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Research Paper

Effect of suspending hybrid nano-additives on rheological behavior of engine oil and pumping power

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HIGHLIGHTS

- Preparing SAE40 based nanofluids containing Al_2O_3-MWCNTs hybrid nano-additives.
- Performing tests in concentration range of 0–1.0% and temperature range of 25–50 °C.
- All hybrid nanofluid samples were Newtonian fluid at all temperatures considered.
- Performing sensitivity analysis for viscosity using experimental findings.
- Proposing a new correlation to predict the viscosity of the hybrid nanofluid.

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ABSTRACT

In this paper, the rheological behavior of engine oil containing various quantities of hybrid nano-additives has been examined. The experiments were performed in the solid volume fraction range of 0–1.0% and temperatures ranging from 25 °C to 50 °C. Viscosity measurements, at the shear rate range of 1333–13,333 s^{-1}, showed that Al_2O_3-MWCNTs/SAE40 hybrid nanofluid had a Newtonian behavior at all solid volume fractions and temperatures considered. Experimental results also indicated that the viscosity of the hybrid nanofluid increased with increasing nano-additives concentration and decreasing temperature. Results of relative viscosity of the hybrid nanofluid showed that the maximum augmentation of the viscosity was about 46%. Results from sensitivity analysis of viscosity revealed that the viscosity sensitivity to temperature variation is minor, while it is more sensitive to the variations of solid volume fraction. Furthermore, an accurate correlation was proposed to predict the viscosity of the hybrid nanofluids for application in thermal engineering. Finally, the effects of nano-additives on the pumping power for the oil flow have been reported.

1. Introduction

Engine oil is a type of lubricant employed in many engineering applications such as engine generators, power cars, bearings and machines including moving parts. In mechanical systems, the friction between the moving parts diminishes the efficiency by altering the kinetic energy to heat. The chief duty of oils is to reduce friction between parts which move contrary to each other. In addition, the engine oil can cool the parts that are heated due to friction.

The thermal conductivity and viscosity of engine oil are two important properties in cooling and lubricating of mechanical systems, respectively. The viscosity also affects the pumping power and oil flow. It is clear that engine oils with enhanced thermal conductivity can improve the heat transfer rate. One of the methods to improve the thermal conductivity is dispersing nano-additives in liquids, called nanofluids [1]. Many researchers reported that suspending the nano-additives to base fluid significantly enhances the thermal conductivity [2–12]. They revealed that the amount of the enhancement depends on various parameters including temperature and concentration.

However, when the nano-additives are suspended in a base fluid to improve its thermal conductivity, the viscosity is also affected. Many analytical and experimental studies on rheological behavior of fluids containing nano-additives have been performed. For example, Batchelor [13], Drew and Passman [14] and Wang et al. [15] suggested analytical models for estimating the viscosity of nanofluids. Moreover, a summary of experimental studies on the viscosity of nanofluids is presented in Table 1. These works have

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Nomenclature

d	tube diameter (m)
f	Fanning friction factor
h	vertical position (m)
K	pressure loss coefficient
m	mass (kg)
P	power (J/s)
T	temperature (°C)
Q	volumetric flow rate (m^3/s)
V	velocity (m/s)
Greek letters	
Δp	pressure drop (pa)
φ	solid volume fraction (%)
μ	dynamic viscosity (kg/ms)
ρ	density (kg/m^3)
Subscripts	
bf	base fluid
Exp	experimental data
nf	nanofluid
Pred	predicted value
s	solid particles
MWCNTs	multi walled carbon nanotubes
Al_2O_3	alumina
SAE40	engine oil

Table 1
A summary of experimental studies on the viscosity of nanofluids.

Authors	Additives	Base fluid	Temperature (°C)	Concentration (%)
Duangthongsuk and Wongwises [16]	TiO_2	Water	15–35	0.2–2 vol
Sahoo et al. [17]	Al_2O_3	EG-water	(−35)–50	1–10 vol
Kole and Dey [18]	Al_2O_3	Water	10–50	0.1–1.5 vol
Kole and Dey [19]	CuO	Gear oil	10–80	0.5–2.5 vol
Bobbo et al. [20]	SWCNT-TiO_2	Water	10–80	0.01–1 wt
Sundar et al. [21]	Fe_3O_4	EG-water	0–50	0–1 vol
Vakili-Nezhaad and Dorany [22]	SWCNT	Lubricant	25–100	0.01–0.2 wt
Vajjha and Das [23]	Al_2O_3 CuO SiO_2	EG-water	20–90	10 vol 6 vol 10 vol
Yiamsawas et al. [24]	Al_2O_3 TiO_2	EG-water	15–40	0–4 vol
Esfe et al. [25]	MgO	Water	24–60	<1 vol
Esfe and Saedodin [26]	ZnO	EG	25–50	0.25–5 vol
Esfe et al. [27]	MWCNT	Water	25–55	0.05–1 vol
Esfe et al. [28]	DWCNT	Water	27–67	0.01–0.4 vol
Baratpour et al. [29]	SWCNT	EG	30–60	0.0125–0.1 vol
Toghraie et al. [30]	Fe_3O_4	Water	20–55	0.1–3 vol

