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An experimental study on viscosity of alumina-engine oil: Effects of temperature and nanoparticles concentration

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A R T I C L E I N F O

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A B S T R A C T

In the present study, the dynamic viscosity of alumina-engine oil nanofluid in different solid volume fractions and temperatures was experimentally investigated. The nanofluid samples were prepared in the solid volume fractions of 0.25%, 0.5%, 0.75%, 1%, 1.5% and 2% under the temperature range of 5 to 65 °C. The measurements were carried out by CAP 2000+ Viscometer, supplied by Brookfield of the USA. Using the experimental data, new correlations for predicting the dynamic viscosity of alumina-engine oil at different temperatures were proposed. The experiment results at different shear rates showed that all nanofluid samples exhibit the Newtonian behavior. The results also revealed that the viscosity of the nanofluid increases with the solid volume fraction. Moreover, it has been found that with increasing temperature, the viscosity of nanofluids decreases, and it was more tangible at the lower temperatures. The comparison between experimental findings and theoretical models showed that these models failed to predict the correct values of the viscosity of the nanofluids at all solid volume fractions. The experimental data also indicated that the maximum viscosity enhancement of nanofluid was 132% compared with that of base fluid.

1. Introduction

The engine oil is a type of lubricants and coolants that is used in many engineering applications. The engine oils diminish the friction between moving parts. These also may remove heat away from moving parts. The lower viscosity causes easier oil pumping, while higher viscosity causes an increase in bearing load capability. Therefore, using suitable engine oil can lead to higher efficiency and low fuel consumption. To improve the heat transfer rate of working fluids (e.g., oil, water and ethylene glycol), many researchers added the nanoparticles into these fluids, called nanofluids [1–8]. Due to the increasing use of nanofluids instead of common fluids, the measurement of their thermophysical properties is an important subject. Based on the literature, alumina (Al_2O_3) nanoparticles are one of the most common particles that are used to prepare the nanofluids. Many researchers have reported that the thermal conductivity of alumina based nanofluids is a function of nanoparticles concentration, temperature, size and shape of nanoparticles, and the base fluid [9–14].

However, when the nanoparticles are added to the base fluids, the dynamic viscosity is changed. Many studies have been done on the viscosity, and all of them have shown that the viscosity of nanofluids is a function of shape and size of nanoparticles, temperature and concentration of nanoparticles [15–20]. A summary of experimental studies on the dynamic viscosity enhancement of nanofluids containing Al_2O_3 nanoparticles has been listed in Table 1. In these works, the researchers focused on the effects of temperature, nanoparticles concentration, and size of nanoparticles on the dynamic viscosity of nanofluids.

In some aforementioned studies, the experiments were compared with the classical models. One of the classical models was presented by Batchelor [31]. He presented a correlation to predict the viscosity of nanofluids with spherical shape nanoparticles, applicable for volume concentration up to10%, which is given as

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 + 2.5\phi + 6.2\phi^2\right) \quad (1)$$

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Table 1
A summary of experimental studies on the dynamic viscosity enhancement of nanofluids containing Al_2O_3 nanoparticles.

Author	Base fluid	Size (nm)	Temp. range (°C)	Volume fraction (%)	Max. enhancement (%)
Masuda et al. [21]	Water	13	32–87	1.30–4.30	300
Pak and Cho [22]	Water	13	25	0.99–10	19,900
Wang et al. [23]	Water	28	Room	0–6.0	85
	EG			0–3.5	40
Das et al. [24]	Water	38	20–60	1–4	46
Heris et al. [25]	Water	20	24	0.2–3.0	40
Nguyen et al. [26–27]		36,47	Ambient to 75	0–13	450
Lee et al. [28]	Water	30	21–39	0.01–0.3	3
Kole and Dey [29]	EG/water	50	10–80	0.1–3.5	300
Tavman et al. [30]	Water	30	20–50	0.5–1.5	80

Moreover, the classical model using liquid particle interaction for volume concentration less than 1% was proposed by Einstein [32] and is known as follows:

$$\frac{\mu_{nf}}{\mu_{bf}} = (1 + 2.5\phi) \tag{2}$$

Furthermore, Wang et al. [23] suggested a model for estimating the viscosity of nanofluids, which is expressed as

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 + 7.23\phi + 123\phi^2\right) \tag{3}$$

In Eqs. (1)-(3), μ is the dynamic viscosity and ϕ is the solid volume fraction nanoparticles. Moreover, the subscripts of n_f and b_f indicate respectively nanofluid and base fluid.

