dfrac{m_p}{\rho_p}}{\dfrac{m_p}{\rho_p} + \dfrac{m_f}{\rho_f}} \tag{2}$$

The sedimentation of nanoparticles at the bottom of the samples led to changes in the physical properties of the bulk nanofluids with time (Duangthongsuk and Wongwises, 2009). In the examined case, the measurement of the thermal properties of the nanofluids requires many individual measurements over at least one month, so need to be taken to check the sample's stability. Samples have been checked after the completion of each test, but no visible sedimentation was found.

THERMOPHYSICAL PROPERTIES

There are many studies that use the regression equations of density (ρ_{nf}) and the specific heat capacity (C_{nf}) (Choi and Eastman, 1995; Das et al., 2008; Fedele et al., 2012; Putra et al., 2003; Trisaksri and Wongwises, 2007; Wang et al., 1999; Wen and Ding, 2004; Williams et al., 2008; Zeinali Heris et al., 2007; Zhou and Ni, 2008):

$$\rho_{\mathbf{nf}} = \left(\frac{\phi}{100}\right)\rho_p + \left(1 - \frac{\phi}{100}\right)\rho_f \tag{3}$$

$$C_{nf} = \frac{\frac{\phi}{100}(\rho C)_p + \left(1 - \frac{\phi}{100}\right)(\rho C)_f}{\rho_{nf}} \tag{4}$$

The base fluid (water) properties are estimated depending on the base temperature as regression equations (Sharma et al., 2012):

$$\rho_f = 1000 \times \left\{1 - \frac{(T_f - 4)^2}{119000 + 1365 \times T_f - 4(T_f)^2}\right\} \tag{5a}$$

$$C_f = 4217.629 - 3.20888 \times T_f + 0.09503 \times T_f^2 - 0.00132 \times T_f^3 + 9.415e^{-6 \times T_f^4} - 2.5479e^{-8 \times T_f^5} \tag{5b}$$

$$k_f = 0.56112 + 0.00193T_f - 2.60152749e^{-6 \times T_f^2} - 6.08803e^{-8 \times T_f^3} \tag{5c}$$

$$\mu_f = 0.00169 - 4.25263e^{-5 \times T_f} + 4.9255e^{-7 \times T_f^2} - 2.0993504e^{-9 \times T_f^3} \tag{5d}$$

The transient hot-wire method, shown in Figure 4(a), is used to experimentally measure the thermal conductivity of the nanofluids. The wire is placed along the axis of the container, which will be surrounded by the fluid whose thermal conductivity is to be measured. Platinum has a high electrical resistivity, i.e. 1.06 × 10−7Ω *m* (at 20°C), an order of magnitude higher than that of other metals. Also it has a temperature coefficient of resistance of 0.0003925 $^{\circ}C^{-1}$ (for pure platinum), which is much higher than that of the other metals chosen as the wire material. The wire is to be used as a line heat source, so the wire diameter is usually kept within 100 µm. The length of the wire is kept to just a few centimetres, which compared to the wire's diameter represents an infinitely long line heat source, assuring unidirectional (radial) heat transfer. The calibration method has been used with a standard fluid (glycerin) which was already brought with the device, the error between the read data and the standard is 0.0023. After that, verification has been performed using the pure liquid (water) and compared with the standard, and the error between them is 0.0014. Experimental data are reported in Table 3, and the thermal conductivity values were estimated with Eq. (6) (Fedele et al., 2012; Gosselin and da Silva, 2004; Ho et al., 2010; Krishna and Sivashanmugam, 2010; Lee and Mudawar, 2007; Li et al., 2003; Murshed et al., 2006; Srinivasa Rao et ao., 2011; Pak and Cho, 1998; Pantzali et al., 2009; Peñas et al., 2008; Pastoriza-Gallego et al., 2011; Syam Sunda rand Sharma, 2011a,b; Sen Gupta et al., 2011; Trisaksri and Wongwises, 2007; Wang et al., 1999; Wen and Ding, 2004; Williams et al., 2008; Xie et al., 2011; Zeinali Heris et al., 2007; Zhou and Ni, 2008).

