# Thermophysical properties of methanol based $Al_2O_3$ nanofluids

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ABSTRACT

In this study, different volume concentrations (0.05, 0.10, 0.15, 0.20 and 0.25 vol%) of cylindrical shaped $Al_2O_3$ nanoparticles (50 nm length and 8 nm diameter) were suspended in methanol to produce methanol based nanofluid (MBNF). The nanofluid was prepared by using an ultrasonic homogenizer without any surfactants. Thermal conductivity ($k$), viscosity ($\mu$), density ($\rho$) and specific heat ($C_p$) of the nanofluid were measured for a wide range of temperatures (5, 10, 15, 20 and 25 °C). The $k$ values in the range of 0.207–0.234 W/mK, $\mu$ values in the range of 0.70–0.94 mPas, $\rho$ values in the range of 791–814 kg/m$^3$ and $C_p$ values in the range of 1.024–1.416 J/g °C were observed as the volume concentration increased from 0.05 to 0.25 vol% with the temperature rising from 5 to 25 °C. The results showed that thermal conductivity, viscosity and density increased while specific heat decreased with increase in $Al_2O_3$ particle concentration. Besides, thermal conductivity and specific heat increased while viscosity and density decreased with increase in temperature.

## 1. Introduction

Heat transfer fluids that are energy efficient are highly sought after for thermal systems. A nanofluid is a new type of heat transport fluid containing dispersed solid nanoparticles (typically 1–100 nm) [1]. Nanofluids have attracted the attention of researchers owing to their enriched thermophysical properties compared to traditional fluids. The properties such as thermal conductivity, specific heat, density and viscosity play significant roles in improving the overall heat transfer performance of thermal devices. Nanofluids requires lower pumping power, possess higher surface area and dispersion stability apart from higher ability for clogging the particles compared to base fluids. Therefore, nanofluids can potentially be used in a wide range of applications where heat transfer is involved such as engines, electronics instruments, transformer oil, heat exchanging devices, solar water heater, diesel generator, chillers and refrigeration system [2].

Thermal conductivity is one of the most important parameters for investigating heat transfer enhancement of nanofluids [3,4]. Numerous experimental and theoretical models on enhancement of thermal conductivity have been developed [5,6]. Different parameters such as particle type, particle shape, particle size, base fluids properties and operating temperature also influence thermal conductivity of nanofluids [7]. Pang et al. [8] measured thermal conductivity of $Al_2O_3$–methanol nanofluids at 293.15 K. Their result showed that thermal conductivity increased with increase in particle volume concentrations and the enhancement was up to 10.74% at 0.5 vol%. Moreover, Pang et al. [9] experimentally investigated the thermal conductivity enhancement of $Al_2O_3$ nanofluids of a mixed aqueous solution of NaCl and methanol. They observed an enhancement up to 6.5% for 10 wt% NaCl with 40 vol% $CH_3OH$ at 0.1 vol% of $Al_2O_3$ nanoparticles

Viscosity is one of the most crucial factors in heat transfer and fluid flow applications. It measures interfacial friction, which is the internal resistance of fluid layers. It is an important parameter for all thermal applications involving fluid flow [10]. Nguyen et al. [11] experimentally investigated the volume concentration and temperature effect on viscosity of $Al_2O_3$–water nanofluids. Their result showed that viscosity increased with volume concentration and decreased with increase in temperature. The same was also observed by Wang et al. [12] measured viscosity of $Al_2O_3$–water nanofluids and showed 20–30% of augmentation compared to base fluids water at 3 vol%.

Density is the other important property due to its effects on friction factor, pump loss, Reynolds number, Nusselt Number, thermal diffusivity as well as heat transfer coefficient of a heat transfer fluid. However, only a limited number of studies have been conducted on density of nanofluids. Sommers et al. [13] observed a linear relationship between density and particle concentration for $Al_2O_3$–propanol nanofluid. Correspondingly, Teng et al. [14] found that the density of alumina $Al_2O_3$–water nanofluid increased with

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**Nomenclature**

| | |
|---|---|
| MBNF | methanol based nanofluids |
| $m$ | mass |
| $k$ | thermal conductivity (W/m K) |
| *vol.* | volume |
| $C_p$ | specific heat (J/g °C) |

*Greek Symbols*

| | |
|---|---|
| $\varphi$ | volume concentration (%) |
| $\rho$ | density (kg/m$^3$) |
| $\mu$ | viscosity (mPas) |

*Subscripts*

| | |
|---|---|
| *np* | nanoparticle |
| *nf* | nanofluid |
| *bf* | base fluid |

volume concentrations (0.5–1.5 wt%) and decreased with increase in temperature (10–40 °C).

