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Dynamic viscosity of MWCNT/ZnO–engine oil hybrid nanofluid: An experimental investigation and new correlation in different temperatures and solid concentrations☆

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ABSTRACT

The major objective of the present study was to investigate the dynamic viscosity of MWCNT/ZnO–engine oil hybrid nanofluid. The experiments carried out in different temperatures ranging from 5 °C to 55 °C and solid concentrations ranging from, 0.125% to 1%. The viscosity of the MWCNT/ZnO nanoparticle with the mean diameter of 30 nm dispersed in engine oil was measured using Brookfield cone and plate viscometer. The effect of temperature and solid concentration on dynamic viscosity of the nanofluid has been experimentally investigated. The results indicated that increasing the temperature resulted in decreasing the dynamic viscosity of the nanofluid by 85% while the dynamic viscosity increased as the solid concentration increased by 45%. Furthermore, based on the experimental data, a new model to predict the dynamic viscosity of the studied nanofluid has been proposed.

1. Introduction

Nanofluids are a suspension of nano-size particles in conventional fluids (water, ethylene glycol, and engine oil). This new type of fluids have grabbed the attention of many researchers in recent years [1–6] since they have been found capable of providing a noticeable enhanced heat transfer in comparison with conventional fluids [7].

There is no disagreement that one of the most important properties of nanofluids, as a new type of fluids, in industrial and engineering applications is the viscosity of them. In this regard, there is a large volume of published studies describing the role of dynamic viscosity on the applications of nanofluids [8–15]. Fedele et al. [16] investigated the viscosity of TiO_2–water nanofluid. They conducted the experiments in different temperatures (ranging from 283 to 343 K) and solid concentrations (ranging from 1% to 35%). In another experimental investigation, the dynamic viscosity of Al_2O_3–water nanofluid has been studied by Chandrasekar et al. [17]. They used the nanoparticles with nominal diameter of 43 nm at room temperature and different solid concentrations. Their results showed that increasing the solid concentration, the dynamic viscosity shows substantial increase. Furthermore, they proposed new model to predict the dynamic viscosity of the nanofluid. Murshed et al. [18] conducted an experimental study on the dynamic viscosity of nanofluids. They found that the viscosity of nanofluids are considerably higher than that of the base fluids. Furthermore, they indicated that the dynamic viscosity of nanofluids is strongly depend on temperature. The dynamic viscosity of CuO–Eg/water nanofluid has been experimentally investigated by Praveen et al. [19]. They conducted the experiments in various temperatures ranging from −35 °C to 50 °C and solid concentrations ranging from 0% to 6%. Furthermore, they proposed a new correlation to predict the dynamic viscosity of the studied nanofluid. In another experimental study, the effective viscosity of Al_2O_3–water nanofluid has been investigated by Lee et al. [20]. Their results showed that the dynamic viscosity of the nanofluid has a direct relation with temperature. Moreover, they found that there is a nonlinear relation between the dynamic viscosity of the nanofluid and solid concentration, especially in low solid concentrations (ranging from 0.1% to 0.3%). Madhusree and Dey [21] conducted an experimental investigation on the effect of aggregation on dynamic viscosity of CuO–gear oil nanofluid. Their results showed that the dynamic viscosity of the nanofluid strongly depend on temperature and solid concentration. Furthermore, they found that the Newtonian behavior of the base fluid changes as the nanoparticle loaded.

From what has been discussed above, previous studies have reported the effect of temperature, solid concentration, and the size of nanoparticles on the dynamic viscosity of nanofluids with water and ethylene glycol as a base fluid. Based on the authors' knowledge, there is no comprehensive study on the viscosity of nanofluids with four seasonal engine oil as a base fluid and researchers have not treated this aspect of nanofluids in much detail.

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In the present experimental study, using two-step method, the MWCNT/ZnO–engine oil hybrid nanofluid has been prepared as the experimental sample. The viscosity of the studied nanofluid was measured in different solid concentrations (ranging from 0.125% to 1%) and temperatures (ranging from 5 °C to 55 °C). Moreover, based on the experimental data, a new correlation to predict the dynamic viscosity of the nanofluid in terms of temperature and solid concentration has been proposed.

