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An experimental study on thermal conductivity of MgO nanoparticles suspended in a binary mixture of water and ethylene glycol☆

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ABSTRACT

In the present study, the effects of solid volume fraction and temperature on the thermal conductivity of MgO/water–EG (60:40) nanofluid are discussed. Samples of nanofluid are provided by two step method at different solid concentrations, including 0.1%, 0.2%, 0.5%, 0.75%, 1%, 1.5%, 2% and 3%. The experiments are performed for different temperatures ranging from 20 to 50 °C, using KD2 pro thermal analyzer which employed transient hot wire to measure thermal conductivity. The finding shows that thermal conductivity of nanofluid increases with increasing solid volume fraction or temperature. Based on the experimental data, new correlation for modeling the thermal conductivity of MgO/water–EG (60:40) for different solid volume fractions and temperatures was proposed.

1. Introduction

Heat transfer by using of fluids plays a vital role in many industrial applications including heat exchangers, crystal growth, electronic board cooling and so on [1–4]. Numerous techniques have been applied to improve heat transfer in these applications; whereas the efficiency of pure fluids, in the heat transfer processes, is low. A method to enhance the heat transfer is employing nanofluids [5]. Nanofluids are blends of solid nanoparticles suspended in conventional liquids which have higher thermal conductivity compared to pure liquids [6, 7]. Existing experimental studies on thermal conductivity enhancement of Al_2O_3, CuO, Fe_3O_4, ZnO and MgO nanoparticles in water showed that the thermal conductivity of nanofluid is function of the size of nanoparticles, solid concentration, temperature, and thermo-physical properties of nanoparticles and base fluid [6–13].

As we know, one of the essential applications of nanofluids is its use in heat exchangers. Hence, in the winter, mixture of ethylene glycol and water in various volume percentages is usually used to reduce the freezing point of water. In this regard, several studies were performed to investigate the thermophysical properties of nanofluids consisted of nanoparticles, ethylene glycol and water [14–23]. In the mentioned studies, water and ethylene glycol were mixed in different proportions and the nanoparticles have been dispersed in it. These studies confirmed that adding nanoparticles to a mixture of water and ethylene glycol can enhance the thermal conductivity of nanofluids.

Recently, several equations have been theoretically achieved to predict the thermal conductivity of nanofluids but these models have some defects. For this reason, many researchers have tried to provide correlations with high accuracy to predict the thermal conductivity of nanofluids using experimental data. Here, a brief review of empirical correlations for thermal conductivity of different nanofluids is conducted. An empirical correlation for the thermal conductivity enhancement of Al_2O_3/deionized water nanofluids was reported by Chon et al. [24]. This correlation showed the role of temperature (ranging from 21 to 71 °C) and particle size (range of 11 nm to 150 nm) for nanofluid thermal conductivity enhancement. Li and Peterson [25] experimentally studied thermal conductivity of Al_2O_3/water with particle size of 36 nm over a volume fractions range of 2.0% to 10.0% in temperature ranging from 27.5 °C to 34.7 °C. They proposed an empirical correlation for thermal conductivity ratio of Al_2O_3/water. They also suggested a correlation to predict the thermal conductivity enhancement of CuO/water (29 nm) nanofluids for same mentioned range of temperature and solid volume fraction.

The thermal conductivity of TiO_2/water nanofluid was experimentally reported as a function of temperature and solid volume fractions by Duangthongsuk and Wongwises [26]. Thermal conductivity of MgO/EG nanofluids was measured in a temperature range of 15 °C to 35 °C for volume fractions up to 2.0%. They presented thermophysical correlation for estimating of the thermal conductivity of TiO_2/water nanofluid with particle diameter of 21 nm. Teng et al. [27] presented an experimental correlation to estimate the thermal conductivity ratio of Al_2O_3/water nanofluids for various weight fractions, temperatures and nanoparticles diameter. Hemmat Esfe et al. [28] measured the thermal conductivity of COOH-functionalized multi walled carbon nanotubes/water was at different temperatures (25–55 °C) and solid

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volume fractions (0.05–1%). Using the measurements, they suggested a correlation for estimating of the thermal conductivity ratio of COOH-functionalized MWCNTs/water nanofluids.

