RESEARCH PAPER

Examination of Effects of Multi-Walled Carbon Nanotubes on Rheological Behavior of Engine Oil (10W40)

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ABSTRACT

In this study, effects of multi walled carbon nanotubes and temperature on rheological behavior of engine oil (10W40) have been examined. For this purpose, the experiments were carried out in the temperature range of 5-55°C for several suspensions with solid volume fractions of 0.025%, 0.05%, 0.1%, 0.25%, 0.5% and 0.75%. The viscosity of all samples was measured in the shear rate range of $666 s^{-1}$ to $13333 s^{-1}$ at all temperatures considered. The viscosity measurements at different shear rates revealed that all nanofluid samples showed non-Newtonian behavior. The results also revealed that for an increase in the solid volume fraction from 0 to 0.75%, the viscosity increases to 2.5 times. The consistency and the power law index were attained by curve-fitting method for all samples and temperatures. Furthermore, the curve-fitting results revealed that the consistency index and apparent viscosity of nanofluid increases with augmenting the solid volume fraction and diminishes with growing temperature.

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INTRODUCTION

The chief role of engine oils is to diminish wear on moving parts. They also cool the engine by transporting heat away from moving parts; while low its thermal conductivity limits its use as coolants in industrial applications. In 1995, Choi [1] reported that the adding nanoparticles to common fluids, called nanofluids, can lead to improve their thermal conductivity. After that, this allegation has been confirmed by many researchers repeatedly [2-10]. On the other hand, some researchers reported that the viscosity of the fluids also has been influenced by adding nanoparticles [11-21]. Viscosity is one of the most important thermophysical properties of engine oils as it affects pumping power and convective heat transfer. In this regard, the study of the effects of solid particles on the viscosity of engine oil has attracted the interest of some researchers. For example, Vakili-Nezhaad and Dorany [22] investigated the influence of temperature and concentration on the viscosity index of oil-MWCNT nanofluids theoretically and experimentally. Their results indicated that viscosity enhanced with increasing the MWCNT concentration and decreasing temperature. Chen et al. [23] investigated the effects of MWCNTs on rheological behaviors of silicone oil experimentally. They reported that the nanofluid shows Newtonian behavior in all studied MWNTs volume fractions and temperatures. The effect of α-Al_2O_3 and γ-Al_2O_3 on the viscosity of engine oil was examined

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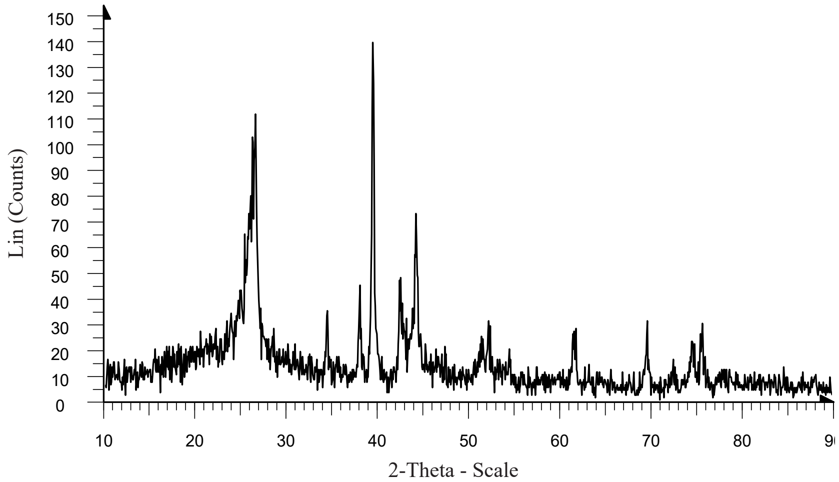

Fig. 1. XRD pattern for MWCNT nanoparticles.

by Vasheghani et al. [24]. Their results showed that by adding 3 wt% of nano α-Al_2O_3 and γ-Al_2O_3 to the engine oil, the viscosity increases by 36% and 38%, respectively.

