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An Empirical Investigation on the Dynamic Viscosity of $Mg(OH)_2$- Ethylene Glycol in Different Solid Concentrations and Proposing New Correlation Based on Experimental Data

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Abstract

In the present study, the dynamic viscosity of the $Mg(OH)_2$-ethylene glycol(EG) nanofluid is investigated. The studied nanofluid in different solid volume fractions of 0.1%, 0.2%, 0.4%, 0.8%, 1%, 1.5% and 2% at the temperatures of 23 and 55°C with diameter particle size of 10 nanometer are measured. In addition, by investigating the shear rate of the nanofluid at various sizes and measuring the dynamic viscosity of the nanofluid, the Newtonian behavior of this nanofluid is proofed. Regarding the weakness of the previous correlations for predicting the dynamic viscosity of this nanofluid and according to the experimental correlations, a new equation is proposed. The results show that by increasing the solid volume fraction, the dynamic viscosity is increased. This increase is by far more at lower temperatures compared with higher temperatures. Also, at the temperature of 55°C, the solid volume fraction has no great effect on the dynamic viscosity of the nanofluid which this issue can be take into account as an important achievement in the industrial and engineering applications.

Keywords: Dynamic viscosity, Ethylene glycol based Nanofluid, $Mg(OH)_2$, Newtonian fluid

INTRODUCTION

A suspension of nano-sized particles in based fluids has been called 'nanofluid'. It has been found that nanofluids are capable to provide a significant heat transfer development in comparison with conventional fluids such as water and ethylene glycol. In recent decade, nanofluids grabbed the interest of many researchers as well as the industrial applications as their usage in different thermal engineering systems such as nuclear reactor, solar energy and so on.

The impacts of the solid volume fraction and the shear rate on the viscosity of Fe_2O_3-diluted water nanofluid were investigated experimentally by Phuoc et al. [1]. An experimental investigation on Al_2O_3-water and TiO_2-water nanofluids containing nanoparticles with mean diameters 13 and 27 nm respectively, were conducted by Pak and Cho [2]. They applied these investigations for solid volume fractions up to 10% in order to measurement the viscosity of nanofluids and observed that with increasing the solid volume fraction, the viscosity of nanofluids increased considerably. In another empirical study, the viscosity of CuO-ethylene glycol and water was measured by Namburu et al. [3]. They observed that Cuo nanofluid shows Newtonian behavior in a mixture of EG-water for solid volume fraction differing up to 0.0612. A study on the CuO-water nanofluid with solid volume fractions between 0.05 and 0.15 was conducted experimentally by Kulkarni et al. [4]. They observed that the nanofluids behave as non-Newtonian fluids in various temperatures, ranging from 5 to 50°C. Kulkarni et al. [5] conducted an experimental study on the copper oxide-water nanofluid. They declared that with solid volume fraction between 0.05 and 0.15, the nanofluid shows the non-Newtonian behavior in the temperature ranging from 5 to 50°C. The impacts of temperature, size of the particles, shear rate and solid volume fraction on the viscosity of Al_2O_3 based nanofluids have been published by Prasher et al. [6]. Their results indicated that viscosity is not dependent on shear rate, so it is proving that nanofluids are Newtonian in nature. The impacts of the solid volume fraction and shear rate on the viscosity of Fe_2O_3 nanoparticles in diluted water as a base fluid were measured by Phuoc et al. [7]. They indicated that the fluid shows non-Newtonian behavior at higher solid volume fraction (>0.02). In another experimental investigation, the viscosity of CuO nano-sized particles which is dispersed in ethylene glycol and water were reported by Namburu et al. [8]. Their observations also showed that CuO–Eg and CuO-water nanofluids exhibit Newtonian behaviour for solid volume fraction differing up to 0.0612. There are some investigations on the viscosity of nanofluids which show the effect of the solid volume fraction and temperature on the viscosity [9-21]. The viscosity of the water based nanofluids containing Al_2O_3 nano-sized particles ranging from 0.01 to 0.3 vol.% was measured by Lee et al. [22]. They reported considerable decrease in the viscosity of Al_2O_3 –water nanofluids with temperature and also nonlinear increase with the solid volume fraction. In another study, Kulkarni et al. [23] reported non-Newtonian behavior for the copper oxide-water nanofluids at solid volume fractions of 5 to 15% in the temperature ranging from 5 to 50°C. The impacts of the solid volume fraction and the shear rates on the viscosity of magnetic-deionized water nanofluids were studied by Kwon et al. [24].

