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Rheological behavior characteristics of TiO2-MWCNT/10w40 hybrid nano-oil affected by temperature, concentration and shear rate: An experimental study and a neural network simulating

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ABSTRACT

In this article, rheological behavior of TiO2-MWCNT (45–55%)/10w40 hybrid nano-oil was studied experimentally. The nano- oils were tested at temperature ranges of 5–55 °C and in shear rates up to 11,997 s^{-1}. With respect to viscosity, shear stress and shear rate variations it was cleared that either of the base oil and nano-oil were non-Newtonian fluids. New equations which were based on thickness of the fluid were presented for different temperature values, R-squared values were between 0.9221 and 0.9998 (the precise of correlation changes depend on temperature). Also to predict the nano-oil behavior, neural network method was utilized. an artificial neural network (MLP type) were used to predict the viscosity in terms of temperature, solid volume fraction and shear stress. to compare the prediction precise of neural network and correlation the results of these two were compared with together. ANN showed more accurate results in comparison with correlation results. R^2 and (MSE) were 0.9979 and 0.000016 respectively for the ANN.

1. Introduction

Oils play an important role in most of heat transfer and engineering systems such as blood flow in the veins, so the act of improving the characteristics of oils can modify these systems to have higher performances [1]. The most important mechanical characteristics which should be improved in order to modify systems performance are viscosity, rheological properties and heat transfer characteristics. To do so adding nanoparticles into the base oil is one of the most appropriate solutions which is also relatively cost effective. Although using nanofluids is useful when the favorable effect on thermal conductivity is greater than unfavorable effect on dynamic viscosity [2–11]. many experiments have done to introduce a more efficient nanofluid [12–21].

Viscosity of water based TiO_2 nanofluids has decrement with temperature [22]. Some experimental models and correlation for prediction of viscosity variation [23–29] thermal conductivity [30–34] and rheological properties [35–41] were developed. Lately, some studies were conducted on modeling of thermal conductivity and dynamic viscosity of nanofluids [42–51]. For this purpose, artificial neural network was applied. Based on the results of all the studies, ANN has good precision to predict thermos-physical properties of nanofluid and is a strong method for modeling. It has observed in TiO2–MWCNT/water based nanofluid that viscosity has enhancement with TiO2 nanoparticle increasing. The decoration of Multiwall Carbon Nanotube determine the dilatant behavior [51]. MWCNT- Water-ethylene glycol 0.9 wt% has the most enhancement in thermal conductivity. The specific heat of nanofluids has decrement with volume fraction [52]. The rheological analysis showed that the transition region from shear thinning to Newtonian extended to the higher shear stress range compared to that of base fluids [53,54]. The thermal conductivity and dynamic viscosity of diamond & MWCNT/oil base fluid has enhancement with particle dispersed in nanofluid [55]. In Table 1 summarized of some experimental studies for the viscosity of nanofluids containing TiO2, MWCNT, oil with different base fluid.

Surveying in about rheological behavior studies of nanofluids revealed that TiO2-MWCNT (45–55%)/10w40 hybrid nano-lubricant has not been investigated up to now. In this study, the rheological behavior of the hybrid nano-lubricant was evaluated at various temperatures, solid volume fractions and shear rates. A new correlation

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Nomenclature

T	temperature (°C)
w	weight (gr)
τ	shear stress ($dyne/cm^2$)
φ	nanoparticle volume fraction

Greeks symbols

$\dot{\gamma}$	shear rate (s^{-1})
μ	dynamic viscosity (poise)
ρ	density (kg/m^3)

Subscripts

nf	nanofluid
bf	base fluid

was proposed to predict dynamic viscosity of nano-lubricant, also the rheological behavior was predicted by using neural network.

2. Experimentation

TiO_2-MWCNT/10W40 hybrid nano-oil was made out of combination of 10W40 engine oil with a nanoparticles compound which consisted of 45% TiO_2 of 30 nm diameter and 55% of multi-walled carbon nanotubes (MWCNT) with inner diameter of 2–6 nm and outer diameter of 5–20 nm. Nanoparticles sizes are extracted by X-ray diffraction diagram of Fig. 1.

Physicochemical properties of TiO_2 nanoparticles and MWCNTs are listed in Tables 2 and 3. In this study the nanoparticles were dispersed in 10W40 engine oil, the specifications of which are shown in Table 4. All used nanoparticles are manufactured in US Research Nanomaterials Inc., the advanced nanomaterial company.