$$k_{nf} = (1 + 3\Phi)k_w \tag{6}$$

The standard deviation corresponding to the series of individual data measured for each nanofluid and each temperature was in all cases less than 0.15%. To evaluate the thermal properties of the nanofluids, the viscosity is an important indication. A commercial Brookfield DV-I prime viscometer is used to measure the viscosity at different temperatures and rotor RPMs, which is shown in Figure 4(b). The base fluid (water) has been used to measure the viscosity for calibration, after which nanofluids are used to measure the viscosity. The viscosity of the nanofluid (μ_{nf}) is determined from the well-known Einstein equation for estimating viscosity, which is validated for spherical particles and volume concentrations less than 5.0 vol. % and was defined by (Bahiraei et al., 2012; Duangthongsuk and Wongwises, 2009; Fedele et al., 2012; Gosselin and da Silva, 2004; Han and Rhi, 2011; Namburu et al., 2007).

$$\mu_{nf} = (1 + 2.5\Phi)\mu_w \tag{7}$$

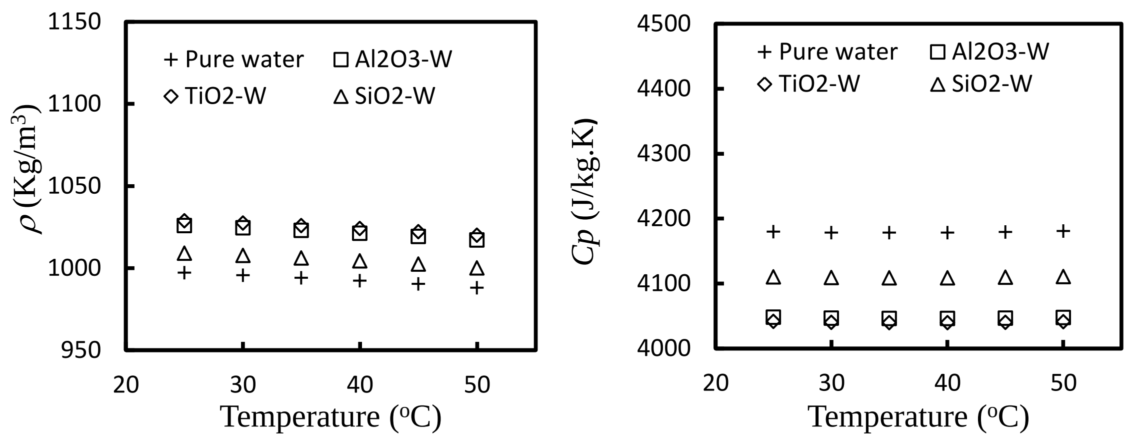
(a) Thermal conductivity device

(b) Viscometer device

Figure 4. Measurements devices.