Ettefaghi et al. [25] investigated the effect of MWCNTs in different concentrations on the viscosity of engine oils. Their results showed that the viscosity of all the samples decreased with increasing temperature. They also observed that with increasing concentration of carbon nanotubes, the viscosity of the oil either reduced or increased after adding carbon nanotubes.

Regarding non-Newtonian nanofluids, Kulkarni et al. [26] studied the viscosity of CuO/water at various solid volume fractions and temperatures. Their results revealed that the nanofluid samples exhibited time-independent pseudoplastic and shear-thinning behavior. Results showed that both nanofluids exhibit shear-thinning behavior. The viscosity of Al_2O_3/car coolant has been studied by Kole and Dey [27]. Their results indicated that the base fluid showed a Newtonian beahvior, while the nanofluid samples were non-Newtonian fluid. The examination of ethylene glycol-titanate nanotube (TNT) nanofluids has been done by Chen et al. [28]. They reported that the samples show shear-thinning behavior mostly at particle concentrations in excess of ~2%. In another work, Chen et al. [29] examined the viscosity of ethylene glycol-TNT nanofluids. Their results showed a very strong shear thinning behavior of the TNT nanofluids. The study of the viscosity of TiO_2-ethylene glycol nanofluids was performed by Cabaleiro et al. [30]. They measured the viscosity of the nanofluid at various nanoparticle mass concentrations, different temperatures and several shear rates. They reported that the nanofluid showed a non-Newtonian behavior. Phuoc et al. [31] investigated the rheological behavior of nanofluids containing MWCNTs. They added MWCNTs to increase or decrease the fluid base viscosity. Their results indicated a reduction up to 20% in the viscosity-reduction case. They also observed a non-Newtonian behavior in the viscosity-enhancement case.

However, few works have been done on the rheological behavior (Newtonian or non-Newtonian) of engine oils. Because of numerous applications of engine oils, there is a requirement to examine the rheological behavior of nano-lubricants. In this work, the rheological behavior of the nanofluid prepared by dispersing multi walled carbon nanotubes in 10W40 engine oil is investigated experimentally. For this purpose, the effects of the shear rates, temperature and MWCNTs volume fractions on the shear stress and the viscosity of the nanofluids are examined.

MATERIALS AND METHODS

Samples preparation

In the present work, multi-walled carbon nanotubes were dispersed in the engine oil at solid volume fractions of 0.025%, 0.05%, 0.1%, 0.25%, 0.5% and 0.75%. In order to obtain a characterization of the MWCNT, its structural properties were measured by using X-ray diffraction as illustrated in Fig. 1.

To prepare stable nanofluids, after magnetic

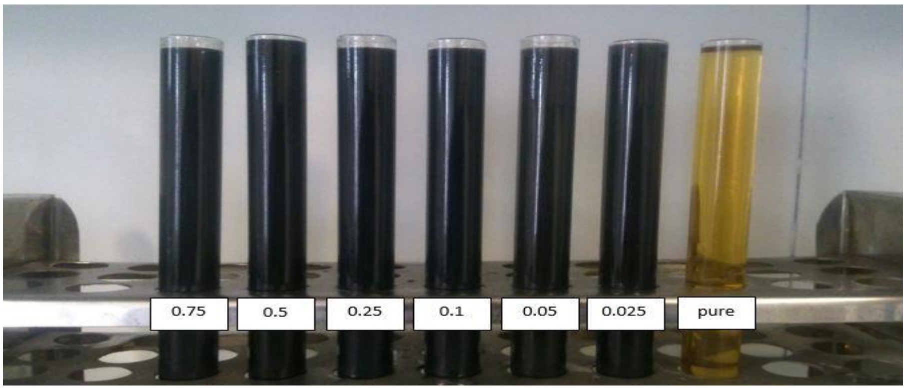

Fig. 2. Photograph of MWCNT-Oil nanofluid

stirring for 2h, the suspensions were exposed to an ultrasonic processor (Hielscher Company, Germany) with the power of 400W and frequency of 24 kHz for 6-7h. The photograph of MWCNTs, engine oil and the nanofluid samples are shown in Fig. 2.