Specific heat is also a frequently studied parameter in the studies of energy performance of nanofluids. Specific heat capacity is the amount of heat needed to change the temperature of a sample by a certain degree. Vajjha and Das [15] examined the specific heat of $Al_2O_3$ nanoparticles for a mixture of 60–water: 40–ethylene glycol. Their result showed that specific heat of the nanofluid increased with both volume concentration and temperature. On the other hand, Tang et al. [14] also determined the specific heat of $Al_2O_3$–water nanofluid but found it increasing with temperature and decreasing with volume concentration.

Firouzfar et al. [16] used silver– methanol nanofluid in thermosyphon heat exchanger to examine the effectiveness of saving energy compared to pure methanol in an air conditioning system. Therefore, methanol based nanofluids can potentially enhance the heat transfer rate of heat exchangers and save energy compared to methanol. The main objective of this study is to experimentally investigate the thermophysical properties (i.e. thermal conductivity, viscosity, density and specific heat) of $Al_2O_3$–methanol nanofluids. This experimental investigation was conducted at different volume concentrations and temperatures. This study promoted the use of methanol based nanofluids in different types of heat pipes such as flat plate, conventional, vapor–dynamic thermosyphons, sorption, micro/miniature heat pipes at a temperature range of 200–500 K [17,18] and HVAC (Heating, Ventilation and Air conditioning) system. Moreover, Lee et al. [19] and Pineda et al. [20,21] examined the effects of methanol based nanofluids on enhancement of absorption of carbon dioxide ($CO_2$). Based on the available literatures, there are a few literatures about thermal conductivity of methanol based nanofluids [8,9,22]. To the best of the authors' knowledge, there is no such study on viscosity, density and specific heat of methanol based nanofluids. Therefore, the present study helps identify the effect of nanoparticle on thermophysical properties of MBNF.

## 2. Experimental procedure

### 2.1. Materials and preparation of nanofluids

$Al_2O_3$ (purity 99.5%) nanoparticles procured from Sigma Aldrich, USA were used for this investigation. The nanoparticles structure and composition were characterized with Field Emission Scanning Electron Microscopy (FESEM). AURIGA (made by Zeiss, Germany) FESEM was used in this study. Fig. 1 (a) shows the FESEM image of $Al_2O_3$ nanoparticle. The $Al_2O_3$ nanoparticles are about 50 nm long and 8 nm in diameter. This nanoparticle was selected because it is chemically stable, easily available and produced in a large scale in the industry. Methanol ($CH_3OH$) supplied by R&M Chemical with a purity of 99.9% was used as a base fluid.

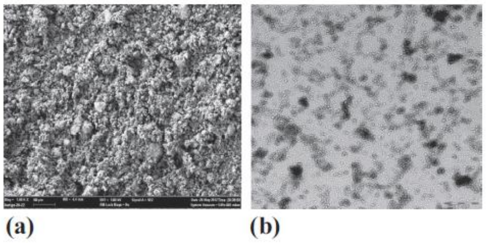

Fig. 1. (a) FESEM image of $Al_2O_3$ nanoparticles (b) TEM image of $Al_2O_3$–methanol.

