



Experimental Analysis on Influence of Temperature and Volume Fraction of Nanofluids on Thermophysical Properties

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Abstract: A colloidal mixture of nano-sized (<100 nm) particles in a base liquid called nanofluid, which is the new generation of heat transfer fluid for various heat transfer applications where transport characteristics are substantially higher than the base liquid. In the present study, the effects due to temperature and concentration on thermophysical properties (thermal conductivity, viscosity and density) for Al₂O₃/water/ethylene glycol based nanofluids are experimentally investigated. The volume fractions of nanoparticles used were 0.1%, 0.25%, 0.50% and 1.0%. The present work focuses on thermal conductivity and viscosity measurement of fluid mixture. This however, has not been addressed properly so far. Results show that thermal conductivity increases with nanoparticles concentration as well as with the temperature. Whereas, viscosity and density decreases with temperature and increases with nanoparticles concentration.

Keywords: Nanofluids, thermal conductivity, viscosity, density, volume fraction

I. Introduction

Nanofluids are a new class of nanotechnology-based heat transfer fluids engineered by dispersing nanoparticles into conventional heat transfer fluids such as water, ethylene glycol, and engine oil [1]. Many researchers have been trying to create new kinds of heat transfer fluids in order to enhance the heat transfer performance of the base fluids [2]. To evaluate nanofluids' potential use in heat transfer applications, an investigation of both thermal conductivity and viscosity as fundamental thermophysical properties is essential.

From investigations in the past decade [3–8], nanofluids were found to exhibit substantially higher thermal properties particularly thermal conductivity even when volume fraction (ϕ) of suspended nanoparticles are very low ($\phi < 5\%$). However, the increments of thermal conductivities are different for different types of nanofluids. The thermal conductivity of nanofluids varies with the size, shape, and material of nanoparticles. For example, nanofluids with metallic nanoparticles were found to have a higher thermal conductivity than nanofluids with non-metallic (oxide) nanoparticles. The smaller the particle size, the higher the thermal conductivities of nanofluids. Furthermore, nanofluids with spherical shape nanoparticles exhibit a smaller increase in thermal conductivity compared with the nanofluids having cylindrical (nano-rod or tube) nanoparticles [9]. In addition, temperature may play an important role in enhancing the effective thermal conductivity of nanofluids. As reported, most experimental studies on the determination of the thermal conductivity of nanofluids have been conducted at room temperature. Very few studies [7, 10, 11] have been performed to investigate the temperature effect on the effective thermal conductivity of nanofluids. Hence, to confirm the effects of these parameters on the effective thermal conductivity of nanofluids, more experimental studies are essential.

Alumina (Al₂O₃) is the most common nanoparticle used by many researchers in their experimental work. Most of the researchers have measured the thermal conductivity and viscosity of nanofluids with metal oxides for $\phi > 1\%$. However, not much research has been done at very low volume concentration, say $\phi < 1\%$, using metal oxide nanoparticle [12]. Also a very few studies have been reported on fluid mixtures. Hence, this study is found to be significant. Therefore, in the present work, the temperature-dependent properties of Alumina nanoparticles (Al₂O₃) suspended in distilled water (DW), ethylene glycol (EG) and their mixture are measured with $\phi < 1\%$. The objectives of the article are (1) to measure thermal conductivity for temperatures between 25 °C and 60 °C (2) to measure viscosity and density for temperatures between 25 °C and 90 °C.

II. Experimental

A. Materials

Alumina nanoparticles were purchased from M/s. Alpha Aesar, A Jhonson Matthey Chemicals India Pvt. Ltd., Hyderabad. The size of the nanoparticle was 40 – 45 nm. Ethylene Glycol was purchased from S.D. Fine-Chem. Limited, Mumbai. All the chemicals were used as received without any further purification.

