

# Thermal conductivity and viscosity of Mg(OH)<sub>2</sub>-ethylene glycol nanofluids

## Finding a critical temperature

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**Abstract** A series of experiments have been carried out to determine the thermal conductivity and viscosity of a novel nanofluid, i.e., Mg(OH)<sub>2</sub>/ethylene glycol (EG). The thermal conductivity and viscosity of nanofluids with volume fractions by 2 % in the temperature range of 25–55 °C are measured. The results unfold that in the temperature of 35 °C, called critical temperature, the ratio of nanofluid viscosity to water viscosity is minimized. This critical temperature reveals that it is more advantageous to use Mg(OH)<sub>2</sub>/EG nanofluids instead of water at temperatures higher than 35 °C from the pressure drop and pumping power viewpoint.

**Keywords** Critical temperature · Viscosity · Thermal conductivity · Nanofluid · Pressure drop

## Introduction

So far, extensive studies, both theoretically and experimentally, have been performed on methods of preparation [1–4], thermophysical properties [5–9], and applications of nanofluids [10–12]. After preparation and applying special

methods to stabilize of nanofluids, it is essential to determine the thermophysical of stable suspensions. By measurement of thermophysical properties such as thermal conductivity and viscosity, the performance of thermal engineering devices can be estimated. Here, some of recent papers on the properties of nanofluids are briefly reviewed.

Gallego et al. [13] reported the data on the thermal conductivity, viscosity, and density of ZnO/ethylene glycol (EG) nanofluids for different temperatures, sizes of nanoparticles, and volume fractions. By measuring the viscosity in the temperature range between 10 and 50 °C and volume fractions up to 4.7 %, it was found that the nanofluid behaves as a Newtonian fluid. Thermal conductivity of nanofluids with volume fractions up to 6.2 % was measured and showed a nonlinear enhancement with temperature. In addition, a decrease in size led to increases in thermal conductivity. Hemmat Esfe et al. [8] conducted an experimental investigation on thermal conductivity of MgO-EG nanofluid in different temperatures ranging from 22 to 55 °C and solid volume fractions up to 5 %. They observed that the impact of particle size and solid volume fraction is bigger than the effect of temperature on the thermal conductivity. Cabaleiro et al. [14] measured the properties of cylindrical shape nanoparticles of ZnO suspended in ethane-1,2-diol (ED) and in a {ED (1) + water (2)} mixture. They compared their results on thermal conductivity and viscosity with the available models in the literature. An experimental study on the thermal conductivity of Al<sub>2</sub>O<sub>3</sub>-water nanofluid in different solid concentrations and temperatures has been done by Hemmat Esfe et al. [5]. They proposed a model to predict the thermal conductivity as a function of solid concentration and temperature. Said et al. [15] measured the properties of Al<sub>2</sub>O<sub>3</sub> nanoparticles suspended in two different base fluids including water and a mixture of water and EG. They found that there is no

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considerable penalty in the pressure drop when nanofluids with low concentrations are used instead of base liquids. Yu et al. [16] performed an investigation on thermal conductivity and viscosity of aluminum nitride nanofluid. They have found that the effect of temperature on the thermal conductivity is negligible. Su et al. [17] experimentally studied the thermal conductivity, viscosity, and surface tension of the CNTs–ammonia binary nanofluids. They found that increases in the ammonia concentration have no considerable effect on the nanofluid thermal conductivity. In another experimental investigation, thermal conductivity of ZnO-EG nanofluid was measured by Kim et al. [18]. They observed that the thermal conductivity measured experimentally is higher than the value calculated based on the Hamilton–Crosser correlation.