In the present study, the effects of different solid volume fractions on the dynamic viscosity of $Mg(OH)_2$ were investigated. Also, the Newtonian behavior of nanofluid is studied and the results were presented in this article. In addition, a comparison between the experimental data and theoretical equations, which proposed by other researchers, were applied. Furthermore, a new correlation was proposed to predict the dynamic viscosity of $Mg(OH)_2$-EG nanofluid in solid volume fraction less than 2%. Based on the authors' Knowledge, no comprehensive research was done on the changes of the viscosity with the changes in the solid volume fraction of the $Mg(OH)_2$-ethylene glycol so far. Therefore, regarding the importance of this parameter, viscosity, and the necessity to comprehension of its effects, the present investigation was applied.

Nanofluid Preparation

As the experimental sample, the $Mg(OH)_2$-EG nanofluid produced by two-step method was used without using any surfactant. Also, Mechanical mixture was used in order to dispersing the nano-sized particles into seven solid volume fraction such as 0.1%, 0.2%, 0.4%, 0.8%, 1%, 1.5% and 2%. For the given solid volume fractions of the nanofluid, an precise amount of $Mg(OH)_2$ with diameter of 10 nanometers is added to the ethylene glycol and after that a magnetic stirrer is used in order to mix the particles and ethylene glycol for 2 h. In the next step, an ultrasonic processor with the power of 400W and frequency of 24 kHz was used and the suspension is inserted inside it for 5 h in order to breaks down the agglomeration between the particles and also prevent the sedimentation problem. By using this method, the samples are remained stable for a long period of time (at least 7days) and no sedimentation is noticed with naked eyes.

A

B

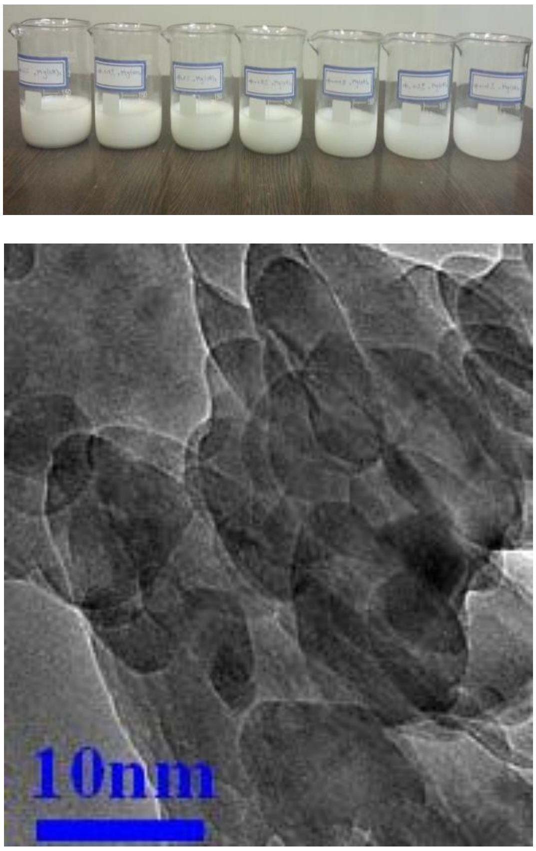

Figure 1. (A) Prepared nanofluid with two-step method (B) TEM image of $Mg(OH)_2$-ethylene glycol nanoparticles with diameter of 10 nanometers

Viscosity Equipment

The viscosity of the nanofluid was measured using Brookfield viscometer (LVDV-I PRIME) equipped with an UL adapter (Fig. 4) supplied by Brookfield engineering laboratories of USA.

Figure 2. Brookfield rheometer

Newtonian behavior

Since there are some discussion in the realm of the rheological behavior (Newtonian or non-Newtonian), for instance Kabelac and Kuhnke [25] indicated that for Al_2O_3 nanofluid the viscosity would decrease in different shear rates while quite the contrary, the results of another investigation on the viscosity of TiO_2-water nanofluids, which conducted by Fedele [26], showed the Newtonian behavior. In this study, the rheological investigation of $Mg(OH)_2$ was conducted in order to characterize the produced nanofluid. The Newtonian behavior's equation of a nanofluid is defined as

$$\tau=\mu\gamma$$

Where $\boldsymbol{\tau}$ represents the shear stress, $\boldsymbol{\mu}$ and $\boldsymbol{\gamma}$ are the shear rate and the dynamic viscosity, respectively.