B. Preparation of nanofluids

Preparation of nanofluids is the first key step in the experimental studies with nanofluids. In present work, $\text{Al}_2\text{O}_3/\text{DW}/\text{EG}$ nanofluids with volume fractions 0.1%, 0.25%, 0.5% and 1.0% were prepared using two step process. Nanofluid with a required volume concentration was prepared by dispersing a specified amount of Al_2O_3 nanoparticles in distilled water, ethylene glycol and a fluid mixture of distilled water (75%) and ethylene glycol (25%). To get a uniform dispersion and stable suspension, which determines the final properties of nanofluids were kept under ultrasonic vibration continuously for 4 hours.

C. Measurement of thermophysical properties

The thermal conductivity of $\text{Al}_2\text{O}_3/\text{DW}/\text{EG}$ nanofluid was measured by using a KD2 Pro thermal properties analyzer (Decagon devices, Inc., USA). The KS-1 sensor needle was used for measuring thermal conductivity of nanofluids. Each measurement cycle consists of 90 s. During the first 30 s, the instrument will equilibrate which is then followed by heating and cooling of sensor needle for 30 s each. At the end of the reading, the controller computes the thermal conductivity using the change in temperature (ΔT) – time data from Eqn. (1).

$$k = \frac{q (\ln t_2 - \ln t_1)}{4\pi (\Delta T_2 - \Delta T_1)} \quad (1)$$

k : Thermal Conductivity, t : Time, ΔT : Change in temperature

For the measurement of viscosity of nanofluids, Ubbelohde viscometer is used, which uses a capillary based method for the measurement of nanofluids. The advantage of this instrument is that the values obtained are independent of the total volume. The viscosity of the test liquid is determined by measuring the time it takes for the sample, whose volume is defined by two ring – shaped marks to flow laminarily through a capillary under the influence of gravity. The viscosity of the nanofluid was calculated from Eqn. (2).

$$\mu_{nf} = \mu_w \frac{t_{nf} \rho_{nf}}{t_{bf} \rho_{bf}} \quad (2)$$

μ : Dynamic viscosity, ρ : Density, subscripts nf : nanofluids, bf : basefluid

For the measurement of density of nanofluids, pycnometer (also called specific gravity bottle or relative density bottle) is used. First, weigh the empty pycnometer and pour 5 ml nanofluid in it. Then weigh the pycnometer again. Density of nanofluid was found from Eqn. (3).

$$\rho = \frac{\text{weight of nanofluid}}{\text{volume of pycnometer}} \quad (3)$$