Viscosity measurement

The dynamic viscosity of nanofluid samples were measured by the CAP 2000+ Viscometer (Brookfield Engineering Laboratories, Inc.). This Viscometer is suitable for medium to high shear rates, and had Cone-Plate geometry and integrated temperature control. In this work, cone 01 was used, which can measure the viscosity in the range of 20 to 2000 centipoise. The range of accuracy and repeatability of the Viscometer are ±2.0% and ±0.5%, respectively. Experiments were carried out in the shear rate range of 666s^{-1} to 13333 s^{-1} for various solid volume fractions and temperatures.

RESULTS AND DISCUSSION

Fig. 3 shows the rheological behavior of engine oil in the absence of MWCNTs. In Fig. 3a the viscosity of engine oil is illustrated versus shear rate. It can be seen that the viscosity is independent of the shear rate, which means that the engine oil is Newtonian. Fig. 3b demonstrates the shear stress versus shear rate and confirms the behavior of engine oil observed in Fig. 3a. As shown in this figure, the shear stress is a linear function of shear rate, indicating Newtonian behavior.

Fig. 4 illustrates the viscosity versus shear rate for various nanofluid samples at different temperatures. It can be observed that the viscosity of all samples is dependent on the shear rate and decreases with increasing the shear rate. This figure reveals that the samples exhibit nano-Newtonian and shear thinning behavior. Fig. 4 evidently demonstrates that the viscosity of all samples decreases with increasing the shear rate, while increases with increasing solid volume fraction.

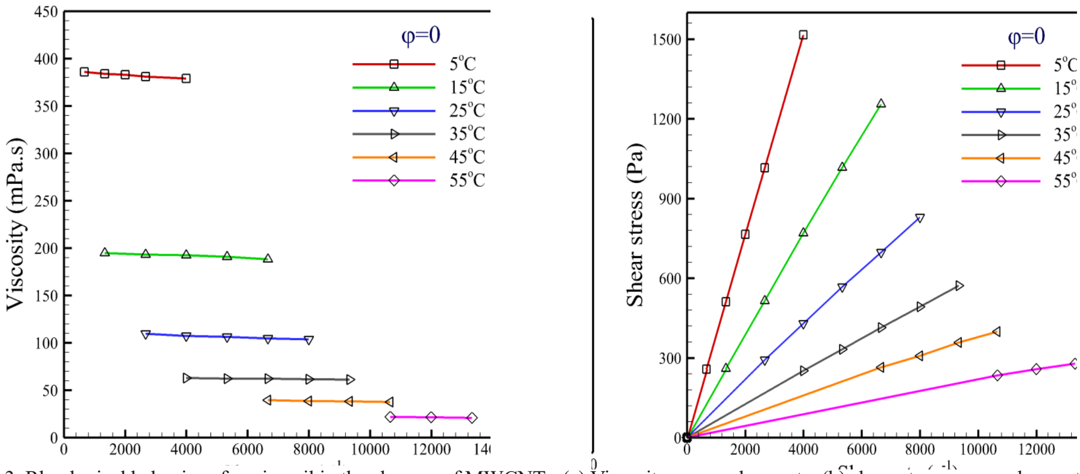

Fig. 3. Rheological behavior of engine oil in the absence of MWCNTs. (a) Viscosity versus shear rate, (b) shear stress versus shear rate.

