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# Effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluid: Experimental study

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## HIGHLIGHTS

- Measurement of dynamic viscosity of MgO-MWCNTs/EG nanofluid.
- Presenting effects of temperature and hybrid particles volume fraction.
- All nanofluid samples exhibited Newtonian behavior at all temperatures considered.
- The classical models were unable to predict the dynamic viscosity of the nanofluid.
- Suggesting a new correlation to estimate the dynamic viscosity of the nanofluid.

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## ABSTRACT

In this paper, the effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluid is examined. The experiments carried out in the solid volume fraction range of 0 to 1.0% under the temperature ranging from 30 °C to 60 °C. The results showed that the hybrid nanofluid behaves as a Newtonian fluid for all solid volume fractions and temperatures considered. The measurements also indicated that the dynamic viscosity increases with increasing the solid volume fraction and decreases with the temperature rising. The relative viscosity revealed that when the solid volume fraction enhances from 0.1 to 1%, the dynamic viscosity increases up to 168%. Finally, using experimental data, in order to predict the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluids, a new correlation has been suggested. The comparisons between the correlation outputs and experimental results showed that the suggested correlation has an acceptable accuracy.

## 1. Introduction

The thermophysical properties of fluids which used for heating and cooling in the thermal engineering devices play an important role in energy efficient heat transfer equipment. Dynamic viscosity and thermal conductivity are two important properties of fluids. A low viscosity fluid is suitable for the pumping applications, while a fluid with high viscosity increases the bearing load capability. In the other hand, a higher thermal conductivity can lead to increase the rate of heat transfer. Since, the heat transfer fluids, including water, ethylene glycol (EG) and oil have a low thermal conductivity, Choi [1] used nanoparticles to improve the thermal conductivity of these fluids. After that, nanofluids have been used in a variety of applications such as energy industry, chemical engineering industry, microelectronics and so on [2–6]. Many researchers have reported that the adding metallic or non-metallic, oxide nanoparticles, and carbon nanotubes (CNTs), can lead to improve the thermal conductivity of heat transfer fluids [7–10]. However, many studies revealed that the viscosity of fluids was affected by dispersing the additive to them. A literature review on the available studies of the viscosity of metal oxide nanofluids is presented in Table 1.

CNTs has attracted the attention of researchers because of their unique heat transfer characteristics [23–25]. The results implied that the viscosity increases with increasing the concentration of particles, resulting in the increase pumping power. These studies also revealed that the viscosity of nanofluids is a function of temperature, concentration, shape and size of nanoparticles. Furthermore, some empirical correlations for estimating the thermophysical properties of nanofluids as a function of temperature and volume concentrations were proposed by many researchers [11,14,16,21,26–29]. Lately, a new kind of nanofluids, called hybrid

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**Table 1**
A literature review on the available studies of the viscosity of metal oxide nanofluids.

| Authors | Base fluid | Particles | Temp. Range/°C | Volume Fraction/% |
|---|---|---|---|---|
| Tseng and Lin [11] | Water | $TiO_2$ | 25 | 5–12 |
| Putra et al. [12] | Water | $Al_2O_3$ | 20–60 | 1–4 |
| Kulkarni et al. [13] | Water | CuO | 5–50 | 5–15 |
| Nguyen et al. [14] | Water | $Al_2O_3$<br>CuO | 25–75 | 1–12 |
| Lee et al. [15] | Water | $Al_2O_3$ | 21–39 | 0.01–0.3 |
| Duangthongsuk and Wongwises [16] | Water | $TiO_2$ | 15–35 | 0.2–2 |
| Hemmat Esfe et al. [17] | Water | MgO | 24–60 | $< 1$ |
| Sundar et al. [18] | Water/EG | $Al_2O_3$/CuO | 15–50 | $< 0.8$ |
| Hemmat Esfe et al. [19] | EG | $Mg(OH)_2$ | 23–55 | 0.1–2 |
| Li et al. [20] | EG | ZnO | 15–55 | 1.75–10.5 |
| Hemmat Esfe et al. [21] | EG | ZnO | 25–50 | 0.25–5 |
| Baratpour et al. [22] | 0–0.1 | 30–60 | SWCNT | EG |