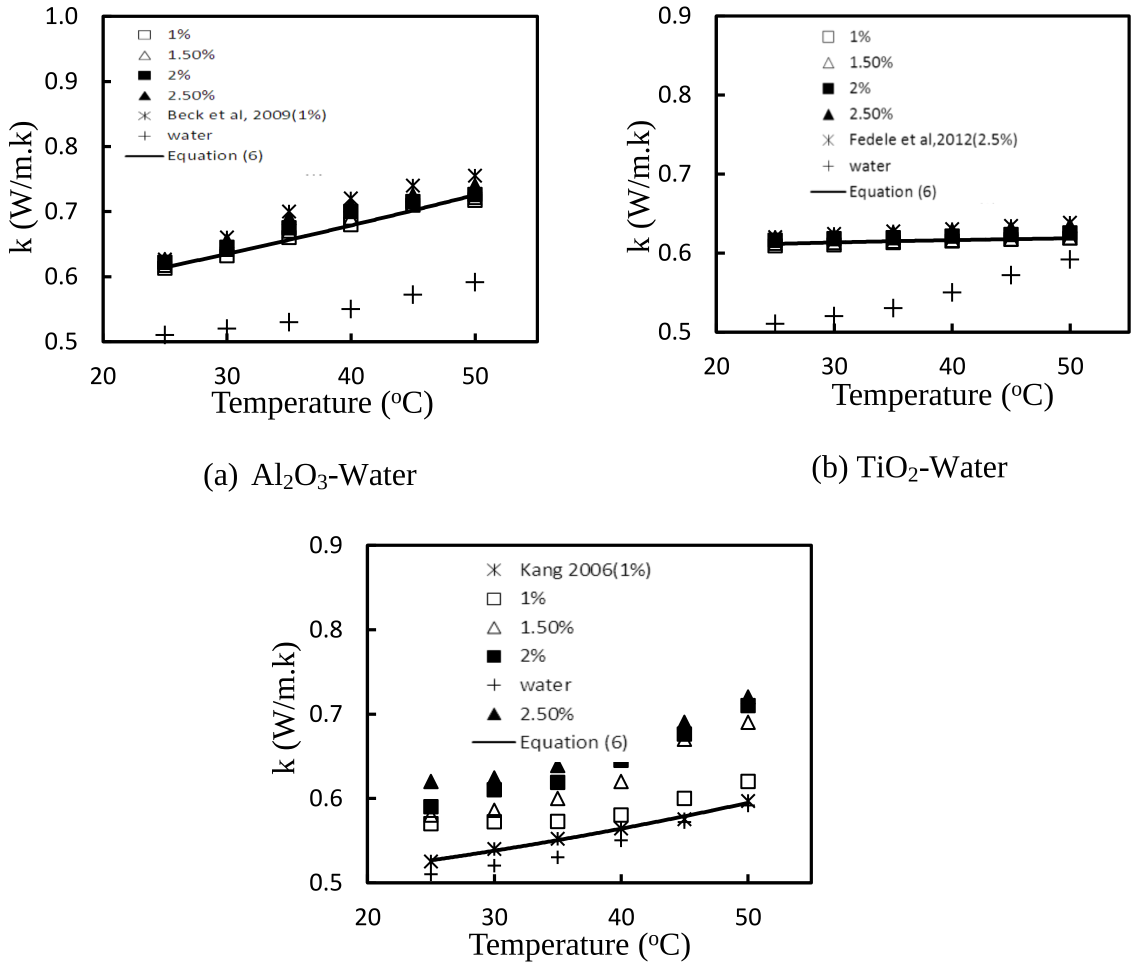
RESULTS AND DISCUSSION

The density and specific heat of the nanofluids and base fluid are presented in Figure 5. There was no much change in the temperature and volume concentrations. The TiO_2 nanofluid has the highest values of density and the lowest value of specific heat, followed by Al_2O_3, SiO_2 and finally pure water has the lowest density and the highest specific heat. In fact, the thermal conductivity always increased when nanopowder was added to the base fluid to prepare the nanofluids, as well as the temperature increasing due to the increase in thermal conductivity (Pak and Cho, 1998). The thermal conductivity of the (Alumina, Titania and Silica) nanofluids at various volume concentrations and base fluids have been measured for range of temperatures from 25^{o}C to 50^{o}C, and the experimental data are presented in Figure 6. This figure showed significant enhancement in the thermal conductivity of the nanofluids with temperature and volume concentration. The theoretical data of the thermal conductivity from Eq. (6) has been drawn as a solid black line to validate the measured data. On the other side, the experimental data of other researchers have been displayed with different volume concentrations, and there was good agreement, with deviations of no more than 4% (Das et al., 2007).