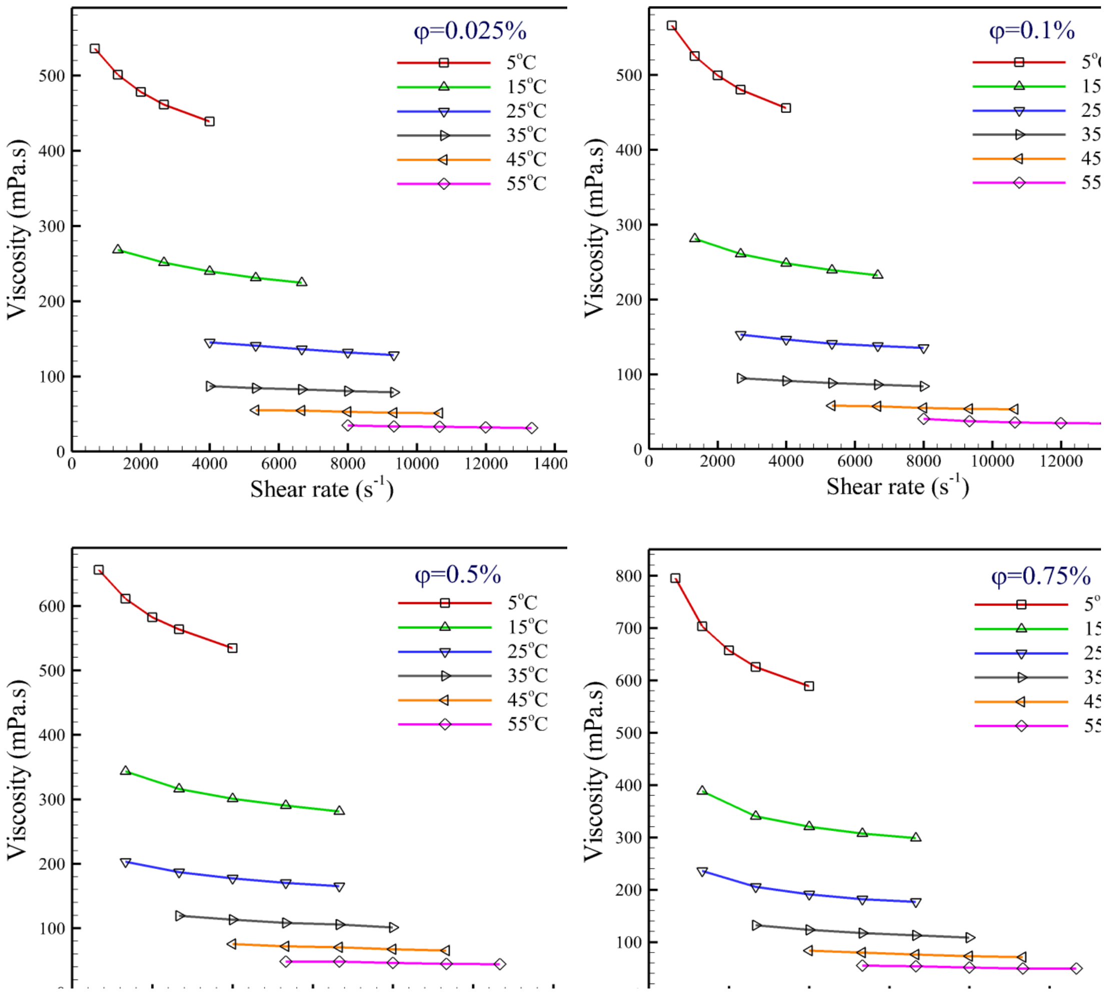

Fig. 4. Viscosity versus shear rate for various nanofluid samples at different temperatures.

Fig. 5 shows the shear stress versus shear rate for various nanofluid samples at different temperatures. As shown in this figure the nanofluid samples exhibit a pseudoplastic rheological behavior and follow the power law model expressed in Eqs. (1) and (2). These equations indicate that the apparent viscosity decreases with augmenting shear rate.

$$\tau = m\dot{\gamma}^{n} \tag{1}$$

$$\mu = m\dot{\gamma}^{n-1} \tag{2}$$

where, τ is the shear stress, $\dot{\gamma}$ is the shear rate, m is consistency index, n is the power law index (n<1), and μ is the apparent viscosity.