nanofluids, combined of various nanoparticles is considered [8,30–35]. Among these studies, Suresh et al. [31] prepared the nanofluids consist of $Al_2O_3$–Cu hybrid particles by dispersing in deionised water. Their results showed that both thermal conductivity and viscosity increase with the nanoparticles volume concentration. Also, increasing the viscosity is significantly higher than the increase in thermal conductivity. The measurement of thermal conductivity showed a maximum enhancement of 12.11% for a volume concentration of 2%. Hemmat Esfe et al. [32] investigated the thermophysical properties of Ag–MgO/water hybrid nanofluids. Their results implied that dynamic viscosity and thermal conductivity increase with increasing nanoparticles concentration. Moreover, they proposed new correlations to predict the nanofluid thermophysical properties. Baghbanzadeh et al. [33] investigated the effect of MWCNTs, silica nanospheres and hybrid nanostructures on the thermal conductivity of distilled water. Their results showed that with increasing the nanomaterials concentration, the effective thermal conductivity of nanofluids increases. Furthermore, the hybrid nanofluids consisting of the higher percentage of MWCNTs compared with the other hybrid nanofluids showed more increase in effective thermal conductivity of the nanofluid. Munkhbayar et al. [34] conducted an experimental study using silver-nanoparticle-based aqueous nanofluids with the addition of negligible amounts of multi-walled carbon nanotubes (MWCNTs). They reported that a significant enhancement in the thermal conductivity was occurred compared to the base fluid. The size of silver nanoparticles was measured using a particle sizing system and transmission electron microscopy and the results implied that the size of the silver nanoparticles was approximately 100 nm. Recently, Eshgarf and Afrand [35] investigated the rheological behavior of COOH functionalized MWCNTs-$SiO_2$/EG-water hybrid nano-coolant at temperatures ranging from 27.5 °C to 50 °C. They changed the solid volume fraction from 0.0625% to 2% and measured the viscosity at the shear rate range of 0.612–122.3 $s^{-1}$. Their results showed that the base fluid exhibits Newtonian behavior and the nano-coolant samples exhibit a pseudoplastic rheological behavior.

According to the theoretical studies, researchers obtained some models for prediction of dynamic viscosity as a function of the solid volume fraction. Einstein, Batchelor and Wang equations that are the some well-known models have been used for comparing the measured data with the predicted viscosity. On the subject of the nanofluids with spherical shape nanoparticles, Batchelor suggested a correlation for isotropic structure of suspension to predict the viscosity which is given as [36]:

$$\frac{\mu_{nf}}{\mu_{bf}} = 1 + 2.5\phi + 6.2\phi^2 \tag{1}$$

Einstein [37] proposed another correlation to estimate the effective viscosity of a suspension of spherical solids as a function of volume fraction. This equation was expressed by:

$$\frac{\mu_{nf}}{\mu_{bf}} = 1 + 2.5\phi \tag{2}$$

Moreover, Wang et al. [38] introduced a model for estimating the viscosity of nanofluids which is presented as:

$$\frac{\mu_{nf}}{\mu_{bf}} = 1 + 0.723\phi + 123\phi^2 \tag{3}$$

In the above equations, $\mu$ is the dynamic viscosity, $\phi$ is the solid volume fraction and the subscripts of *nf* and *bf* are related to nanofluids and base fluids respectively.

Many researchers experimentally investigated the viscosity of nanofluids and concluded that the theoretical models [36–38] were unable to predict the viscosity. Therefore, they proposed some empirical correlations for estimating the viscosity as a function of temperature and volume concentrations were proposed [11,14,16,21,39–42].

Review of the aforementioned articles showed that the thermophysical properties of various nanoparticles into the different base fluids were investigated in different studies. From each work, different results were obtained and each of which could be useful in its position. However, a few works have been performed on the viscosity of the hybrid nanofluids. Therefore, in this study, MgO-MWCNT/EG hybrid nanofluid samples are prepared at different solid volume fractions. The viscosity of nanofluid samples was measured in volume concentrations ranging from 0 to 1%. Moreover, for dynamic viscosity a new correlation in terms of temperature and solid volume fraction in the considered experimental temperature range from 30 °C to 60 °C is proposed. Finally, the relative viscosities are compared with the theoretical values obtained from the existing models [36,38].