Most research reports on the thermophysical properties of nanofluid which use water, ethylene glycol and oil as base fluid. Literature survey reveals that there are a few works on the thermal conductivity of the nanoparticles dispersed in binary mixture of water and ethylene. On the other hand, very few papers are available on magnesium oxide based nanofluids, which has good chemical and physical stability, even though it is not widely investigated. Therefore in the current research, thermal conductivity of MgO/EG–water (40–60%) is measured experimentally. Furthermore, due to lack of model to estimate the thermal conductivity of this nanofluid, some new correlations in terms of temperature and solid volume fraction have been suggested based on experimental data.

2. Experiment

2.1. Preparation of nanofluid

In this work, the nanofluids at volume concentrations of 0.1%, 0.2%, 0.5%, 0.75%, 1%, 1.5%, 2% and 3% are prepared with two step method by dispersing MgO nanoparticles in the mixture of DI water and EG as the base fluid. Depending on the volume fraction, specified amount of MgO nanoparticle with an average diameter of 40 nm is dispersed in mixture of EG and water and after that, the mixture is well stirred. The mixture is stirred for 60 to 80 min, and then the suspension is inserted inside an ultrasonic homogenizer (Topsonic, 400 W, Iran) for 4 h to break down the agglomeration of particles. After 12 h, no sedimentation was observed in any sample of nanofluids with naked eyes. Fig. 1 illustrates the TEM image of nanoparticle.

2.2. Measurement of thermal conductivity

A KD2 Pro device (Decagon Devices, USA) has been utilized to measure the thermal conductivity of nanofluid. In this device, the transient hot-wire method is employed. The KS-1 sensor with 60 mm long and 1.27 mm diameter made of stainless steel is used for thermal conductivity measurement. This sensor was interpolated into a vessel filled with nanofluid located in a stable temperature bath. The sensor operates as a line heat source. Thermal conductivity was characterized by measuring of fluid temperature during cooling and heating phases. By comparing the measured values with available thermal conductivities values for water, it was found that the differences were less than 1% in the temperature range of 25–50 °C. All the measurements of the thermal conductivity were repeated at least three times to make certain the accuracy of measurements.

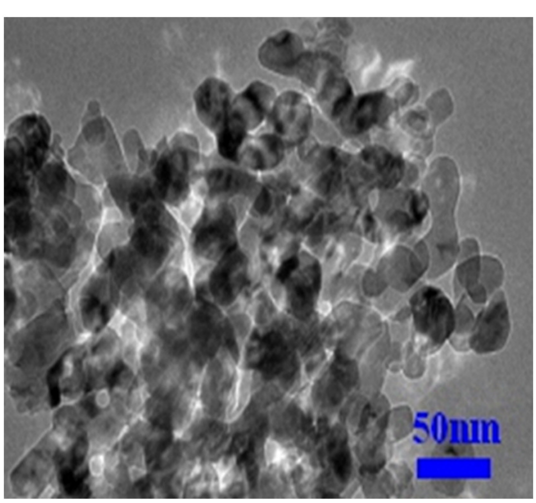

Fig. 1. Transmission electron microscopy (TEM) image of MgO nanoparticles.

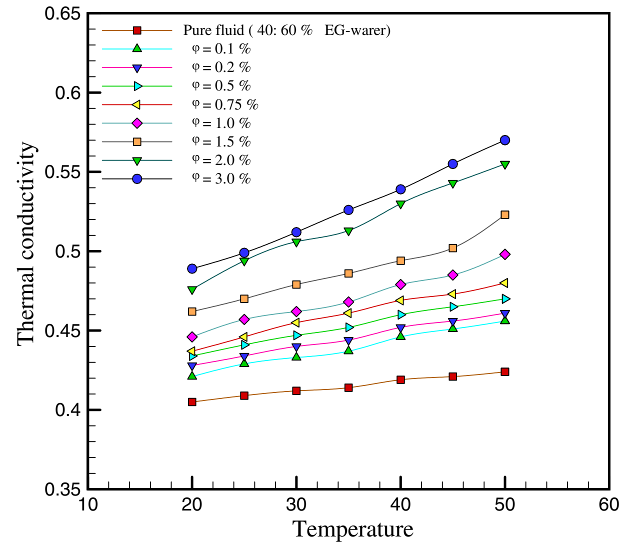

Fig. 2. Variations of thermal conductivity of nanofluid for various temperatures and solid volume fractions.

3. Results and discussion

At the present study, the variations of effective thermal conductivity of MgO/water–EG (60:40) with temperature and particle concentration are studied experimentally. In the next step, to estimate thermal conductivity of above mentioned nanofluid, new correlations have been proposed by using regression at different solid volume fractions and temperatures.