This rheological behavior is very important for engineering applications such as convective heat transfer and pumping power. Therefore, the investigation of the consistency index (m) and the

Table 1. Power law index values for curve-fitting.

T (ºC)	Solid volume fraction (%)					
	0.025	0.05	0.1	0.25	0.5	0.75
5	0.8816	0.9047	0.8732	0.881	0.8799	0.8374
15	0.8828	0.8988	0.8765	0.8774	0.8747	0.8486
25	0.8756	0.8907	0.8876	0.8629	0.8668	0.8284
35	0.9666	0.8662	0.8837	0.8738	0.8496	0.821
45	0.8779	0.8931	0.8627	0.8622	0.8271	0.7994
55	0.8158	0.8602	0.7496	0.8338	0.8541	0.8303

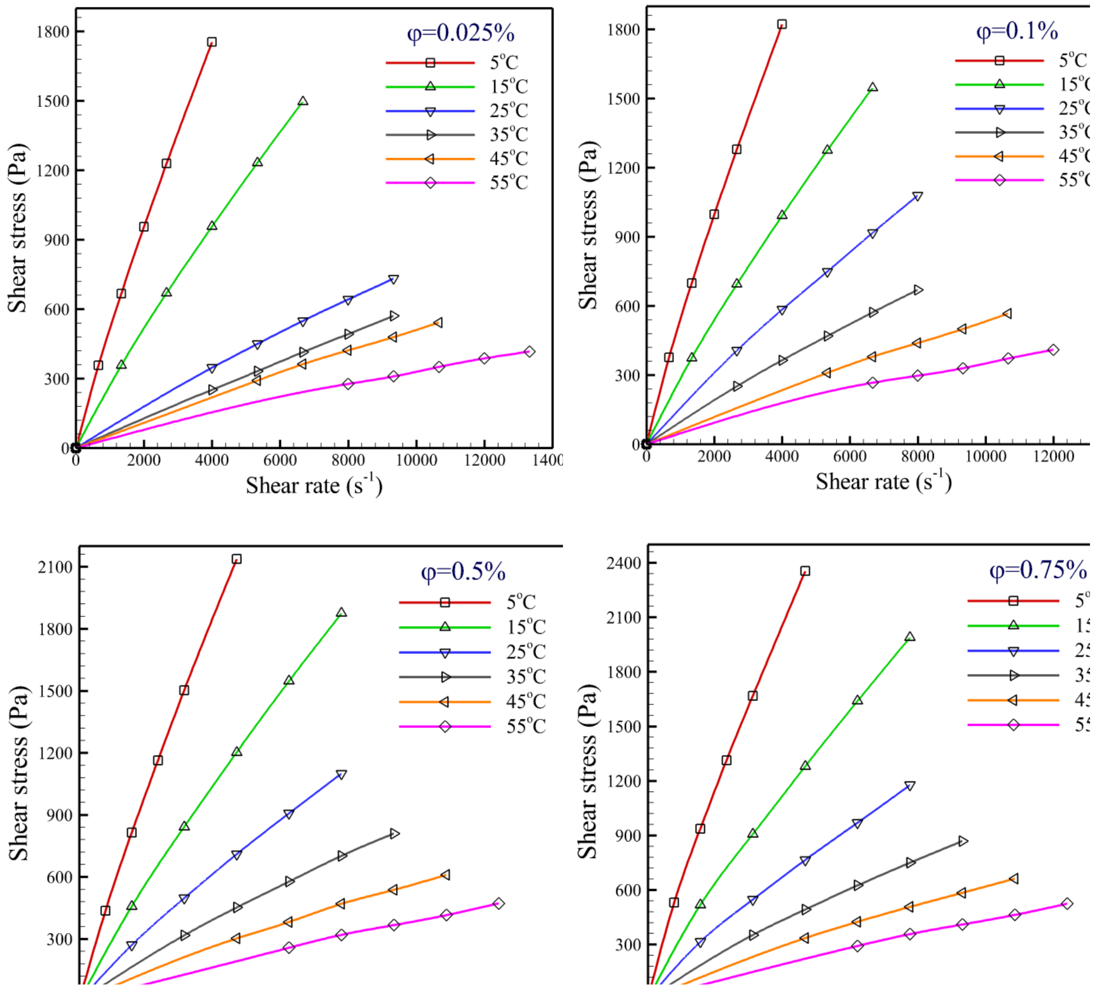

Fig. 5. Shear stress versus shear rate for various nanofluid samples at different temperatures.

power law index (n) seems necessary.

As shown in Figs. 4 and 5, non-Newtonian behavior of the nanofluids and consequently the consistency and the power law index are as a function of solid volume fraction and temperature. Using Eq. (1), these parameters could be attained by curve-fitting on the experimental data related to shear stress and shear rate. Based on curve-fitting results, the power law index values for all nanofluid samples at different temperatures are reported in Table 1. It can be found from Table 1 that all power law indices are in the range of 0.7496 to 0.9666.

Consistency index values for all nanofluid samples at different temperatures are shown in Table 2. As mentioned in Eq. (2), the consistency index is directly a function of apparent viscosity. Results reported in Table 1 show that the

Table 2. Consistency index values for curve-fitting.

T (ºC)	Solid volume fraction (%)					
	0.025	0.05	0.1	0.25	0.5	0.75
5	1.172	0.9996	1.305	1.287	1.448	2.264
15	0.6315	0.5649	0.6898	0.7181	0.8491	1.129
25	0.2454	0.3564	0.3703	0.4777	0.5335	0.7965
35	0.0832	0.2745	0.2387	0.2721	0.3932	0.5434
45	0.1578	0.1396	0.1893	0.199	0.3186	0.4443
55	0.1809	0.1215	0.3559	0.1706	0.1706	0.2363

Table 3. R^2 values for curve-fitting.

T (ºC)	Solid volume fraction (%)					