2. Nanofluid preparation

Using two-step method and without utilizing any surfactant, MWCNT/ZnO–oil (four season engine oil 10W40, Behran Super Pishtaz, Behran oil company, Iran) hybrid nanofluid has been produced as the experimental sample. First of all, the nanoparticles have been dispersed into five solid volume fractions, 0.125%, 0.25%, 0.5%, 0.75%, and 1%. It must be noted that the ratio of using MWCNT and ZnO nanoparticles were 15% and 85%, respectively. In the next step, the MWCNT and ZnO nanoparticles have been mixed in the base fluid utilizing a magnetic stirrer for 2 h so as to achieve a stable nanofluid. Then the suspension has been inserted into an ultrasonic processor (20 kHz, 1200 W, Topsonic, Iran) for 1 h. The aim of using ultrasonic processor is, on the first hand, to achieve a superb dispersion and on the other hand to break down the agglomeration of nanoparticles. In this manner, a long time stable (at least 1 week) nanofluid has been produced and no sedimentation has been observed by the naked eyes. Fig. 1 shows the TEM image of the nanoparticles. This photo indicates that the average size of the nanoparticles are 30 nm.

3. Dynamic viscosity measurement

In the present study, the viscosity of the nanofluid has been measured utilizing a Brookfield cone and plate viscometer (CAP2000) supplied by Brookfield engineering laboratories of the US. This device is able to set the temperature of the fluid in a short time and keep it stable over the period of experiments. The working temperature range of the device is between 5 °C and 75 °C. Furthermore, the speed of its spindle is between 5 and 1000 RPM. Fig. 2 shows a view of the viscometer. The accuracy of the device is ±2%. It must be noted that each experiment has been repeated at least three times and the average values have been reported.

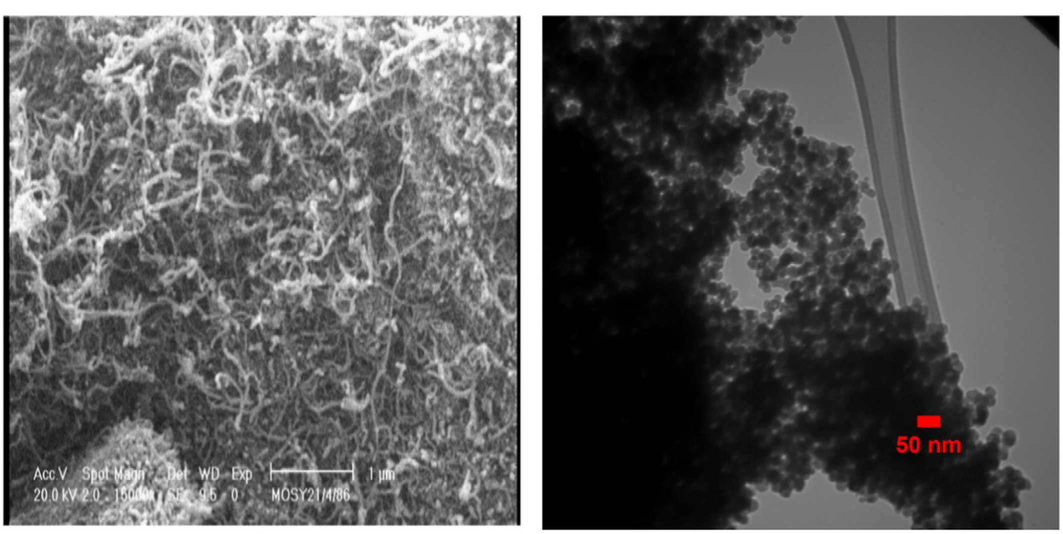
Fig. 2. Brookfield cone and plate viscometer (CAP2000).

4. Newtonian behavior

Since many debates about the rheological behavior of nanofluids (Newtonian or non-Newtonian) have been observed in the previous research conducted by different researchers [16,22], the first step in the present study is to investigate the rheological behavior of MWCNT/ZnO–engine oil hybrid nanofluid. The Newtonian behavior of a nanofluid can be express by the following equation

$$\tau = \mu\gamma \quad (1)$$

where τ, μ, and γ represent the shear stress, dynamic viscosity, and shear strain, respectively. Fig. 3 shows the dynamic viscosity of the



A B

Fig. 1. TEM image of the (A) MWCNT (B) ZnO nanoparticles.