## 2. Preparation of nanofluid

The first part of preparing the nanofluids is dispersing the nanoparticles in the base fluid and then stabilizing the suspension. In this work, ethylene glycol (Merck product, Germany) was used as the base fluid, which its characteristics are presented in Table 2. The chemical and physical properties of additive particles, composed of an equal volume of MWCNTs and MgO nanoparticles, also are presented in Tables 3 and 4.

The structural properties of the dry MgO nanoparticles and MWCNTs were measured using X-ray diffraction, which is shown in Fig. 1.

MgO-MWCNTs/EG hybrid nanofluids with solid volume fractions of 0.1%, 0.2%, 0.4%, 0.8%, and 1% were prepared using a two-

**Table 2**
Chemical and physical data of Ethylene Glycol (EG).

| Parameter | Value |
|---|---|
| Ignition temperature | 410/°C |
| Saturation concentration (air) | 0.15/g $m^{-3}$ |
| Melting point | $-13$/°C |
| Molar mass | 62.07/g $mol^{-1}$ |
| Density | 1.11/g $cm^{-3}$ |
| pH value | 6–7.5 |
| Boiling point | 197.6/°C |
| Vapor pressure | 0.053/kPa |

**Table 3**
Properties of multi walled carbon nanotubes (MWCNT).

| Parameter | Value |
|---|---|
| Purity | > 97% |
| Color | Black |
| Outer diameter | 5–20 (nm) |
| Inner diameter | 2–6 (nm) |
| Thermal conductivity | 1500 (W/m K) |
| Apparent density | 0.15–0.35 (g/cm$^3$) |
| Specific heat capacity | 630 (J/kg K) |

**Table 4**
Properties of silica nanoparticles (MgO).

| Parameter | Value |
|---|---|
| Purity | > 99% |
| Color | White |
| diameter | 40 (nm) |
| SSA | ~25 (m$^2$/g) |
| Morphology | polyhedral |
| True density | 3.58 (g/cm$^3$) |

step method. The quantity of MWCNTs and MgO nanoparticles required for various solid volume fractions can be determined using the standard formula [18],

$$\phi\% = \left[ \frac{\left(\frac{w}{\rho}\right)_{MgO} + \left(\frac{w}{\rho}\right)_{MWCNTs}}{\left(\frac{w}{\rho}\right)_{MgO} + \left(\frac{w}{\rho}\right)_{MWCNTs} + \left(\frac{w}{\rho}\right)_{EG}} \right] \tag{4}$$

where $\varphi$ is the percentage of solid volume fraction, $\rho$ is the density and $w$ is the weight. The preparation of nanoparticle samples was performed by using a sensitive electronic balance with an accuracy of 1 mg.

In the experiment, at the first, to prepare stable MgO-MWCNTs/EG hybrid nanofluids magnetic stirring was used for 2 h and then the suspensions was exposed to an ultrasonic processor (Hielscher company, Germany) with the power of 400 W and frequency of 24 kHz for 7 h. This method was used in order to break down the agglomeration between the particles, which leads to attain a stable suspension and a uniform dispersion. Stability of the prepared nanofluid was studied by using a pH meter (HANNA, HI 83141) to measure the pH values. In order to obtain a characterization of the sample, first step included the analysis of dry nanoparticles used in the preparation of nanofluids.

## 3. Dynamic viscosity measurement

The viscosity of different volume concentrations (0.1%, 0.2%, 0.4%, 0.8%, and 1%) of MgO-MWCNTs/EG hybrid nanofluid was measured in the range from 30 °C to 60 °C by Brookfield Viscometer. This device is supplied by Brookfield engineering laboratories of USA and equipped with a temperature bath. The range of accuracy and repeatability of Brookfield Viscometer is respectively ±1.0% and ±0.2%. The Viscometer was tested with ethylene glycol at room temperature before the measurement of dynamic viscosity of nanofluids. All experiments were repeated at different shear rates for each temperature and solid volume fraction to make sure its repeatability and then the average of measured data was recorded. Based on the measurements, the “relative viscosity” is defined as the ratio of the dynamic viscosity of MgO-MWCNTs/EG hybrid nanofluids to dynamic viscosity of base fluid (EG).

## 4. Results and discussion

### 4.1. Measurements validation

Earlier experiments were performed to make sure of the accuracy of the Viscometer. Fig. 2 shows a comparison between the viscosities of EG obtained by the Viscometer at various temperatures and those reported by Chen et al. [2]. As shown in Fig. 2, the examinations are in good agreement with the data obtained by Chen et al. [2].