**Table 1**
Experimental conditions.

| | |
|---|---|
| Base fluid | Methanol |
| Nanoparticle | $Al_2O_3$ |
| Nanoparticle type | Cylindrical |
| Nanoparticle size (nm) | Long 50 nm diameter 8 nm |
| Volume concentration (vol%) | 0.05, 0.01, 0.15, 0.20 and 0.25 |
| Ultra-sonicator | Time [min] 120<br>Power [W] 500<br>Frequency [kHz] 20<br>Pulse [s] 2<br>Term [s] 2 |

The nanoparticle volume concentration was calculated using Eq. (1).

$$\text{Volume concentration, } \phi = \left(\frac{m_{np}/\rho_{np}}{m_{np}/\rho_{np} + m_{bf}/\rho_{bf}}\right) \quad (1)$$

The two-step method was applied to prepare MBNF at different volume concentrations. Firstly, the nanoparticles were suspended into the base fluid (methanol) followed by shaking in the incubator for 30 min at 150 rpm. The nanoparticles were then dispersed in the mixture using an ultra-sonication homogenizer so that the nanoparticles were uniformly and evenly distributed. The details of experiment conditions are summarized in Table 1. The microstructure of methanol based nanofluids was analyzed after 24 h by using Transmission Electron Microscopy (TEM) System Performance of 120 kV at magnification scale of 20,000. TEM LIBRA 120, made by Zeiss, Germany was used to analyze the TEM image. Fig. 1 (b) shows the TEM image of $Al_2O_3$–methanol nanofluids. It is observed from Fig. 1 (b) that the nanoparticles in this study were dispersed well and less agglomeration were detected in nanofluids.

### 2.2. Stability of nanofluids

The stability of methanol based nanofluids was inspected by Ultra Violet–Visible spectrophotometer (UV–Vis). Lambda 35 UV–Vis Spectrophotometer (made by Perkin Elmer) with an absorption range of 190 nm to 1100 nm was used in this study. The inspection range was within the wavelength range of 200–800 nm. Use of Spectrophotometer for appraising the stability of nanofluids has first been suggested by Jiang et al. [23].

Fig. 2 shows the stability of $Al_2O_3$–methanol nanofluids after ultrasonic agitation. It also shows that the peak absorbance of $Al_2O_3$ nanoparticle suspension in methanol occurred at 223 nm. The absorption range of the nanofluid was 1.25. The UV–visibility was measured after seven days and there was no distinguished difference between the density of freshly prepared nanofluids and the one after seven days.

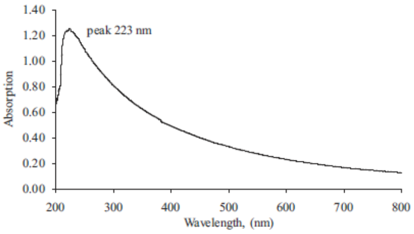

Fig. 2. UV–Vis spectrum of $Al_2O_3$–methanol nanofluids.

### 2.3. Thermal conductivity

Thermal conductivity was measured by using a $KD_2$ pro thermal conductivity meter (Made in Decagon, USA). This device measures thermal conductivity by transient hot wire method over the range of 0.02 to 2.00 W/m K. The accuracy of the equipment is ± 0.001%. Thermal conductivity of $Al_2O_3$–methanol nanofluids at different volume concentrations (0.05, 0.01, 0.15, 0.20 and 0.25 vol%) was measured at temperatures of 5, 10, 15, 20 and 25 °C respectively. All the data were recorded for three times and the corresponding average values were taken. The measured values of methanol based nanofluids were then compared with the values obtained from the existing models. Timofeeva et al. [24] investigated the effects of particle shape on thermophysical properties of $Al_2O_3$ nanofluids and developed a correlation between thermal conductivity and particle shape factor, as shown below:

$$k_{nf} = (1 + (C^{shape} + C^{surface}))k_{bf} = (1 + C_k\phi)k_{bf} \tag{2}$$

where, $C_k$ is the thermal conductivity enhancement coefficient of nanofluids suspension. The value for cylindrical shape is 3.95.