(a) Density (b) Specific heat

Figure 5. Density and specific heat at different temperatures

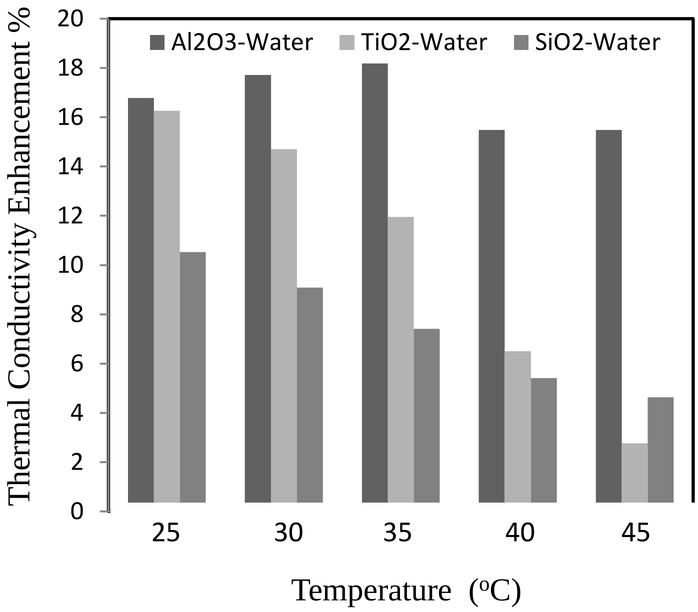


(a) Al_2O_3-Water (b) TiO_2-Water

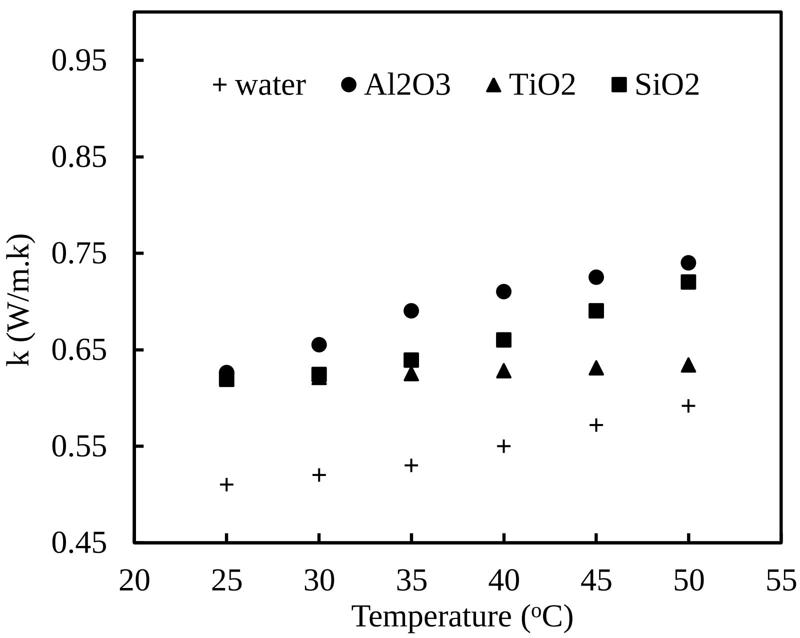
(c) SiO_2-Water

Figure 6. Thermal conductivity of nanofluids at different temperatures and volume concentrations.

The enhancement ($\eta\%$) in thermal conductivity is represented as a percentage deviation in thermal conductivity of the nanofluids against the base fluid $\eta\% = ((k_{nf} - k_w)/ k_{nf}) \times 100$ and the values tabulated with the range 0.5–20%, as shown in Figure 7(a).



(a) Percentage of thermal conductivity enhancement

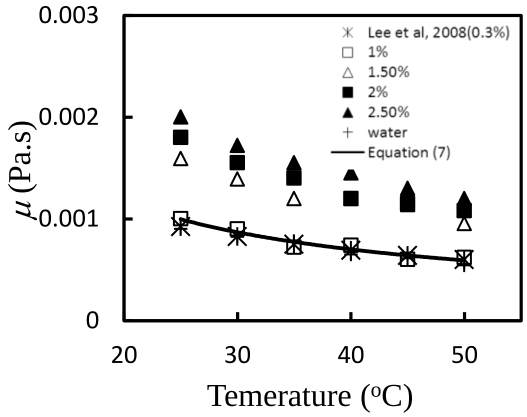


(b) Comparison between nanofluid thermal conductivity

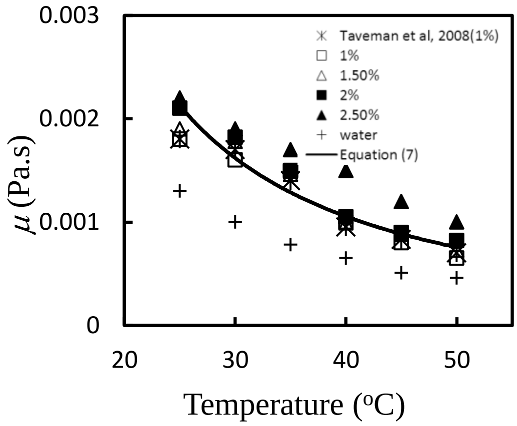
Figure 7. Thermal conductivity at different temperature: (a) percentage enhancement and (b) comparison between nanofluid.