Ghanbarpour et al. [19] measured the thermal conductivity and viscosity of Al<sub>2</sub>O<sub>3</sub>/water nanofluids with mass concentrations up to 50 %. They reported that the thermal conductivity enhances by 87 % and viscosity increases up to 300 % in the temperature range of 293–313 K. Hemmat Esfe et al. [20] presented the data on viscosity and thermal conductivity of MgO/water nanofluids and investigated their potential for application in double tube heat exchangers under turbulent flow. In another work, Hemmat Esfe et al. [21] measured thermal conductivity and viscosity of COOH-functionalized DWCNTs/water nanofluids with volume fractions up to 0.4 % and temperatures between 300 and 340 K. Recently, Estelle et al. [22] measured thermal conductivity and viscosity of CNTs/water nanofluids where lignin was used as a surfactant. They indicated that using lignin instead of sodium dodecyl benzene sulfonate (SDBS) can reduce the viscosity, while the thermal conductivity changes are negligible.

The main aim of the present work is to study thermal conductivity and viscosity of a novel nanofluid, i.e., Mg(OH)<sub>2</sub>/EG. The results are presented for volume fractions up to 2 % and different temperatures. Interesting trends are observed in the viscosity variation with temperature. This suggests defining a critical temperature that will be discussed in details in the next sections.

### Nanofluid preparation

To prepare Mg(OH)<sub>2</sub>-EG nanofluids, a two-step procedure has been applied without using any surfactant. Nanofluids in seven concentrations including 0.1, 0.2, 0.4, 0.8, 1, 1.5, and 2 % by volume are formulated. To make a given nanofluid concentration, a specified value of Mg(OH)<sub>2</sub> nanoparticles is gradually added to EG and simultaneously a magnetic stirrer is used to mix the particles with the base liquid. This process takes about 2 h. After that, the suspension is inserted in an ultrasonic vibrator (20 kHz, 400 W, Topsonic, Iran) for 5 h

to increase the stability time of nanofluids. It was observed that nanofluids are stable for at least 1 week without any visible sedimentation.

Figure 1 shows TEM and XRD images of the nanoparticles. This figure describes the shape and size of nanoparticles. The average size of nanoparticles is obtained by using the data of XRD image (bruker-D8 Germany) and Debye–Scherrer relation [23]:

$$d = \frac{0.89\lambda}{\beta \cos \theta} \quad (1)$$

where  $d$  is nanoparticle diameter,  $\lambda$  is X-ray wavelength (1.5406),  $\beta$  is the peak width, and  $\theta$  is the Bragg angle. The analysis of XRD image, performed in our laboratory, shows that the average size of nanoparticles is approximately 20 nm.

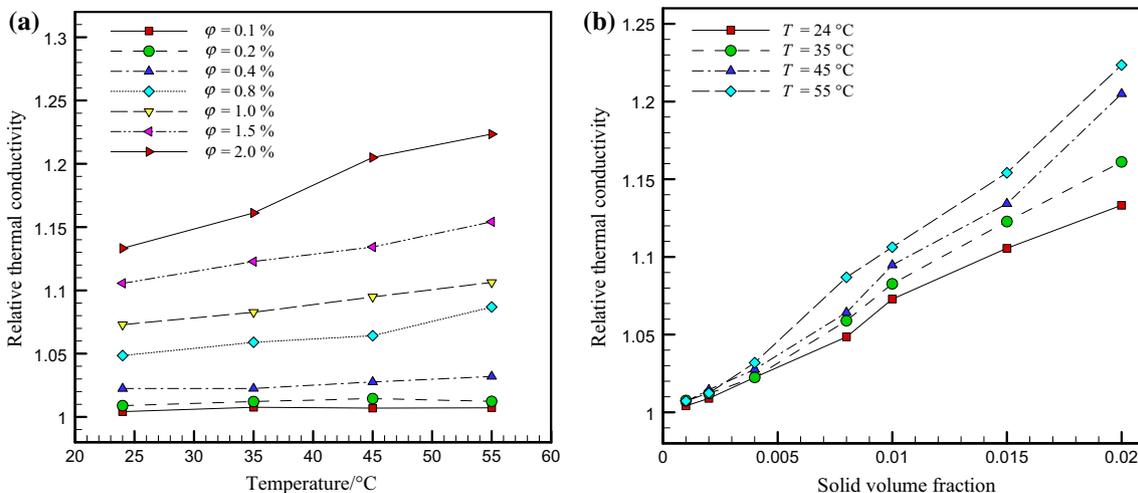
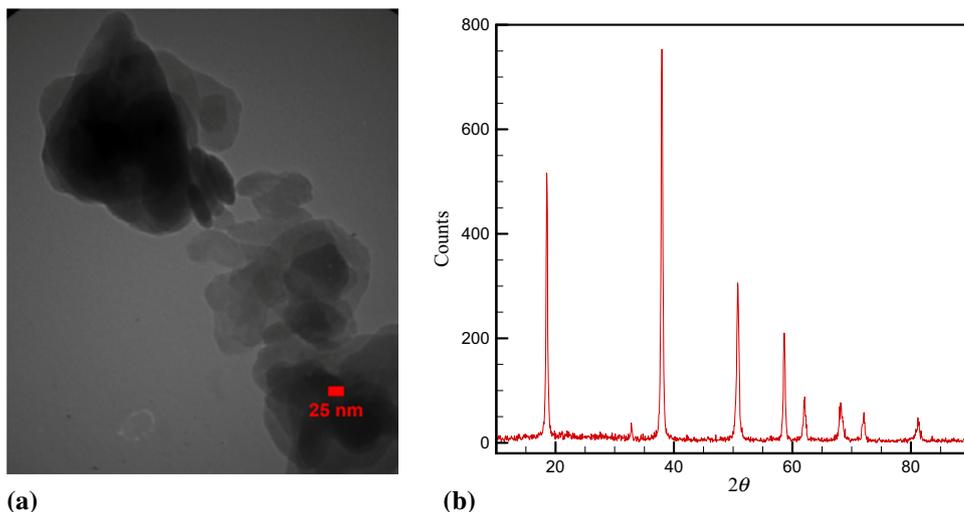
### Thermal conductivity and viscosity measurements