### 4.2. Compared to previous theoretical and experimental works

A comparison of the ratio of the dynamic viscosity of nanofluid between experimental data and the estimated values from Batchelor [36] and Wang [38] models is shown in Fig. 3. It can be seen that both theoretical models are unable to estimate the viscosity of MgO-MWCNT/EG hybrid nanofluids. Moreover, the experimental data for the viscosity of hybrid nanofluids are greatly higher than Batchelor and Wang models.

A comparison between the viscosity ratios of MgO-MWCNTs/EG hybrid nanofluid (present work) and those of $Fe_3O_4$–Ag/EG

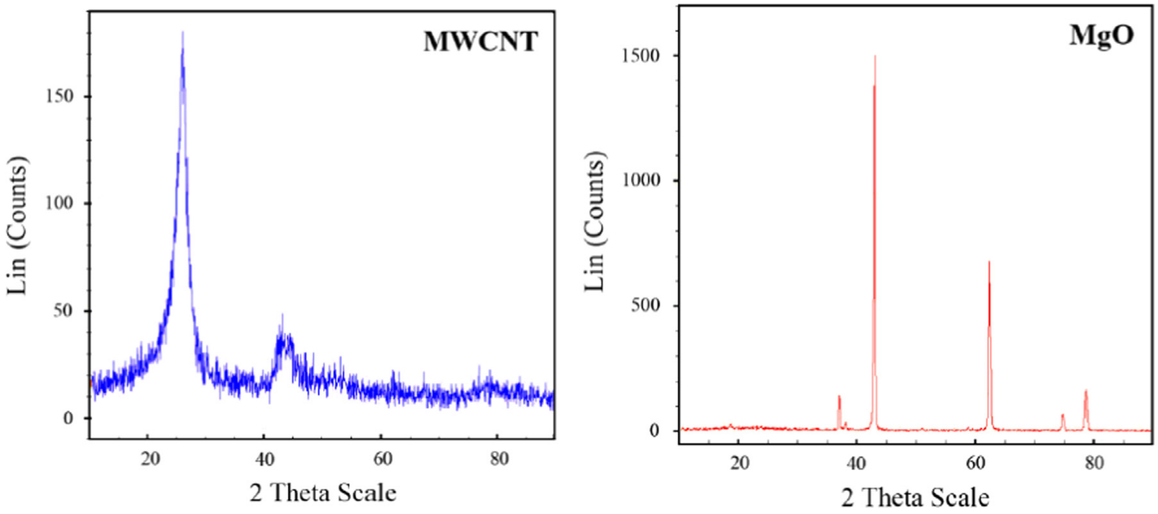

**Fig. 1.** XRD pattern for MWCNTs and MgO nanoparticles.

(obtained by Afrand et al. [4]) is presented in Fig. 4. It can be observed that the viscosity ratio for present nanofluid is lower than that obtained by Afrand et al. [4].

### 4.3. Newtonian behavior

In fluid mechanics, a Newtonian fluid is a fluid in which the viscosity is independent of shear rate. In order to understand the Newtonian or non-Newtonian behavior of MgO-MWCNT/EG hybrid nanofluids, Fig. 5 shows the shows the shear stress versus shear rate for nanofluid at nanoparticles volume fraction of 1% and various temperatures. This figure revealed that the nanofluid behaves as a Newtonian fluid.

### 4.4. Effects of temperature and nanoparticles volume fraction on dynamic viscosity

Fig. 6 shows the dynamic viscosity of hybrid nanofluid versus nanoparticles volume fraction for various temperatures. It can be seen that the viscosity of the hybrid nanofluid increases with increasing nanoparticles volume fraction at various temperatures with a similar trend. This is probably due to the different interactions between MgO nanoparticles, MWCNTs and EG molecules.