### 2.4. Viscosity

The most widely used LVDV programmable viscometer was used for measuring the viscosity of low-viscous nanofluids. A Brookfield (LVDV III ultra–programmable) viscometer was used in this experiment to measure the viscosity at different volume concentrations and temperatures. The device was connected to a computer to collect and store data. The spindle of the viscometer was submerged into the nanofluid. The viscous is developed against the spindle due to deflection of the calibrated spring with the aid of Ultra low adapter (ULA) attached with the main equipment The viscosity of $Al_2O_3$–methanol at various volume concentrations (0.05, 0.10, 0.15, 0.20 and 0.25 vol%) was measured at temperatures of 5, 10, 15, 20 and 25 °C, respectively. A refrigerated circulating bath was used to control temperature. All data were recorded three times and the corresponding averaged values were plotted. The measured values of methanol-based nanofluids were then compared with those obtained through Timofeeva et al. [24]'s model for cylindrical nanoparticle, which is as follows:

$$\mu_{nf} = (1 + 13.5\phi + 904.4\phi^2)\mu_{bf} \tag{3}$$

### 2.5. Density

The density of methanol based nanofluids was measured by using a density meter, KEM-DA 130 N (Kyoto, Japan). This device measures a density range of 0 to 2000 kg/m$^3$. The accuracy of the equipment is ± 0.001% kg/m$^3$. The density was measured at different temperatures and volume concentrations in his study. All data were recorded for three times and the corresponding averaged values were plotted. As there is no existing literature related to density of methanol based nanofluids, the experimental values were then compare with that obtained from the most used Pak and Choi [25]'s model, which is as follows:

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \rho_{np}\phi \tag{4}$$

### 2.6. Specific heat

The specific heat of methanol based nanofluids was measured by using Differential Scanning Calorimeter (model: DSC 4000, Perkin Elmer, USA). The specific heat was measured for every 0.05 vol% increase within the range of 0.05–0.25 vol% and every increase of 5 °C within the temperature range of 5–25 °C. All data were recorded for three times and the corresponding average values were plotted. Then the experimental data were compared with that from Xuan and Roetzel's [26] equation which is expressed as follows:

$$c_{pnf} = [\{(1 - \phi)\rho_{bf}c_{pbf} + \phi\rho_{np}c_{pnp}\}\rho_{nf}] \tag{5}$$

where the value of $\rho_{nf}$ is calculated by using Eq. (4).

## 3. Result and discussion

### 3.1. Thermal conductivity

The thermal conductivity of $Al_2O_3$–methanol nanofluids at various volume concentrations and temperatures is depicted in Fig. 3. The figure shows that thermal conductivity increased with volume concentrations. At 5 °C, the thermal conductivities were 1.72%, 2.70%, 4.18%, 5.16% and 5.65% for 0.05, 0.10, 0.15, 0.20 and 0.25 vol% respectively, which were higher than that of base fluids (methanol). This happened because the particles had higher

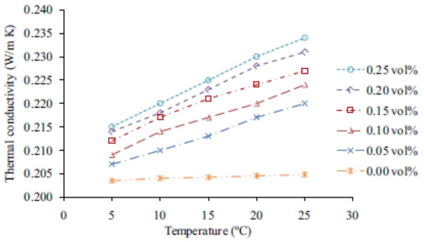

Fig. 3. Thermal conductivity of $Al_2O_3$–methanol as a function of temperature and volume concentration.

particle surface to volume ratio. The enhancement mechanism may be due to particle to particle interaction, particle cluster and Brownian motion of the particles [27]. Fig. 3 also shows that temperature affected thermal conductivity enhancement. Thermal conductivity increased with temperature. The thermal conductivities at 25 °C was higher than that at 5 °C, which were 7.45%, 9.40%, 10.87%, 12.82% and 14.29% at the same volume concentration. The highest enhancement was found to be 14.29% at 25 °C for 0.25 vol%. It was because increased temperature decreased viscosity which intensified the Brownian motion and the effects of nanoconvection.

The thermal conductivity of $Al_2O_3$–methanol nanofluids at 25 °C was then compared with that obtained values from the existing correlation, as shown in Fig. 4. There is no experimental data available for cylindrical nanoparticles suspended into methanol. The experimental result was found to be 13.54% higher thermal conductivity than the existing correlation value obtained by Timofeeva et al. [24]. This was possibly attributed to difference in particle size, preparation method, particle distribution, particle cluster and interfacial layer between particle/fluid [28].