Thermal conductivity of nanofluids is measured using KD2-PRO thermal analyzer that acts based on transient hot wire technique. The accuracy of the device is  $\pm 5$  %. To measure the thermal conductivity of samples, the sensor should be inserted vertically in the liquid to minimize the free convection. Any deviation from vertical position will make errors in the reported data [24]. The viscosity of nanofluid is measured using a Brookfield viscometer (LVDV) equipped with a UL adapter supplied by Brookfield engineering laboratories of USA. The accuracy of this device is  $\pm 5$  %. The measurements are repeated at least five times, and the average values are reported.

### Results and discussion

Figure 2a exhibits variations of relative thermal conductivity with temperature at different volume fractions. As seen, the sensitivity of relative thermal conductivity to temperature increases with an increase in the nanoparticle volume fraction. It is found that for volume fractions <0.4 % and temperature range between 24 and 55 °C, the changes in thermal conductivity with respect to temperature are negligible. This happens because at low concentrations, the number of existing particles in a given volume of nanofluid is low. Therefore, in this case, by assuming a uniform suspension, the distance between solid particles in the liquid is relatively larger than that of high concentrations. With the increases in temperature, although the kinetic energy of particles increases, the high distance between particles avoids a considerable increase in thermal conductivity. However, by increasing the volume fraction of nanoparticles (e.g., volume fractions higher than 0.4 %), the increase in temperature will increase considerably

**Fig. 1** **a** TEM image of nanoparticles, **b** XRD image of nanoparticles



**Fig. 2** Variations of relative thermal conductivity: **a** with temperature at different concentrations, **b** with volume fraction at different temperatures

the number of random collisions between particles because of the close distance of nanoparticles (Fig. 3). Figure 2b displays the variation of relative thermal conductivity with concentration at different temperatures. It is realized that at lower temperatures, the variation of relative thermal conductivity with concentration is more linear. For volume concentration of 2 %, the thermal conductivity enhancement is about 22 % when the temperature is 55 °C, while at 24 °C the enhancement is about 13 %. Therefore, it is concluded that the role of nanoparticles in the thermal conductivity enhancement of base fluids is more prominent at high temperatures.