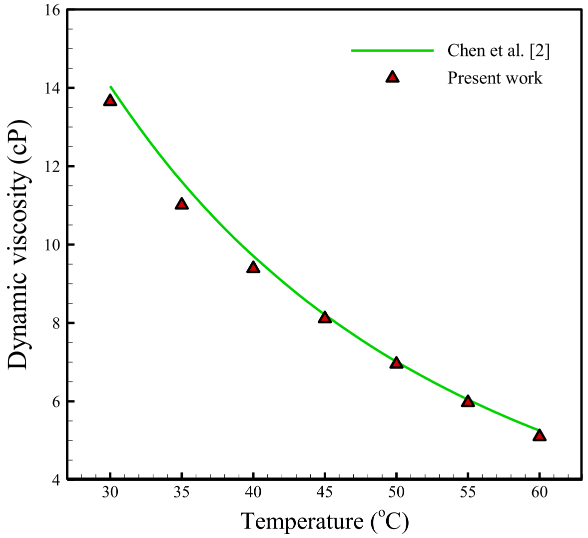

**Fig. 2.** Comparison between the viscosities of EG obtained by the Viscometer at various temperatures and those reported by Chen et al. [2].

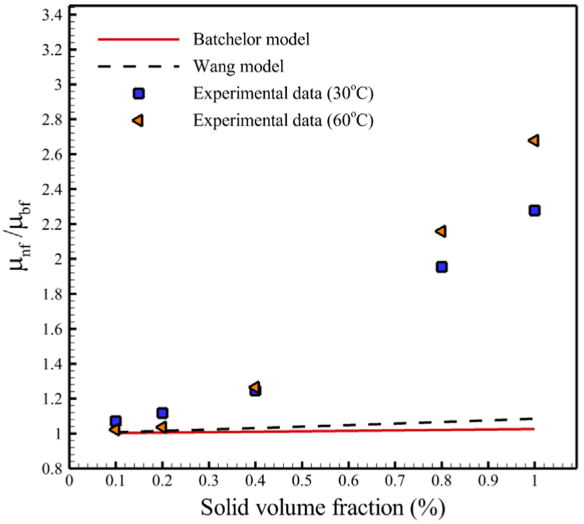

**Fig. 3.** Comparison between theoretical models and experimental data.

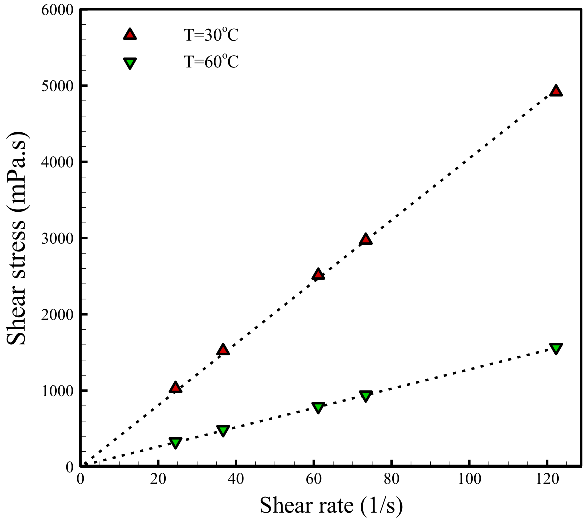

**Fig. 5.** Shear stress as a function of shear rate for MgO-MWCNT/EG hybrid nanofluid at solid volume fraction of 1% and various temperatures.