The variations of thermal conductivity of MgO/water–EG (60:40) with various temperatures are depicted in Fig. 2 for various solid volume fractions. As shown in Fig. 2, in all considered solid volume fractions, thermal conductivity of nanofluid increases with increasing temperature. The variations of thermal conductivity with temperature are more tangible at higher concentration. On the contrast, in low solid volume fraction, the temperature doesn't play an important role on the variation of thermal conductivity.

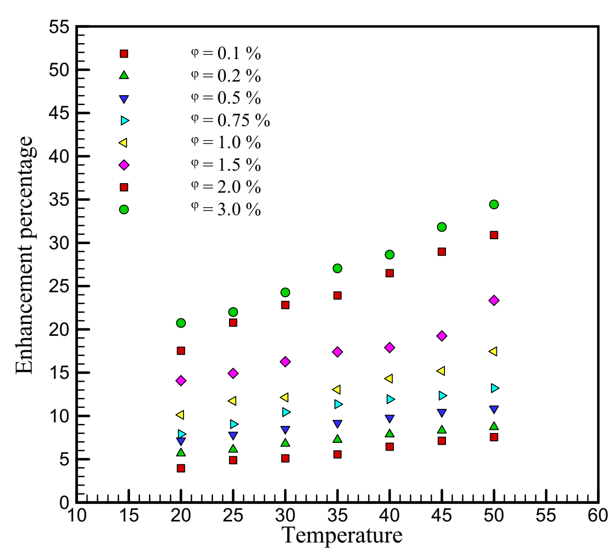

Fig. 3. Enhancement percentage of thermal conductivity with respect to temperature.

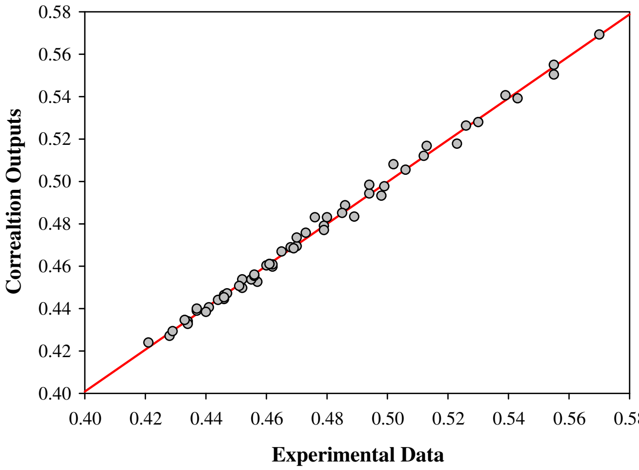

Fig. 4. Comparison between experimental data and correlation outputs.

Thermal conductivity enhancement of MgO/water–EG (60:40) nanofluid for various temperatures and solid volume fractions is plotted in Fig. 3. It is clear in Fig. 3 that thermal conductivity enhancement strongly depends on the solid volume fraction. The temperature has little effect on enhancement percentage at low solid volume fraction. At solid volume fraction higher than 1%, the effect of temperature on enhancement percentage is tangible and visible. Therefore, it can be concluded that the maximum values of thermal conductivity and enhancement percentage have been measured at the highest temperature and solid concentration.

The thermal conductivity of MgO/water–EG (60:40) is varied with temperature and solid concentration. Therefore, to estimate the thermal conductivity of MgO/water–EG (60:40) nanofluid, a new accurate correlation has been derived as follows.

$$k_{nf} = 0.4 + 0.0332\varphi + 0.00101T + 0.000619\varphi T + 0.0687\varphi^3 + 0.0148\varphi^5 - 0.00218\varphi^6 - 0.0419\varphi^4 - 0.0604\varphi^2 \quad (1)$$

To ensure the accuracy of proposed correlation, experimental data are compared with the values obtained from correlation, as shown in Fig. 4. As can be observed in Fig. 4, all of points are on the bisector or in its neighborhood. It indicates that there is an excellent agreement between experimental data and the results of the correlation.

4. Conclusion

Experimental investigation on thermal conductivity of MgO nanoparticles dispersed in binary mixture of water and ethylene glycol has been measured with temperature ranging from 20 to 50 °C for different solid volume fractions up to 3%. According to the results, thermal conductivity of nanofluid increases with an increase in solid concentration or temperature. Furthermore, the rate of changes of thermal conductivity increases with increasing solid concentration. New correlation was proposed for various solid volume fractions and temperatures for MgO/water–EG (60:40) nanofluids. There is excellent agreement between them which shows the accuracy and capability of proposed correlation.

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