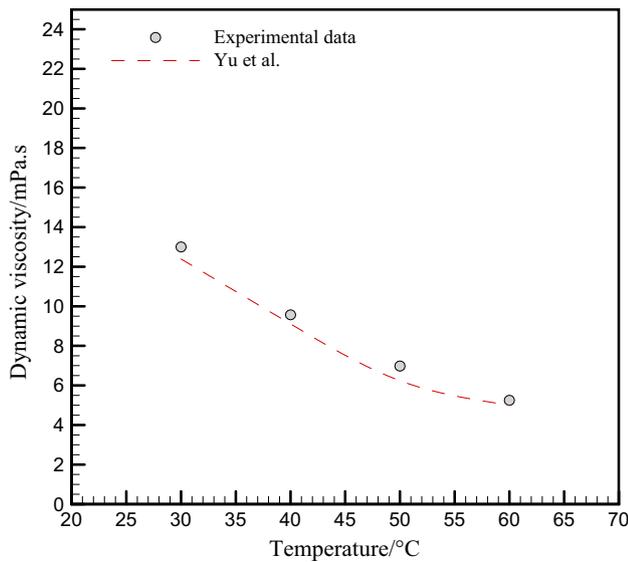
Before measuring the viscosity of nanofluids, the accuracy of viscometer is evaluated. To this end, viscosity of EG is measured at different temperatures and the results are compared with the data available in the literature. Figure 4 reveals that the measured data of viscosity are close to the results reported by Yu et al. [25].

Figure 4 shows the variation of viscosity of Mg(OH)<sub>2</sub>/EG nanofluid with shear rate at solid volume fraction of 0.8 % and different temperatures. The viscosity of a liquid is defined as follows:

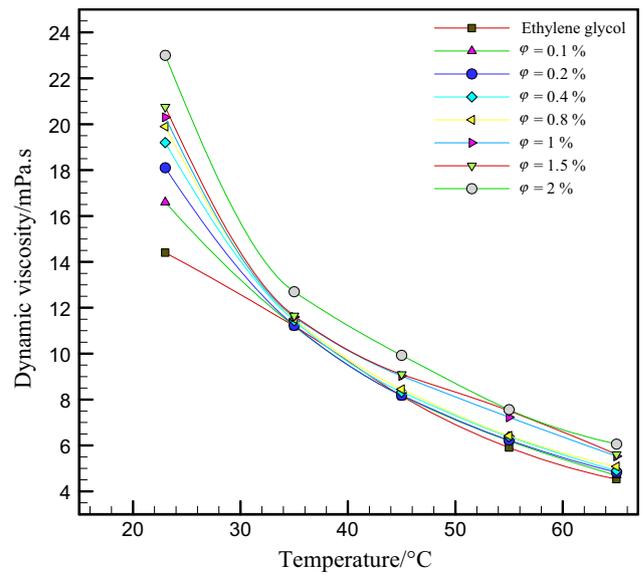
$$\mu = \frac{\tau}{\gamma} \tag{2}$$

where  $\tau$  is the shear stress,  $\gamma$  is the shear rate, and  $\mu$  represents the dynamic viscosity of nanofluid. A liquid is Newtonian when the viscosity is constant for all values of shear rate. Therefore, Fig. 4 indicates that the nanofluid is Newtonian. This trend is observed for all concentrations and temperatures.

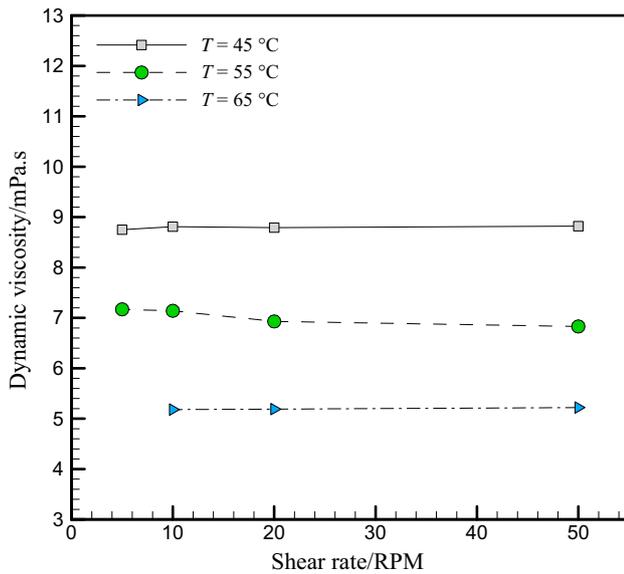
After knowing that nanofluids are Newtonian, the changes of viscosity with temperature and volume fraction are investigated. Figure 5 illustrates the variation of viscosity with temperature for different volume fractions of