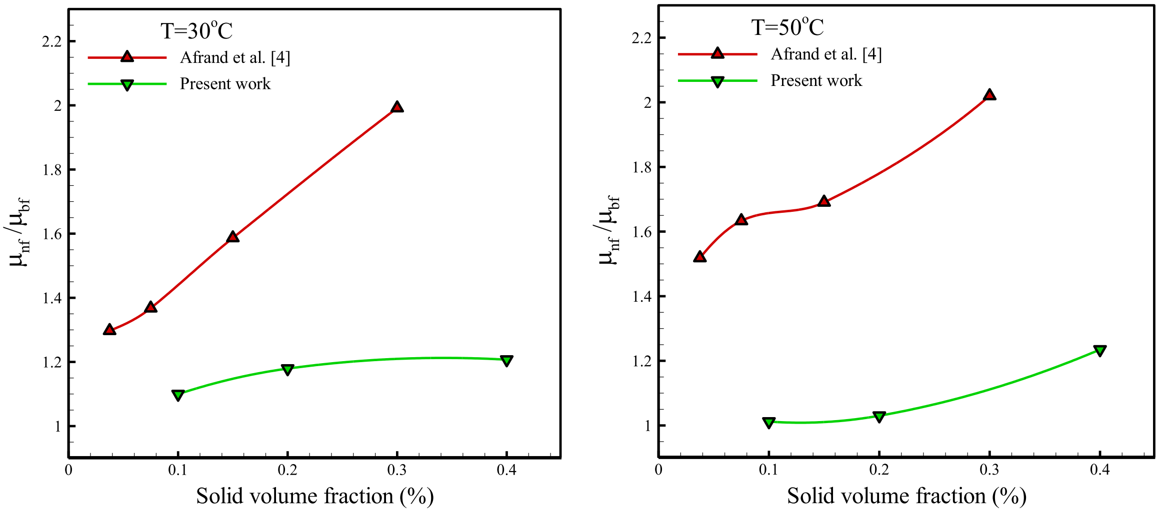

**Fig. 4.** Comparison between previous experimental work [4] and present experimental data at various temperatures.

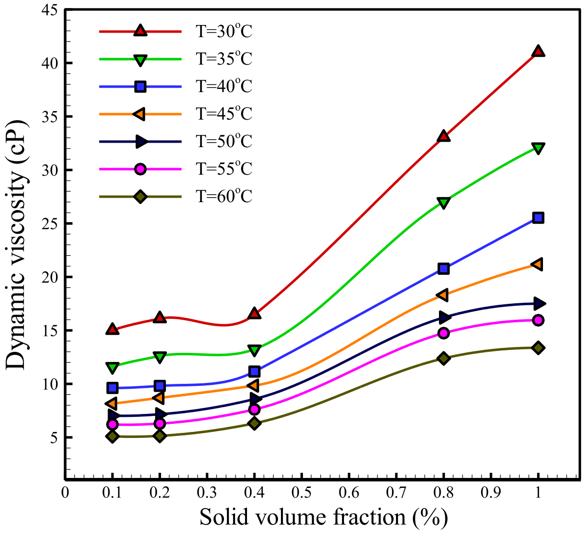

**Fig. 6.** Variations of dynamic viscosity with nanoparticles volume fraction at different temperatures.

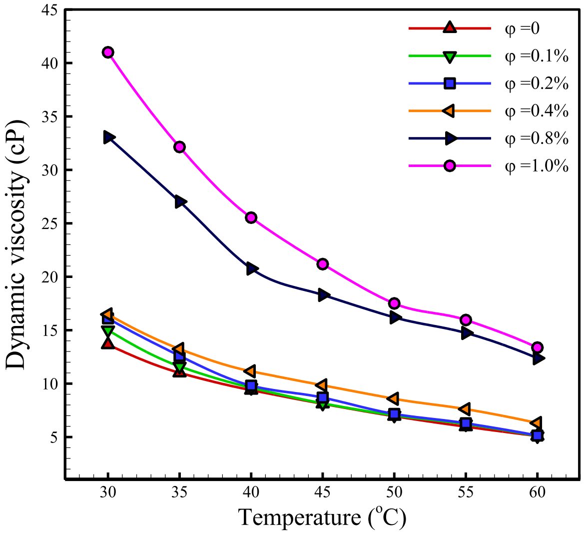

**Fig. 7.** Variations of dynamic viscosity with temperature at different nanoparticles volume fractions.

It can also be found that the enhancement of dynamic viscosity at lower volume concentrations (0.1%, 0.2% and 0.4%) is less, while it is very significant at higher volume concentrations (0.8% and 1%). The reason may be related to the connecting the nanotubes to each other and consequently forming a chain of nanotubes.

Fig. 7 shows the dynamic viscosity of hybrid nanofluid versus temperature at nanoparticles volume fractions. It can be understood that the dynamic viscosity decreases with increasing temperature. This is due to fact that, at higher temperatures, the energy of molecules and intermolecular distance is higher, resulting in the lower influences of molecules on each other. Moreover, the results reveal that for nanoparticles volume fractions of 0.8% and 1% the effect of temperature on the viscosity of nanofluid is more noticeable.

The effects of temperature and nanoparticles volume fraction on the relative viscosity of hybrid nanofluid are depicted in Fig. 8. It is found that the maximum enhancement of viscosity of MWCNT/MgO-EG hybrid nanofluid is 168%. This occurred at the nanoparticles volume fraction of 1.0% and temperature of 60 °C. This figure also showed that at nanoparticles volume fractions of 0.8% and 1.0% the dynamic viscosity enhancement is much more than that at lower solid volume fractions.