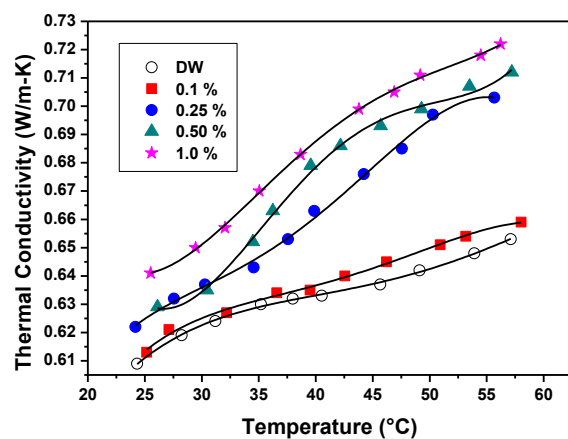
III. Results & Discussion

A. Thermal Conductivity measurement

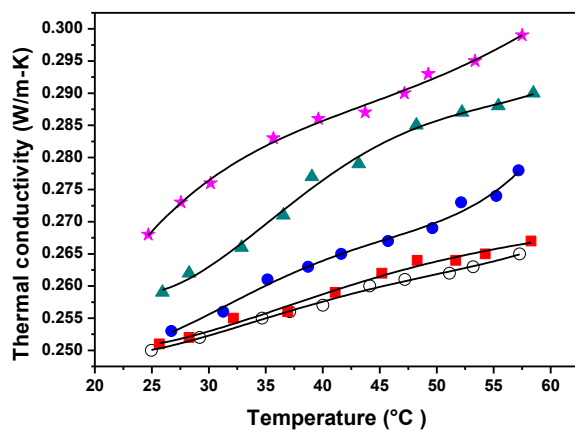
Before thermal conductivity of $\text{Al}_2\text{O}_3/\text{DW}/\text{EG}$ nanofluids was measured, the thermal conductivity of pure distilled water and ethylene glycol was measured at temperatures from 25 °C to 60 °C. Then, the measured data were compared with the reference data presented in the standard text book [13]. The results show relatively good occurrence between the measured value and the uncertainty of the thermal conductivity measurement is around 5%. Experimental results from researchers have shown that the KD2-Pro' KS-1 sensor can make accurate measurements in water and aqueous solutions up to about 60 °C. Above this temperature, the viscosity of the water becomes too low and free convection begins to affect the measurement.

The thermal conductivity as a function of volume fraction and temperature for $\text{Al}_2\text{O}_3/\text{DW}$, $\text{Al}_2\text{O}_3/\text{EG}$ and $\text{Al}_2\text{O}_3/\text{DW}(75\%)/\text{EG}(25\%)$ based nanofluids is respectively shown in Figure 1 (a), (b) and (c). The thermal conductivity of the nanofluid is observed to increase with an increase in temperature and particle volume fraction. The minimum enhancement of approximately 1% for $\Phi = 0.1$ vol% and a maximum enhancement of 5 – 6 % for 1.0 vol% are observed at an average room temperature. The current experimental data agree well with the measured data of Das et al. [10]. A linear relationship between the thermal conductivity and volume fraction can be attributed to large regions of particle-free liquid with high thermal resistances created by highly agglomerated nanoparticles. The relationship between the thermal conductivity enhancement and volume fraction is usually nonlinear for nanoparticles with a high aspect ratio [8].

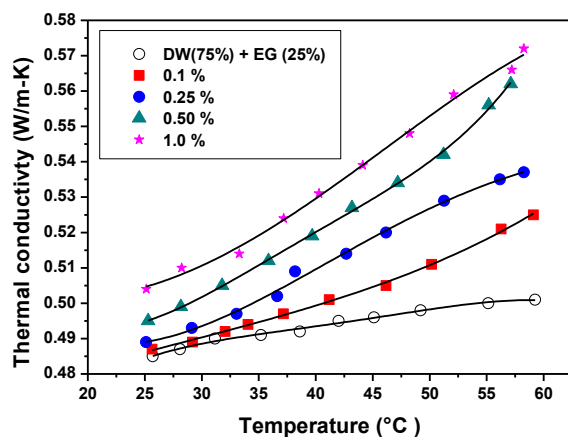
In present work, there is an average increase of 6% to 12% in thermal conductivity from 25 °C to 60 °C when compared with pure water for the same temperature. Different groups measured thermal conductivity at different temperatures. Das et al. [10] varied temperature in the range of 21°C to 51 °C demonstrating an enhancement of 2% to 10% for the particle load of 2.0 vol%, which is in agreement with the present work. The authors suggested that strong temperature dependence of nanofluid thermal conductivity is due to the motion of the particles. Murshed et al. [14] showed that at a temperature of 60 °C, the effective thermal conductivity of Al_2O_3 (80 nm)/EG based nanofluid increases by about 9% and 12% for nanoparticle volumetric loading of 0.55 and 1.0% respectively, which is also in close agreement with the present work. And there is very few studies reported on fluid mixture.