Figure 7(b) presents the comparison between nanofluids thermal conductivity at 2.5% volume concentration which showed that the Al_2O_3 nanofluid has the highest values of thermal conductivity, followed by SiO_2, TiO_2 and finally pure water has the lowest thermal conductivity. Although TiO_2 nanoparticles have a higher thermal conductivity than SiO_2 but the last one appeared higher values of thermal conductivity at 2.5% volume concentration when added to water as a nanofluid due to the enhancement of thermal conductivity with volume concentration for TiO_2 nanofluid is slightly than SiO_2 nanofluid. Similarly nanofluids increase as water with the increase in temperature.

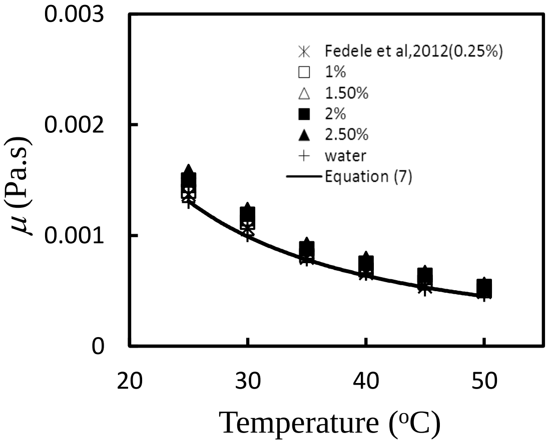
Experimental data on the viscosity of the nanofluids and base fluid (water) were measured from 25°C to 50°C in increments of 5°C per step. The expected values of the shear rate ranged from 200 to 1300 s, and all measured data were closed to this range with a percentage average deviation of about 4%. The experimental data on the viscosity are presented in Figure 8 with the temperatures and volume concentrations. The theoretical data on viscosity as given in Eq. (7) was drawn as solid black lines and the experimental data of other investigators presented to validate the measured data.



(a) Al_2O_3-Water



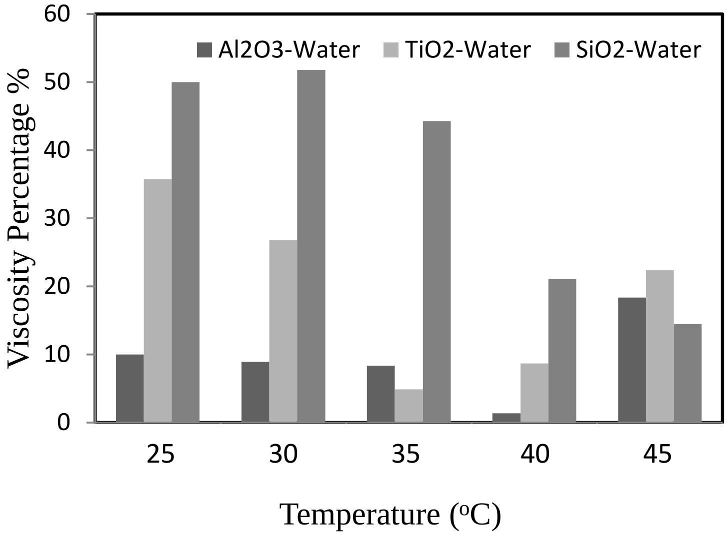
(b) TiO_2-Water



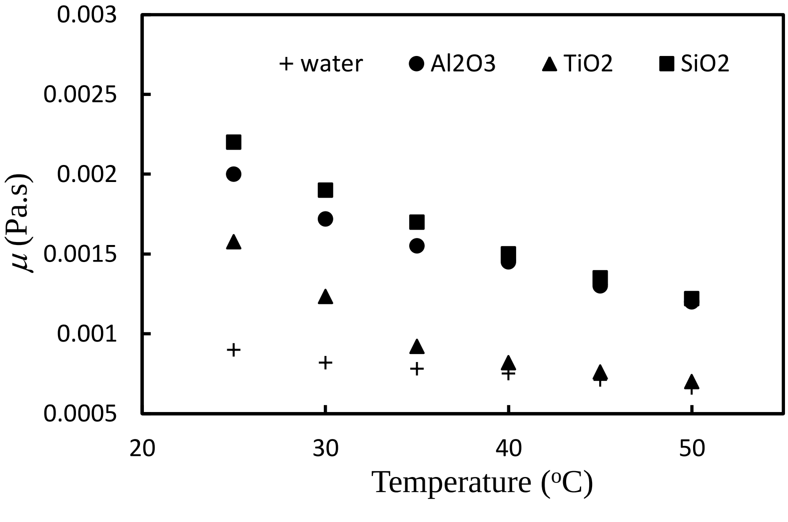
(c) SiO_2-Water

Figure 8. Viscosity of nanofluids with different temperatures and volume concentrations.