The viscosity measurement was done by a Spindle type Brookfield rheometer and showed that shear rate features are more or less linear. So, the results confirm a Newtonian behavior of the fluid ranging from 0% to 2% solid volume fraction. Fig.3 shows the viscosity as a function of shear rate in different temperatures and confirms the Newtonian behaviour of this nanofluid.

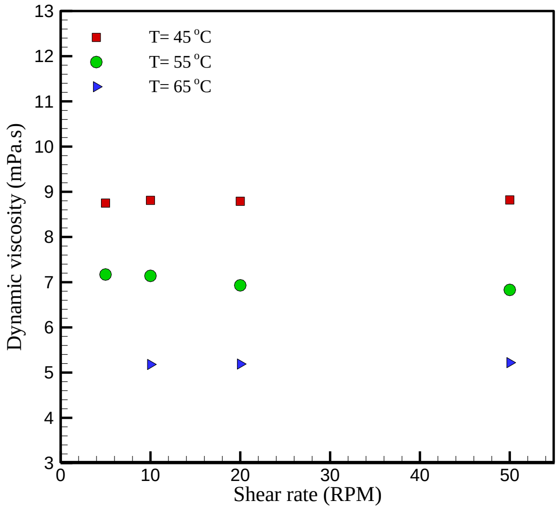

Figure 3. Dynamic viscosity with respect to shear rate for $Mg(OH)_2$-EG nanofluid at solid volume fraction of 0.8%.

Validation

In order to assessment the validity of the measurement, the results of the measured viscosity of ethylene glycol are compared with the results of the investigation of Yu et al. [27]. Fig.4. shows the compared results as clearly as possible. As it can be seen in the Fig.4.the results of the present study are in accordance with the results of Yu et al.

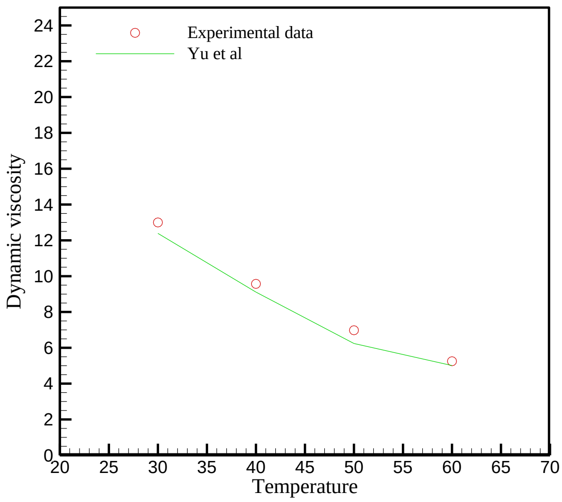

Figure 4. Viscosity of ethylene glycol as a function of temperature.

Comparison

Fig.5. illustrates the viscosity of $Mg(OH)_2$ –EG nanofluid by using the theoretical equations and experimental data. As it can be clearly seen in the Fig. 5, the rheological equations have no acceptable capability so as to make a precise prediction of this nano-fluid's behavior at different solid volume fractions.

In Fig.5 and 6, the obtained experimental viscosities were compared by Hemmat et al.[28] and Batchelor [29] correlations, respectively.

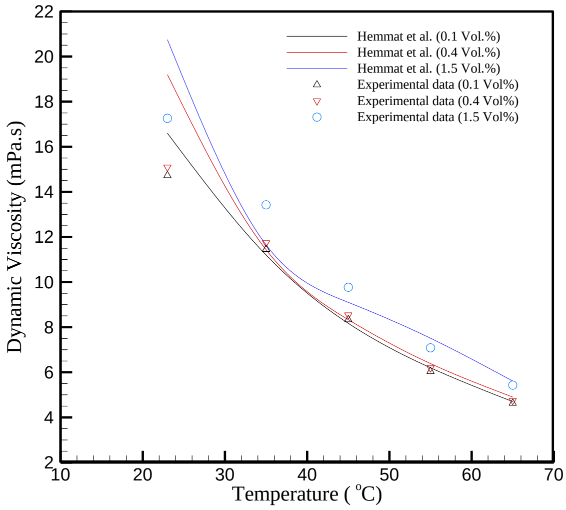

Figure 5. Comparison between experimental data versus Hemmat et al.[28] equation.