	0.025	0.05	0.1	0.25	0.5	0.75
5	0.999983	0.999991	0.999988	0.999994	0.999982	0.999973
15	0.999974	0.99998	0.999986	0.999981	0.999991	0.99992
25	0.99995	0.999986	0.999983	0.999941	0.999983	0.99991
35	0.999988	0.99988	0.999974	0.999996	0.999883	0.999994
45	0.999838	0.999852	0.999856	0.999916	0.999754	0.999978
55	0.999753	0.999996	0.999133	0.999974	0.999589	0.999743

consistency indices increase with augmenting the solid volume fraction and decrease with enhancing temperature. This behavior also was reported for Newtonian fluid. This is due to the fact that with increasing temperature intermolecular interactions between the molecules become weak and therefore the apparent viscosity decreases.

The precision criterion for curve-fitting, R^2, is presented in Table 3. The R^2 values reveal that the curve-fitting used to obtain consistency and power law index was very accurate.

CONCLUSION

In this work, the effects of multi walled carbon nanotubes and temperature on rheological behavior of engine oil (10W40) were examined. The experiments were carried out in temperature range of 5-55°C for several suspensions with solid volume fractions of 0.025%, 0.05%, 0.1%, 0.25%, 0.5% and 0.75%. The viscosity measurements at different shear rates revealed that all nanofluid samples showed non-Newtonian behavior. The results also revealed that for an increase in the solid volume fraction from 0 to 0.75%, the viscosity increases to 2.5 times. This shows that this nanofluid can be considered where the pressure drop is not important. Furthermore, the experiments showed that the apparent viscosity decreases with increasing shear rate. Based on non-Newtonian behavior, the consistency index and the power law index were attained by curve-fitting method using shear stress and shear rate. Power law index values indicated that all power law indices were in the range of 0.7496 to 0.9666.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publicaton of this manuscript.

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