### 3.2. Viscosity

The viscosity of $Al_2O_3$–methanol nanofluids, as a function of various volume concentrations and temperatures is illustrated in Fig. 5. It shows that viscosity of nanofluids increased with volume concentration. At 5 °C, the viscosities were 14.47%, 20.39%, 21.38%, 22.70% and 23.68% higher than that of the base fluid for 0.05, 0.10, 0.15, 0.20 and 0.25 vol% respectively. Besides, Fig. 5 shows that viscosity decreased with increases of temperature. The viscosity was 0.77 mPas at 25 °C and 0.94 mPas at 5 °C. This was caused by the weakening adhesion force of the particle. When temperature increases, the interaction time between neighboring molecules of a fluid decreases due to increase in the velocities of individual molecule. Higher temperature also influences the Brownian motion of nanoparticles and hence decreases the viscosity of nanofluids [29].

Fig. 6 shows the experimental values of viscosity compared to the existing correlation at 25 °C. It was observed that the measured viscosity in this experiment was significantly higher than that obtained from the model developed by Timofeeva et al. Thus, the model are not suitable for evaluating the viscosity of methanol based nanofluids [30]. It was because these models were generalized models developed to estimate the viscosity of a suspension. Therefore, agglomeration cluster of nanoparticles can be considered as one of the reasons for higher viscosity.

### 3.3. Density

The density of $Al_2O_3$–methanol nanofluids, as a function of different temperatures and volume concentrations is shown in Fig. 7. The results showed that the density of methanol based nanofluids increased with volume concentration but decreased with temperature. The density of nanofluids was higher than the base fluids. For example, at 5 °C, the density was 807.29 kg/m$^3$ for 0.05 vol% and 814.42 kg/m$^3$ for 0.25 vol%. At volume concentration of 0.25 vol%, the density was 795.45 kg/m$^3$ at 25 °C and 814.42 kg/m$^3$ at 5 °C. When temperature increase the molecules move further apart as their kinetic energy increases. The highest increase was observed for 0.25 vol% and 5 °C. Similarly, the same result was found for all volume concentration in this experiment. This was due to dispersion of high density nanoparticles in the base fluids.

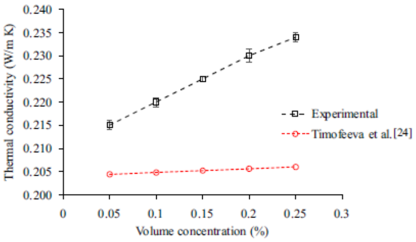

**Fig. 4.** Experimental values of thermal conductivity compared with the values from existing correlation.

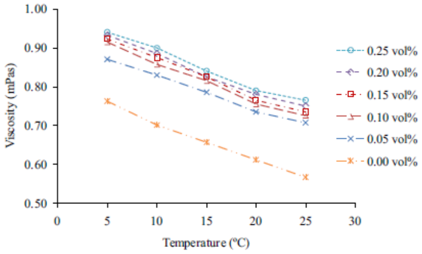

**Fig. 5.** Viscosity of $Al_2O_3$–methanol as a function of temperature and volume concentration.

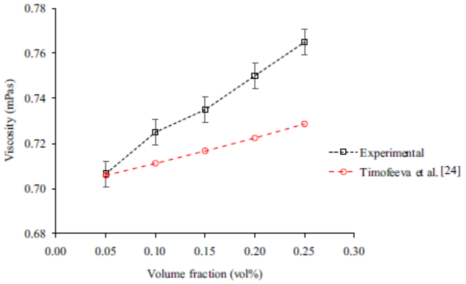

**Fig. 6.** Experimental values of viscosity compared to the values from the existing correlation.

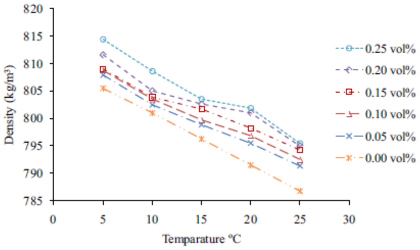

**Fig. 7.** Density of $Al_2O_3$–methanol as a function of temperature and volume concentration.

The experimental value of density of methanol based nanofluids at 25 °C was compared with the model given by Pak and Choi [25] shown in Fig. 8. The experimental value was slightly higher than the existing correlation. The highest deviation of 0.3% from the existing correlation was observed. This was due to the difference in the density of the base fluids and water based nanofluids whereas Pak and Cho's model was proposed for the latter.

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