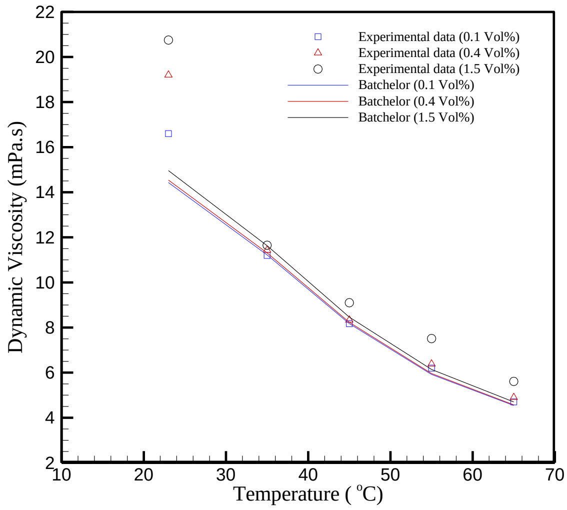

Figure 6. Comparison between experimental data against Batchelor[29] equation.

The measured data of the dynamic viscosity of $Mg(OH)_2$ –EG nanofluid in the temperature of 23 and 55°C and at different solid volume fractions is showed in the Fig.7. As it can be clearly seen in Fig.7 at both of the studied temperatures, by increasing the solid volume fraction of the nanoparticles, the dynamic viscosity increased. This increase is by far the most at the temperature of 23°C compared with 55°C. Also, by increasing the temperature (from 23 to 55°C), the dynamic viscosity is decreased. This decrease is by far the most tangible at high solid volume fraction and on the contrary at the low solid volume fractions, it is very less. According to this figure, it can be pointed out that the effect of solid volume fraction on the viscosity of the nanofluid at higher temperature is by far less than lower temperature. This issue can be useful in the applications of this fluid in the heat exchangers, radiators, heating and cooling systems, etc. The slight increase in the viscosity at high solid volume fractions besides considerable increase in thermal conductivity can play an important and effective role on the heat transfer. The evaluation of the thermal conductivity of this nanofluid in the range of the studied solid volume fractions can take into account as an important issue in the rest of this study.

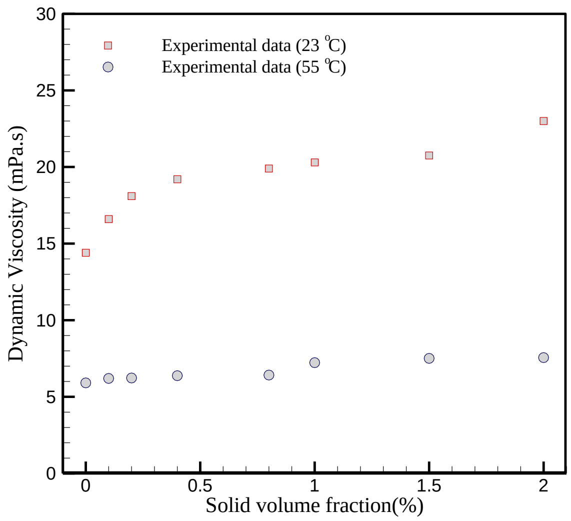

Figure 7. The dynamic viscosity of $Mg(OH)_2$ –EG nanofluid in the temperature of 23 and 55°C and at different solid volume fractions

Fig.8. shows the percentage of increase in the dynamic viscosity of the nanofluid by changing the solid volume fraction and with respect to the based fluid. As it can be clearly seen in the Fig.8.the highest percentage of the viscosity take place in corresponding with the highest solid volume fraction of 2%.The maximum enhancement of this increase are 59.7% and 27.3% at the temperatures of 23 and 55°C, respectively. In general, with decreasing the solid volume fraction the percentage of the enhancement in viscosity decreases although there are some exceptions such as the solid volume fraction of 0.8%.

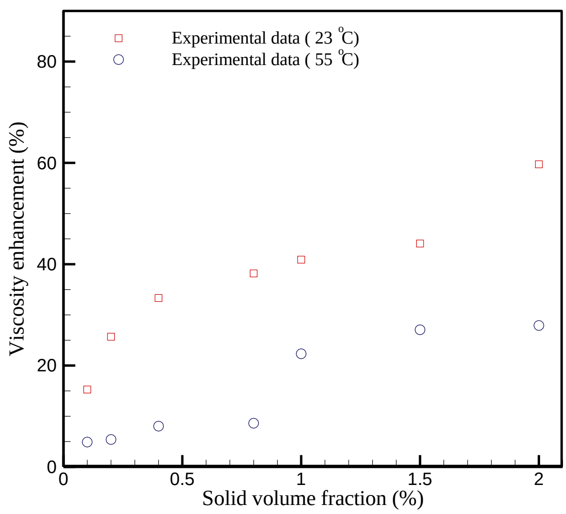

Figure 8. the percentage of increase in the dynamic viscosity of the nanofluid by changing the solid volume fraction and with respect to the based fluid