## 5. Proposed correlation

As mentioned in the previous sections, analytical models are not able to appropriate prediction of dynamic viscosity of nanofluids. As a result an empirical correlation is presented to calculate the dynamic viscosity ratio for MgO-MWCNT/EG hybrid nanofluids. The correlation as a function of temperature ($T$) and volume fraction ($\varphi$) can be written as follows:

$$\frac{\mu_{nf}}{\mu_{bf}} = \left[0.191\varphi + 0.240\left(T^{-0.342}\varphi^{-0.473}\right)\right]\exp\left(1.45T^{0.120}\varphi^{0.158}\right) \tag{5}$$

This correlation is valid for volume fractions $< 1\%$ and the temperature range between 30 and 60 °C.

In order to evaluate the accuracy of new proposed correlation and for demonstrating the deviation at each experimental measurement, the comparisons between experimental data and correlation outputs at different temperatures are presented in Fig. 9. As can be seen, in most measurement data, the points related to the experimental results and correlation overlap each other and

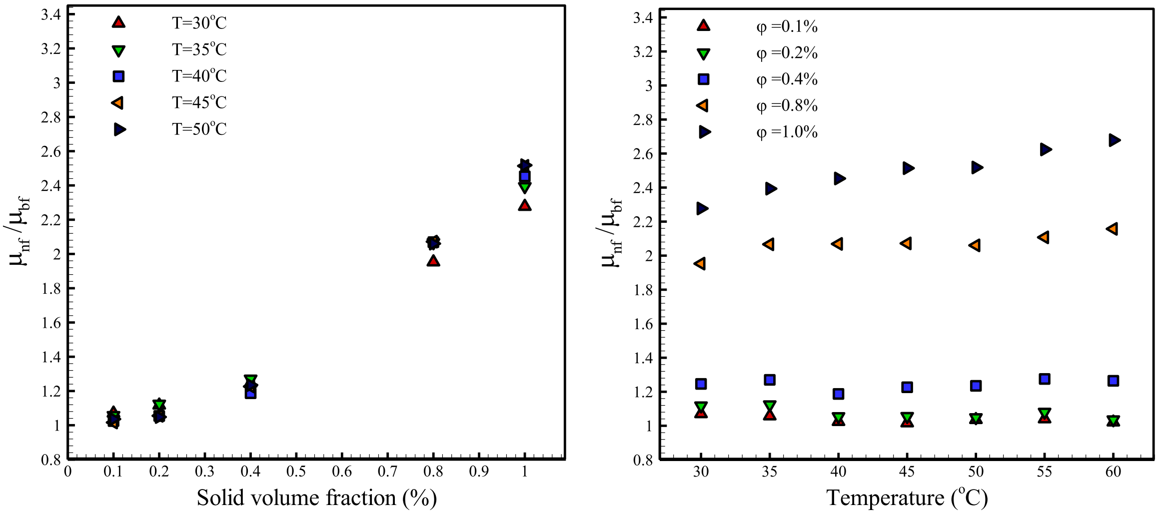

**Fig. 8.** Variations of relative viscosity with solid volume fraction at different temperatures (left), with temperature at different solid volume fraction (right).