Because of several applications of engine oil, improving its thermophysical properties is one of the key factors for industrial requests. Accordingly, the study of the rheological behavior of engine oil has attracted the interest of researchers. For example, Vakili-Nezhaad et al. [33] described the effect of multi-walled carbon nanotubes on the viscosity index of lube oil cuts. Vasheghani et al. [34] considered the effect of Al_2O_3 phases on the enhancement of thermal conductivity and viscosity of nanofluids in engine oil. Thermal and rheological properties of oil-based nanofluids from different carbon nanostructures were examined by Ettefaghi et al. [35,36]. However, there are a few works on the oil viscosity.

In this work, an experimental study on viscosity of alumina-engine oil by considering the effects of temperature and nanoparticles concentration is performed. The nanofluid samples were prepared at the solid volume fractions of 0.25%, 0.5%, 0.75%, 1%, 1.5% and 2%. The experiments were carried out under the temperatures of 5 °C, 15 °C, 25 °C, 35 °C, 45 °C, 55 °C and 65 °C. The effects of temperature and concentration of nanoparticles on the dynamic viscosity of nanofluids were examined by a viscometer. Moreover, the measured viscosities of nanofluids are compared with those obtained from the theoretical models. Finally, using experimental data, for engineering applications, new correlations are proposed to predict the dynamic viscosity of the nanofluid.

2. Experiments

In the present study, the 10 W-40 engine oil was used as the base fluid. Al_2O_3 nanoparticles with average diameter size of 20 nm were dispersed into the oil. In order to obtain average diameter size of the nanoparticles, the TEM image of nanoparticles is shown in Fig. 1.

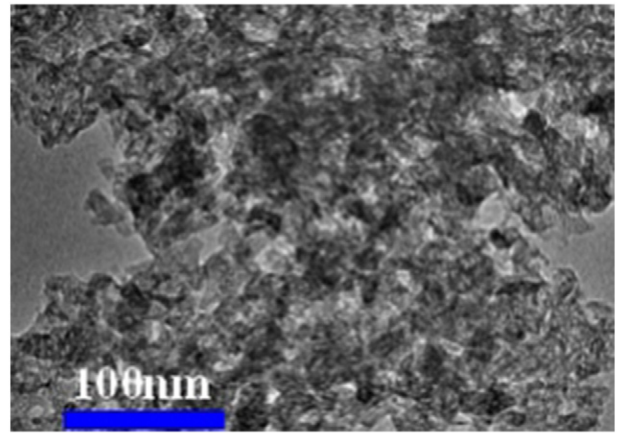

Fig. 1. TEM image of alumina nanoparticles.

The specification of aluminum oxide nanoparticles is presented in Tables 2.

The nanofluid samples with the solid volume fractions of 0.25%, 0.5%, 0.75%, 1%, 1.5% and 2% were prepared by a two-step method. In order to make the most stable and homogenous samples, after magnetic stirring for 2.5 h, the samples were exposed to an ultrasonic processor (Hielscher Company, Germany) for 7 h. The photograph of samples is shown in Fig. 2.

In order to measure the dynamic viscosity of the alumina/engine oil nanofluids, the CAP 2000 + Viscometer, supplied by Brookfield of the USA, was used. The Viscometer is medium to high shear rate instrument with Cone Plate geometry and integrated temperature control. Experiments were performed at various rotational speeds. The ranges of accuracy and repeatability of the Viscometer are ±2.0% and ±0.5%, respectively, of the full scale viscosity range. Before the measurement of dynamic viscosity of nanofluids, the Viscometer was tested with pure engine oil at room temperature. Based on the results, the "relative viscosity" is defined as the ratio of the dynamic viscosity of the nanofluids to dynamic viscosity of base fluid $(\frac{\mu_{nf}}{\mu_{bf}})$.

3. Results and discussion

The measurements of dynamic viscosity of Al_2O_3/engine oil nanofluids were carried out at temperature ranges from 5 °C to 65 °C for different samples with the volume fractions of 0.25%, 0.5%, 0.75%, 1%, 1.5% and 2%.

In order to understand the Newtonian or non-Newtonian behavior of the samples, the dynamic viscosity of nanofluids versus shear rate for different solid volume fractions at various temperatures is presented in Fig. 3. The experiment results display a slight decrease in the viscosity of samples with increasing the shear rate. This behavior may be related to shear heating considerations, which occur in great

Table 2
Specification of aluminum oxide nanopowder (gamma)-hydrophilic.

Purity	99 + %
APS	20 nm
SSA	>138 m^2/g
Morphology	nearly spherical
Color	White
Specific heat capacity	880 J/(kg-K)
Density	3890 kg/m^3