(a)



(b)

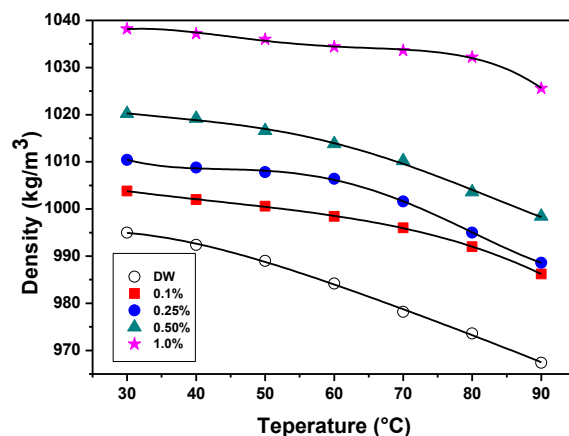


(c)

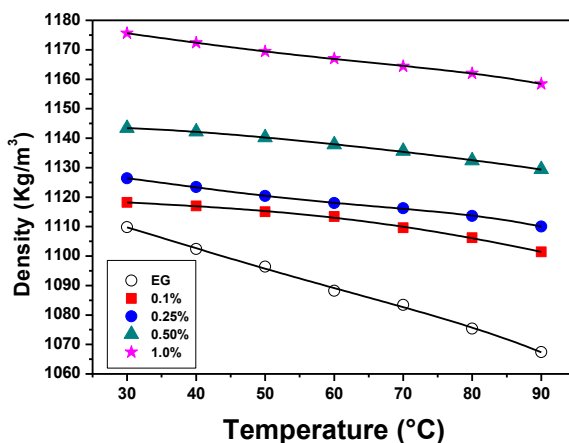
Figure 1 Variation of Thermal conductivity with temperature for (a) Al₂O₃/DW, (b) Al₂O₃/EG and (c) Al₂O₃/ DW (75%) + EG (25%) based nanofluids

B. Viscosity and density measurement

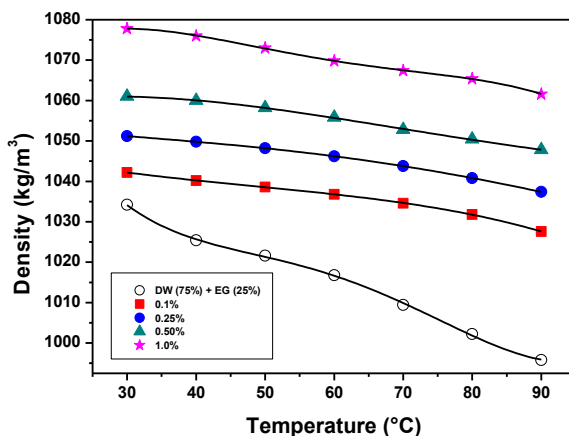
The viscosity and density as a function of volume fraction and temperature for $\text{Al}_2\text{O}_3/\text{DW}$, $\text{Al}_2\text{O}_3/\text{EG}$ and $\text{Al}_2\text{O}_3/\text{DW}(75\%)/\text{EG}(25\%)$ based nanofluids are shown in Figure 2 (a), (b), (c) and Figure 3 (a), (b), (c). The results indicate that the viscosity of nanofluids increases with increasing particle volume fraction and decreases with increasing nanofluid temperature. A minimum increase of 1% and a maximum increase of 5% in density are reported with the nanoparticle volume fraction at room temperature.



(a)



(b)



(c)

Figure 2 Variation of Density with temperature for (a) $\text{Al}_2\text{O}_3/\text{DW}$, (b) $\text{Al}_2\text{O}_3/\text{EG}$ and (c) $\text{Al}_2\text{O}_3/\text{DW}(75\%) + \text{EG}(25\%)$ based nanofluids

At 0.1% volume fraction there is an increase in viscosity from 4% - 7%. But for 1.0% volume fraction, the increase in viscosity of DW, EG and DW (75%) + EG (25%) based nanofluids are 60%, 40% and 21% respectively. The results for DW based nanofluids are in close agreement with the work of Suresh *et al.* [15]. The average decrease in density and viscosity is 1% – 3% and 58% – 76% respectively from 30 °C to 90 °C. This result is accepted as the general characteristics of fluid i.e. density and viscosity decreases with temperature. Similar trends have also been observed in other varieties of nanofluids [2, 16].

