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A novel study on rheological behavior of ZnO-MWCNT/10w40 nanofluid for automotive engines

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ABSTRACT

In the present study, the effects of temperature, solid volume fraction and shear rate on viscosity of ZnO-MWCNT/10w40 hybrid nanolubricant is experimentally investigated. Zinc oxide nanoparticles and multi-walled carbon nanotubes with ratio of 55% to 45% respectively, were dispersed in engine oil, 10w40 type. Viscosity of the samples with solid volume fraction of 0.05 to 1% was measured at the temperatures between 5°C–55°C by Brookfield CAP 2000+ viscometer. The results indicate that the hybrid nanolubricant is shear-thinning non-Newtonian fluid. Power law index was reduced slightly as a result of increasing of solid volume fraction. On the other hand increasing of solid volume fraction was resulted in consistency index increment. A new correlation was proposed in terms of temperature and concentration. By using this correlation viscosity of the hybrid nanofluid can be predicted. This correlation has $R^2 = 0.9822$ and it can predict viscosity of the oil-based nanofluid with acceptable error.

1. Introduction

Engine oil is one of the most important and key factors which can affect durability and cooling of different parts of internal combustion engines, diesel generators and many other mechanical equipment. Using of high quality engine oils as well as appropriate lubrication of movable parts of industrial devices would result in ensured long life and durability of the devices, specifically for internal combustion engines. One the main role of engine oils is to decrease friction between movable parts which are in contact with each other, proper viscosity magnitude which determines the amount of friction between the parts, effectively modify performance of the system. Viscosity and thermal conductivity are two basic parameters of engine oils. With enhancing of oil's viscosity we would be able to increase the capacity of the shear rate acting on the parts; in an internal combustion engine this would help to increase the maximum force that can be applied on the crank shaft [1], furthermore as a result of enhanced magnitude of the viscosity, oil film sticks longer time providing a better protection against friction. Enhancement of engine oils' thermal conductivity improves cooling of movable parts specifically in internal combustion engines. Viscosity and thermal conductivity can be modified by various methods, for doing so; using of metal or metal oxide solid particles is one of the approaches which has attracted many scientists. If the particles being used are smaller than 100 nm, then they are called nanoparticles and dispersion of nano-sized particles in a base fluid leads to a nanofluid. In recent years numerous different types of nanofluids have been prepared by scientists. ZnO, CuO, Fe, Fe_2O_3, MWCNT, $Mg(OH)_2$ and SWCNT [2–10] are examples of the nanoparticles that are used in some of the researches. Nanofluids often divided into three groups of fluids including water based [11–16], Ethylene Glycol based [17–22], oil based [23–30] and various mixtures of these fluids [31–34], water/ethylene glycol for instance. In most of empirical researches on nanofluids characteristics, viscosity [35–40] and thermal conductivity [41–48] are studied. Also many researches have been conducted on measurement of heat transfer coefficient [49–55] of nanofluids. In Table 1, a number of the studies which have been conducted on nanofluids are summarized. The reported results of mentioned studies show that adding nanoparticles to base fluids may have greater viscosity as well as higher thermal conductivity [56–60], these are key characteristics that can provide the basis for the applications of nano-lubricants in cars' engines.

Hemmat esfe et al. [61] empirically studied the effects of nanoparticles diameter on viscosity and thermal conductivity of Fe/water nanofluid, nanoparticles with the sizes of 37, 71 and 98 nm were investigated. The results of their research signified that thermophysical characteristics of the nanofluid was depended to size of nanoparticles and solid volume fraction so that thermal conductivity was enhanced as a result of solid volume fraction increment while increasing in size of nanoparticles had reverse effect of thermal

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Nomenclature

T	Temperature (°C)
w	Weight (gr)

Greeks symbols

$\dot{\gamma}$	shear rate (s^{-1})
μ	dynamic viscosity (poise)
ρ	density (kg/m^3)
τ	shear stress ($dyne/cm^2$)
φ	nanoparticle volume fraction