In order to make the hybrid nano-oil, firstly the various portions of nanoparticles were calculated using Eq. (1).

$$\varphi\% = \frac{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{TiO_2}}{\left(\frac{w}{\rho}\right)_{MWCNT} + \left(\frac{w}{\rho}\right)_{TiO_2} + \left(\frac{w}{\rho}\right)_{10W40}} \tag{1}$$

Then they were added to a predetermined volume of the base oil and the solutions were mixed for 2 hours. An ultrasonic blender made by (Ultrasonic Homogenizer, Development of Ultrasonic Technology, Iran)was utilized for 5-7 hours in order to remove agglomerations of nanoparticles. Fig. 2 illustrates some samples of TiO2, MWCNT, 10W40 oil and the obtained nano-oil.

Table 1
Some studies on nanofluid containing TiO2, MWCNT, and oil.

Ref.	Nanoparticle	Base fluid	Temp.	Conc. (%)	The purpose
Madhesh et al. [52]	Cu-TiO2	Water		0.01–2 wt%	Convective heat transfer rheological characteristics
Cieśliński et al. [53]	Al2O3 TiO2	oil	20–60	0.1–5	Dynamic viscosity, thermal conductivity, electrical conductivity and pH
Hemmat Esfe et al. [54]	MWCNT	Water	25–55	0.05–1	Heat transfer
Sabiha et al. [55]	SWCNT	Water	20–60	0.05–0.25	Thermal conductivity, viscosity, and specific heat
Hemmat Esfe et al. [56]	Cu/TiO2	Water/EG	30–60	0.1–2	Thermal conductivity
Heris et al. [57]	Al2O3-Cuo-Tio2	Turbine oil	20–100	0.1–0.5	Heat transfer
Hemmat Esfe and Rostamian [24]	SiO2-MWCNT	SAE40	25–60	0–1	Dynamic viscosity
Bakhshan and Saljooghi [58]	TiO2	Water	10–60	0–12	Dynamic viscosity
Hemmat Esfe et al. [59]	ZnO	EG	25–50	0.25–5	Dynamic viscosity
Hemmat Esfe et al. [60]	Al2O3	Water	26–55	0.25–5	Thermal conductivity

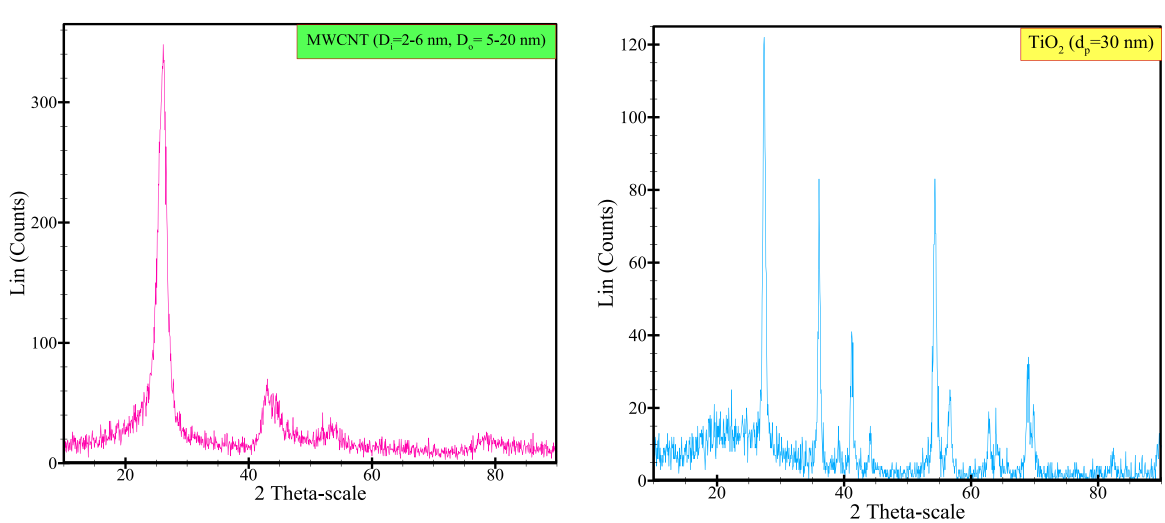

Fig. 1. XRD patterns of TiO_2 nanoparticles and MWCNTs.