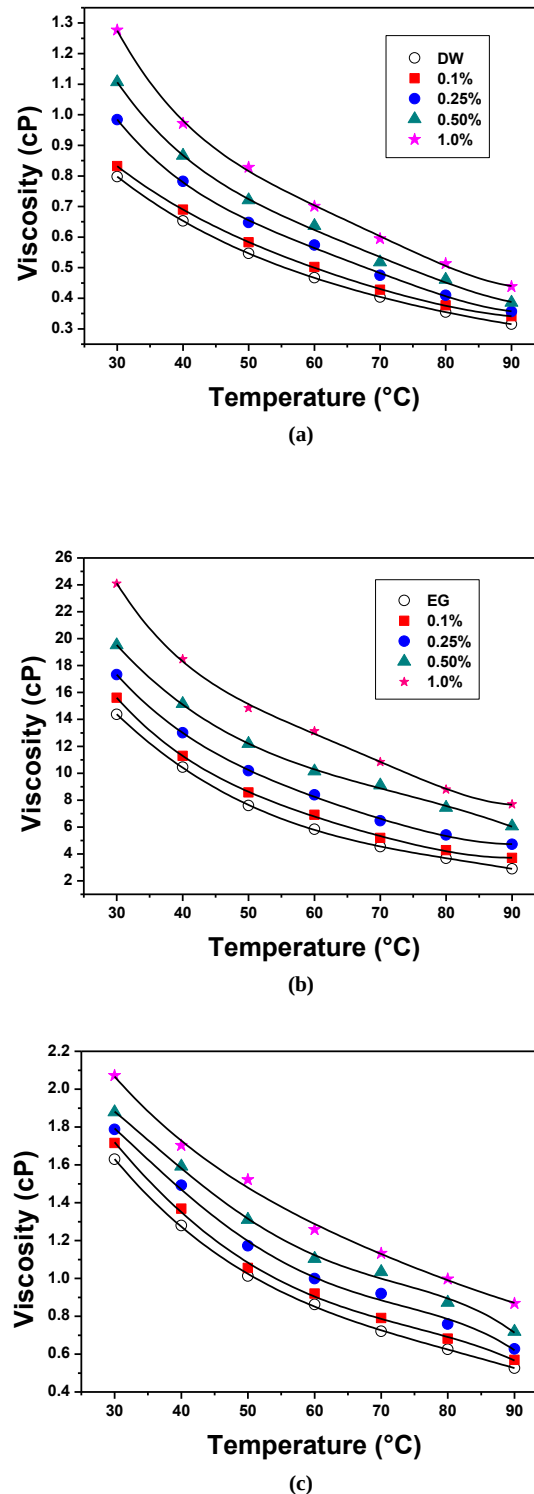


Figure 3 Variation of Viscosity with temperature for (a) $\text{Al}_2\text{O}_3/\text{DW}$, (b) $\text{Al}_2\text{O}_3/\text{EG}$ and (c) $\text{Al}_2\text{O}_3/\text{DW (75\%)} + \text{EG (25\%)}$ based nanofluids

IV. Conclusion

In the present study, the effective thermal conductivity, viscosity and density of $\text{Al}_2\text{O}_3/\text{DW}/\text{EG}$ based nanofluids with particle volume fraction of 0.1, 0.25, 0.50 and 1.0 vol % were investigated experimentally at different temperatures. The results show that the relative thermal conductivity of nanofluid increases with particle volume fraction and temperature. In contrast, the viscosity and density of nanofluids significantly decreases with temperature and increases with particle volume fraction. The effect of temperature on the enhanced thermal conductivity of nanofluids is important for theoretical understanding and needs to be considered for model development. The enhancement of viscosity may diminish the effectiveness of the nanofluids in practical applications. Finally, it is inferred from this study that the thermophysical properties should be considered as important parameters with the use of nanofluids for high-temperature applications.

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