The viscosity enhancement ($\lambda\%$) represented percentage deviations among experimental data of nanofluids and water which is $\lambda\% = ((\mu_{nf} - \mu_w)/\mu_{nf}) \times 100$, with values within the range 0.4 to 60%, as shown in Figure 9(a). The increase in viscosity with an increase in volume concentration, identified due to the increase in percentage deviation, may be related to the fact that no surfactant or chemical additives were used during nanofluid preparation. It seems that the enhancement in viscosity does not only depend on the temperature, but also primarily on the volume concentration (Pastoriza-Gallego et al., 2011).



(a) Percentage of viscosity decrease.



(b) Comparison of nanofluid viscosity

Figure 9. Viscosity at different temperature: (a) percentage decrease and (b) comparison between nanofluid.

Figure 9(b) shows a comparison between the nanofluids viscosity at 2.5% volume concentration. It seems that the SiO_2 nanofluid presents the highest values of viscosity, followed by Al_2O_3, TiO_2 and finally pure water has the lowest viscosity. Also, the nanofluids showed similar behaviour to water with a decrease in temperature. Compared to other investigation of both thermal conductivity and viscosity, the results indicated that there were differences between the measured data and correlations, the reasons for which may be various parameters such as particle preparation, particle size, measurement technique and even different the particle's sources (Xie et al, 2011, Zeinali Heris et al, 2007, Zhou and Ni, 2008).

CONCLUSIONS

In the present study, the Thermophysical properties of three types of nanoparticle suspended in distilled water have been measured experimentally in a thermal laboratory. The nanofluids were prepared in volume concentrations of 1, 1.5, 2.0 and 2.5 vol. %. The density and specific heat capacity were calculated with Eqs. (3)–(4), which showed that the Titania nanofluid has a higher density and lower specific heat than the other nanofluids, and that water has a lower density and higher specific heat. The thermal conductivity and viscosity was measured experimentally between 25^{o}C and 55^{o}C, in increments of 5^{o}C per step. The results of the thermal conductivity showed an increase in volume concentration and temperature due to an increase in the thermal conductivity of the nanofluids, with deviations of 0.5–20% compared with the base fluid. The study showed that the Al_2O_3 nanofluid has the highest value of thermal conductivity, followed by SiO_2, TiO_2 and finally pure water has the lowest thermal conductivity. The viscosity data measured showed that the viscosity of nanofluids significantly decreases with increasing temperature, and increases with increasing particle volume concentration, with a deviation of 0.5–60% compared with the base fluid. The measured data on viscosity concluded that the SiO_2 nanofluid has the highest value of viscosity, followed by Al_2O_3, TiO_2 and finally pure water has the lowest viscosity. Regarding both the thermal conductivity and viscosity data, the results indicated that the measured data are quite different from those obtained by other investigators, which may a result of various parameters such as the particle preparation, particle size, measurement technique or even the different particle sources. Finally, the proposed correlations for predicting the thermal conductivity and viscosity of nanofluids showed good agreement with the experimental results of Beck et al. (2009), Fedele et al. (2012) and Taveman et al. (2008).

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NOMENCLATURE

A - area [m^2]
C - specific heat capacity [W/ kg.^{o}C]
D - diameter [m]
E - energy [W]
f - friction factor
htc - convection heat transfer coefficient

ρ - density [kg/m^3]
τ - shear stress [N/m^2]
ϕ - mass concentration
Φ - volume concentration

[W/m^2.^{o}C]
k - thermal conductivity [W/m.^{o}C]
Nu - Nusselt Number [$htc .D/K_{eff}$]
P - Pressure [N/m^2]
Pr - Prandtl Number [$C.\mu/K_{eff}$]
Re - Reynolds Number [$\rho_{eff} D_{eff} u / K_{eff}$]
u - velocity [m/s]
μ -viscosity [N.s /m^2]

Subscripts

f - liquid phases
p - solid particle
eff - effective
nf - nanofluid

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