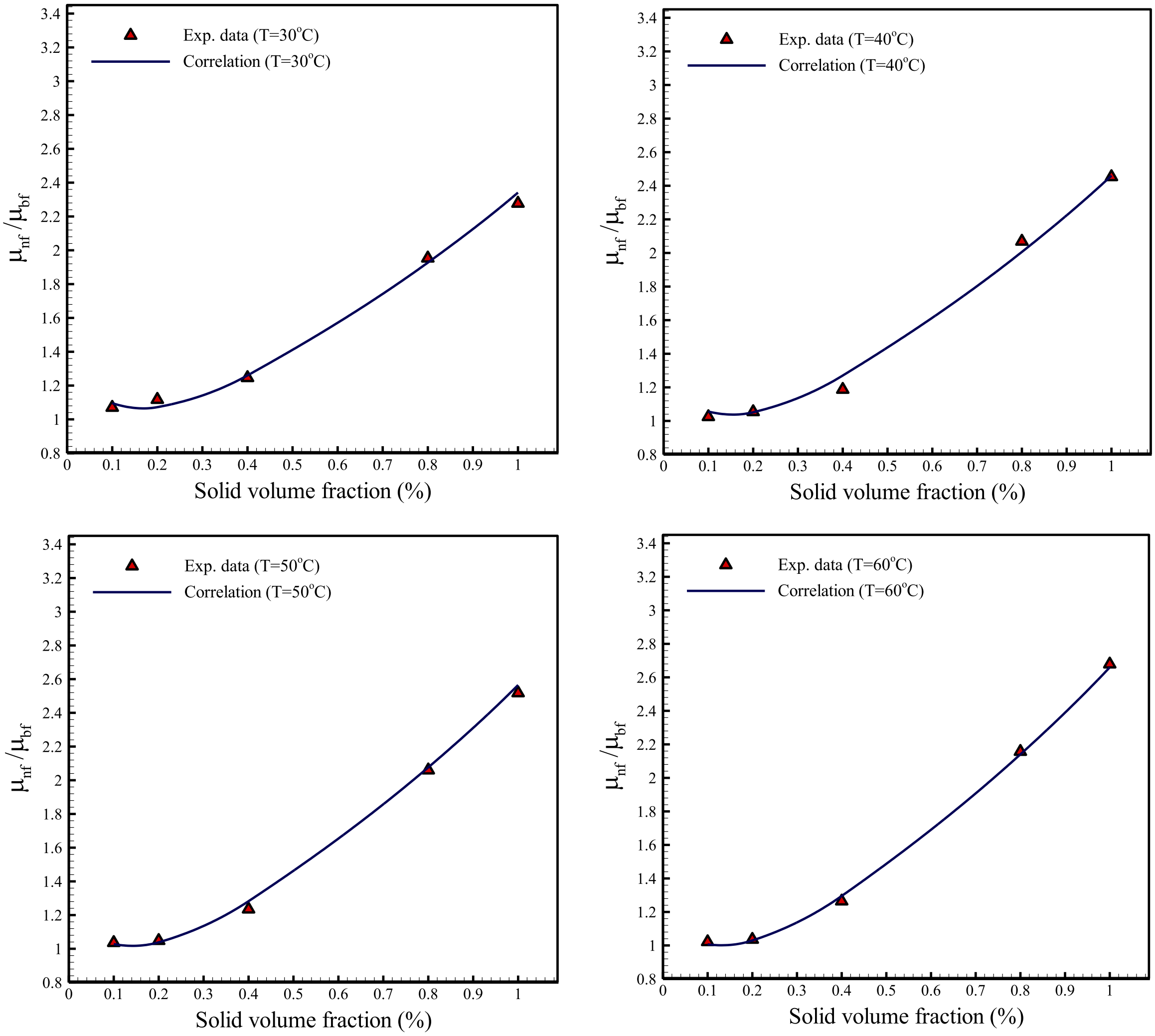

**Fig. 9.** Comparison between experimental data and correlation outputs for relative viscosity at different temperatures.

show a small deviation. This behavior implies that the proposed correlation has an acceptable accuracy.

## 6. Conclusion

In the present study, the effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluid were examined. The viscosity of different volume concentrations (0.1%, 0.2%, 0.4%, 0.8%, and 1%) of MgO-MWCNTs/EG hybrid nanofluid was measured in the range from 30 °C to 60 °C. The experiments performed at the shear rate ranging from 24.46 $s^{-1}$ to 122.3 $s^{-1}$. The measurements at various shear rates showed that the hybrid nanofluid behaves as a Newtonian fluid for all nanoparticles volume fractions and temperatures considered. The measurements also indicated that the dynamic viscosity increases with increasing the nanoparticles volume fraction and decreases with temperature rising. Furthermore, the results reveal that for nanoparticles volume fractions of 0.8% and 1.0% the effect of temperature on the viscosity of nanofluid is more noticeable. The results also showed that the enhancement of dynamic viscosity at lower volume concentrations (0.1%, 0.2% and 0.4%) is less, while it is very significant at higher volume concentrations (0.8% and 1%). Moreover, the relative viscosity revealed that when the solid volume fraction enhances from 0% to 1%, the dynamic viscosity increases up to 168%. Finally, using experimental data, in order to predict the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluids, the new correlation was suggested. The comparisons between the correlation outputs and experimental results showed that the suggested correlation has an acceptable accuracy.

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