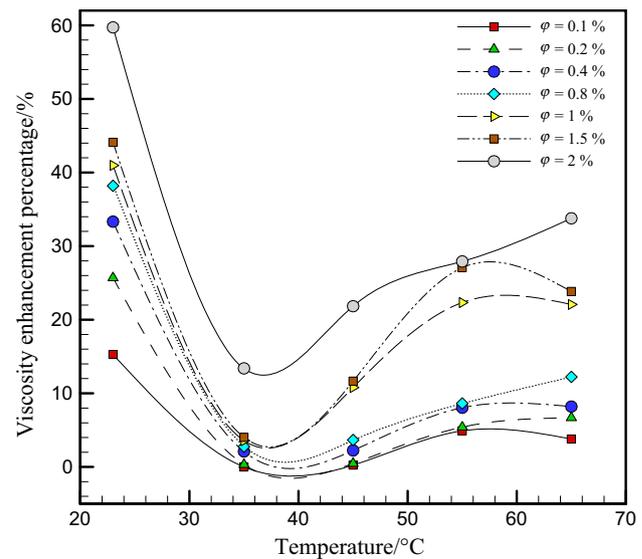
**Fig. 3** Viscosity of ethylene glycol as a function of temperature



**Fig. 5** Dynamic viscosity of the nanofluid at different solid volume fractions and temperatures



**Fig. 4** Dynamic viscosity with respect to shear rate for solid volume fraction of 0.8 %



**Fig. 6** Accurate measure of the dynamic viscosity of the nanofluid at different solid volume fractions and temperatures

nanoparticles. As seen, for temperatures lower than 35 °C, the difference between viscosity of nanofluids and viscosity of EG is higher than that for temperatures higher than 35 °C. In other words, viscosity enhancements due to particle loading are higher for temperatures less than 35 °C. As shown in the figure, the viscosity of all samples decreases with an increase in temperature and a decrease in concentration. It is visible that in the range of tests, the sensitivity of viscosity to temperature is higher than volume fraction. With increase of temperature, the friction between the layers of liquid decreases and, consequently, the viscosity decreases.

Figure 6 shows the variation of viscosity enhancement with temperature for different concentrations. It is clearly observed that the viscosity enhancement is minimized at temperature of 35 °C. Therefore, it can be stated that at temperature of 35 °C, called critical temperature, one can use nanofluids instead of EG by having the minimum viscosity enhancement. Minimum viscosity enhancement implies that increases in pressure drop and pumping power are lowest. As seen, for volume fraction of 2 %, the viscosity enhancements attain 60 and 14 % for temperatures of 24 and 35 °C, respectively.

## Conclusions

In this paper, thermal conductivity and viscosity of a novel nanofluid, i.e.,  $\text{Mg}(\text{OH})_2/\text{EG}$  nanofluid, were measured in the temperature range between 24 and 65 °C. The nanofluids were prepared by using a two-step method at seven concentrations including 0.1, 0.2, 0.4, 0.8, 1, 1.5, and 2 %. The results of this study can be summarized as follows:

The changes in thermal conductivity of nanofluids with temperature are negligible for volume fractions <0.4 %. At lower temperatures, the variation of thermal conductivity with concentration is more linear compared with higher temperatures.

The prepared nanofluids show a Newtonian pattern.

Sensitivity of viscosity to temperature is more than its sensitivity to nanoparticle volume fraction.

A critical temperature was found in which the ratio nanofluid viscosity to EG viscosity is minimized. Therefore, it is suggested that it is better to use the nanofluids for temperatures higher than the critical temperature. In this work, the critical temperature was around 35 °C.

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