indicated that the viscosity of nanofluids depends on temperature, size and concentration of nanoparticles.

As mentioned above, improving thermo-physical properties of engine oils is very important for engineering applications. Accordingly, the study of rheological behavior of engine oil has attracted researcher's interest. In this regard, Vakili-Nezhaad and Dorany [31] investigated the influence of temperature and multi-walled carbon nanotube (MWCNT) concentration on the viscosity index of oil theoretically and experimentally. Their experiments were performed under temperatures ranging from ambient to 100 °C and for MWCNT concentrations ranging from 0.01 to 0.2 wt%. They reported that the viscosity increased with an increase in the MWCNT concentration and reducing temperature. Vasheghani et al. [32] added Al_2O_3 nanoparticles to the engine oil and reported that the its viscosity increased about 38%. They also indicated that the nanofluids (up to 3 wt% of the nanomaterial) exhibited a Newtonian behavior. Ettefaghi et al. [33] added different carbon nanostructures to SAE 20W50 engine oil. They evaluated and compare effects of different carbon nanostructures on thermal and rheological properties of engine oil. Their results revealed that the viscosity of oil depended on the type of additive structures. Recently, Cieśliński et al. [34] measured the dynamic viscosity of thermal oil-MWCNT nanofluid. They tested samples with the concentration of 0.001%, 0.005%, 0.01%, 0.05%, and 0.1% by weight. They compared the results with existing models for liquid/solid particles mixtures.

In the continuation of nanofluids research, the researchers have also made effort to use hybrid nanofluid recently, which is prepared by dispersing unlike nano-sized materials either in mixture or composite form. For example, Baghbanzadeh et al. [35] examined the effects of SiO_2-MWCNTs hybrid nano-additives on the thermal conductivity of distilled water. They reported that the maximum and the minimum enhancement of the fluids were related with MWCNTs and SiO_2 nanoparticles, while the enhancement for the hybrid nano-additives was an amount between MWCNTs and SiO_2 nanoparticles. Esfe et al. [36] experimentally investigated the thermal conductivity of hybrid nanofluids by dispersing Cu and TiO_2 nanoparticles in a binary mixture of water/EG (60:40). They measured the thermal conductivity of nanofluid samples in various temperatures ranging from 30 to 60 °C. Their results showed that a maximum enhancement in the thermal conductivity of the nanofluid (45%) was occurred for the sample with solid volume fraction of 2% at temperature of 60 °C. An experimental investigation on the effects of ZnO–TiO_2 hybrid nano-additives on the thermal conductivity ethylene glycol was presented by Toghraie et al. [37]. Their experiments were performed at temperatures ranging from 25 to 50 °C and solid volume fraction range of 0–3.5%. Their results showed that the thermal conductivity of the hybrid nanofluid enhanced up to 35% at solid volume fraction of 3.5%. Esfe et al. [38] also investigated the effects of CNTs–Al_2O_3 hybrid nano-additives on the thermal conductivity of water at various fluid temperatures of at temperatures ranging from 30 to 60 °C. They reported that the thermal conductivity of the hybrid nanofluid enhanced up to 18% at solid volume fraction of 1%.

However, only a few works have been done on viscosity of hybrid nanofluids. In this way, the viscosity of SiO_2-MWCNTs/water nanofluid was investigated by Baghbanzadeh et al. [39]. Their measurements showed that the viscosity of the nanofluid increased with increasing concentration and reducing the temperature. Afrand et al. [40] examined the effects of temperature and nanoparticles concentration on the rheological behavior of Fe_3O_4-Ag/EG hybrid nanofluid. They measured the viscosity of the nanofluid samples at different shear rates in temperature range of 25–50 °C. Their results indicated that the nanofluid samples with solid volume fractions of less than 0.3% showed Newtonian behavior, while the samples with higher solid volume fractions (0.6% and 1.2%) exhibited non-Newtonian behavior. The rheological behavior of MWCNTs-SiO_2/EG-water hybrid nanofluid in