Proposed Model

According to the experimental data of the $Mg(OH)_2$-EG at the temperature of 23°C and in the different solid volume fractions, an equation is proposed. This equation is the first one in order to predict the viscosity of the $Mg(OH)_2$-EG in the solid volume fractions less that 2%. Based on the authors' knowledge, no other correlation was proposed by this aim for this nanofluid. The proposed model is in the following form

$$\mu_{nf} = 15.89 + 614.4\varphi - 14526\varphi^2$$

The equation is extracted from curve fitting on the experimental data as showed in the Fig.9.

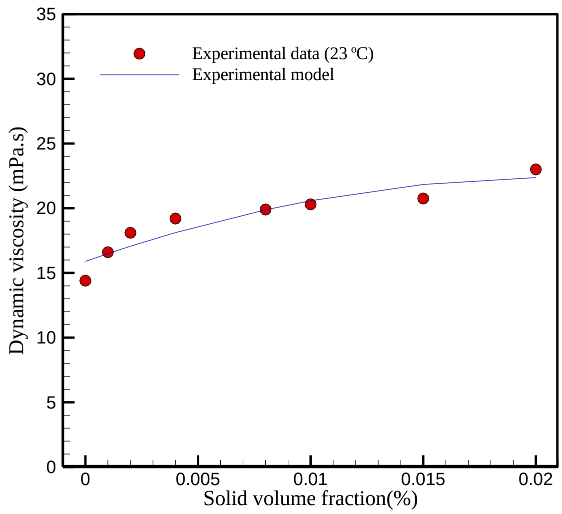

Figure 9. Comparison between theoretical models and experimental data.

Margin Of Deviation (%)

In order to assurance the proposed experimental model in this study, in the Fig.10.the margin of deviation with the experimental data in other temperatures is showed. As this figure shows, in the range of the studied solid volume fraction, the maximum margin of deviation is 7.03% and the minimum one is 0.12%. Regarding to this margin of deviation area, this equation is taken into account as an acceptable correlation in the temperature rate from 23 to 55°C in the solid volume fraction less than 2% for this nanofluid.

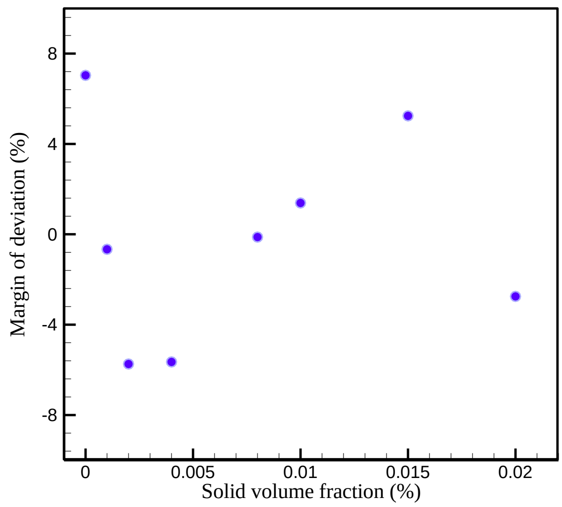

Figure 10. Measured margin of deviation with respect to solid volume fraction.

CONCLUSION

In the present investigation, the dynamic viscosity of the $Mg(OH)_2$-EG nanofluid at two temperatures of 23 and 55°C for different solid volume fractions(0.1%, 0.2%, 0.4%, 0.8%, 1%, 1.5%, 2%) were measured. Investigating the Newtonian and non-Newtonian behavior of the nanofluid, comparing the experimental data with theoretical ones, investigating the percentage of increasing in the viscosity with changes the solid volume fraction, proposing an equation in accordance with solid volume fraction and investigating the margin of deviation are studied in this paper.

The results of the study are showed that the viscosity of the nanofluid at low temperatures are firmly dependent on solid volume fraction which this dependency is very limited for the higher temperatures. In addition, the viscosity of this nanofluid is extremely related to temperature. Also, with decreasing the temperature in higher solid volume fractions, the viscosity increased more slightly which this issue must be considered in the applications related to heat transfer.

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