Subscripts

nf	nanofluid
bf	base fluid

conductivity. Moreover dynamic viscosity of nanofluids would be enhanced as a result of increasing of solid volume fraction and diameter of nanoparticles. Hybrid nanofluid is referred to the nanofluids which have two or more different nanoparticles dispersed in their base fluids. In an experimental research which has been conducted lately by Sander et al. [69], convective heat transfer coefficient and friction of fully developed turbulent flow of MWCNT–Fe_3O_4/water hybrid nanofluid were measured in a cylindrical tube with constant heat flux. The results indicate that Nusselt number was enhanced by 31.10% and pump power were increased by 1.18 times for the nanofluid with 0.3% solid volume fraction. A correlation was offered for predicting Nusselt number and coefficient of friction, this correlation had convenient accuracy. Nano-lubricants and specifically hybrid nano-lubricants are not studied vastly yet. Fonts et al. [70] experimentally investigated the effects of solid volume fraction on thermal conductivity, viscosity and cut-off AC voltage of CNT-diamond/transformer hybrid nano-lubricant. The results signified that thermal conductivity and viscosity were enhanced due to increment of solid volume fraction; whereas cut-off AC voltage was reduced. Lately Afrand et al. [1] studied the effects of solid volume fraction and temperature on SiO_2-MWCNTs/SAE40 hybrid nano-lubricant. They found out that the nanofluid was Newtonian; viscosity was enhanced by 37.4% when solid volume fraction was increased, and viscosity was reduced when temperature was increased. A correlation was proposed for prediction of viscosity behavior of the nanofluid. Up to now many theoretical and experimental correlations have been offered and some of them are summarized in Table 2. The Hybrid nano-lubricants are quite important regarding to their quality, on the other hand they are not yet studied extensively. In the present investigation, rheological behavior of ZnO- MWCNT (55%–45%)/10w-40 hybrid nano-lubricant influenced by temperature and solid volume fraction is investigated. Also a new correlation is proposed for the purpose of predicting relative viscosity of the hybrid nanofluid.

2. Experimentation

In this study MWCNT nanoparticles and ZnO nanoparticles are used. Also 10w40 engine oil has been utilized as the base fluid. MWCNTs and ZnO nanoparticles were distributed in base fluid with the ratio of 55% to 45% by using Eq. (1).

$$\varphi\% = \frac{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{ZnO}}{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{ZnO} + \left(\frac{w}{\rho}\right)_{10W40}} \quad (1)$$

where ρ is the density, φ is the nano-oil solid volume fraction and w is the measured weight.

Morphological properties of the nanoparticles were studied by the use of X-ray diffraction (XRD) method; MWCNTs and ZnO nanoparticles XRD images are depicted in Fig. 1.

Samples of hybrid nanofluids were prepared with solid volume fractions of 0.05%, 0.15%, 0.25%, 0.5%, 0.75% and 1%. MWCNTs and ZnO nanoparticles and 10w40 oil are illustrated in Fig. 2.

Nano-lubricant samples were made by two-step method. Firstly, nanoparticles were weighted and they were dispersed in 10w40 base oil by a magnetic blender. In next step in order to make a stable and homogenized suspensions all samples were exposed to ultrasonic waves for 6 h, to do so a 1200 W ultrasonic processor (Ultrasonic Homogenizer, Development of Ultrasonic Technology, Iran) was utilized. The samples were appropriately stable up to 72 h. In order to measure dynamic viscosity, a CAP2000+ viscometer made by Brookfield engineering laboratories (USA) was utilized. Dynamic viscosity of samples were measured with shear rate range between 666.5 and 11,997 s^{-1}. Accuracy and repeatability of the viscometer were ±1.0% and ±0.2% respectively. For the purpose of assuring from performance of viscometer, it was tested

Table 1
A summary of the conducted researches on thermophysical properties of nanofluids.

Author	Dispersed particles	Base fluid	Temp. (°C)	Conc. (%)	The purpose of experiment
Hemmat Esfe et al. [9]	Al_2O_3	Water	26–55	0.25_5	Thermal conductivity
Hemmat Esfe et al. [61]	Fe	Water		0–0.01	Dynamic viscosity and thermal conductivity
Amiri et al. [62]	MWCNT-COOH	Water	20–70	0.25–1	Specific heat capacity
		EG	20–80		Effective thermal conductivity
					Density
					Dynamic viscosity
Hemmat Esfe et al. [63]	ZnO	EG	25–50	0.25% to 5%	Dynamic viscosity
Beheshti et al. [64]	MWCNT	Oil	20–80	0.01 & 0.001	Thermophysical properties.
Hemmat Esfe et al. [65]	MWCNT	Water	25–55	0.05–1	Turbulent flow of nanofluid flowing through a double tube heat exchanger.
Kotia and Ghosh [66]	Al_2O_3	Gear oil (SAE EP-90)	15–40	0–2	Size distribution
					Dynamic Viscosity
					Density
					Shear stress
					Stability
Afrand et al. [1]	SiO_2-MWCNT	Engine oil (SAE40)	25–60	0–1	Dynamic viscosity
Xing et al. [67]	SWCNTs	water	10–60	0.05–0.48	Thermal conductivity
Elias et al. [68]	Al2O3	water and EG	10–50	0–1	Thermal conductivity
					Dynamic viscosity
					Density
					Specific