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Experimental investigation of the effect of pH on the stability and thermal conductivity of metal oxide nanofluids

Behrouz Raei*

Department of Chemical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

ABSTRACT: The pH level of nanofluids plays an important role in stability and thermal conductivity. However limited studies have been done in this field. In this research, the effect of pH on the stability and thermal conductivity of ZnO-EG nanofluid at concentrations of 0.05 and 0.75% volumetric fraction and MgO-W at concentrations of 0.05 and 0.5% volumetric fraction were investigated. Experimental measurements of the thermal conductivity were performed by a thermal properties analyzer device at a constant temperature of 25 °C. The results showed that the pH strongly affected the stability of nanofluids so that at the pH of the isoelectric point (IEP), complete aggregation and sedimentation were observed. The thermal conductivity of nanofluids has the lowest value at the pH of the isoelectric point, but as the pH moves away from the isoelectric point, the thermal conductivity increases. The highest enhancement in the thermal conductivity of ZnO-EG nanofluid was 63%, which was obtained at a volume fraction of 0.75% and pH = 12. However, the highest enhancement in the thermal conductivity of MgO-W nanofluid was 49%, which was obtained at a volume fraction of 0.5% and pH = 12. Finally, using the experimental results and with the help of curve fitting, equations with good quality were presented to predict the effective thermal conductivity of metal oxide nanofluids.

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1- Introduction

Conventional base fluids such as water, glycols, and oils are used as working fluids in heat transfer devices in a wide range of engineering applications. The thermal efficiency of such devices can be increased by the rising of thermal conductivity of base fluids. This can be achieved when small particles with high thermal conductivity are dispersed in base fluids. However, the dispersion of micro-sized solid particles in the base fluid is not acceptable due to issues related to sedimentation, erosion, fouling, and increased pressure drop. The concept of dispersion of nano-sized solid particles in base fluids, which was developed by Choi et al.[1], has become a popular topic known as nanofluids. To be able to research about nanofluids, preparing these types of fluids in a stable form is a very important factor in starting the work because the stability of nanofluids strongly affects their thermophysical properties [2, 3]. In total, there are three methods for dispersing nanoparticles in base fluids. The first dispersion method is to change the pH value of the fluid, the stability of the nanofluid is directly affected by the zeta potential, which is related to the pH value of the base fluid. The second method is to modify the surface of nanoparticles by using a surfactant. The third method is dispersing by ultrasonic waves, which can produce bubble oscillations and end up with dispersing effects [2].

A review of previous studies shows that the pH level of nanofluids plays an important role in stability and thermophysical properties such as thermal conductivity. However, limited research has been done on the effect of pH on the thermal conductivity of nanofluids. On the other hand, as far as it has been investigated, no general theoretical and experimental correlation has been presented in the field of predicting the thermal conductivity of nanofluids with variable pH. Therefore, the present study aims to experimentally investigate the effect of pH level on the stability and thermal conductivity of metal oxide nanofluids including ZnO-EG and MgO-W. Presenting correlations for predicting the thermal conductivity of metal oxide nanofluids with concentration and pH variables using curve fitting is one of the other goals of this research.

2- Methodology

In this experimental study, zinc oxide and magnesium oxide nanoparticles were used. Nanoparticles are suspended in ethylene glycol and water-based fluids, respectively. Nanofluids have been prepared by two-step method. The transmission electron microscope (TEM) of the used nanoparticles is shown in Fig 1.

*Corresponding author's email: behrouz.raei@iau.ac.ir

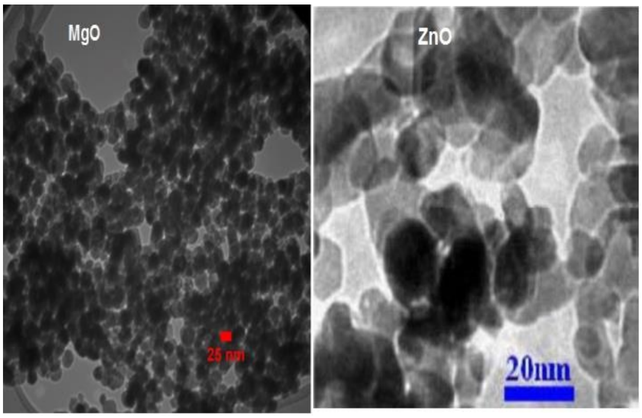

Fig. 1. TEM of nanoparticles

The method of work is as follows: First, appropriate mass amounts of nanoparticles are suspended in 100 cc of base fluid using a digital balance with an accuracy of 4 decimal places. In the next step, the suspension was placed in a magnetic stirrer with medium speed for one hour. Then, using appropriate acid and base, pH adjustment was done for nanofluids. The selection of the pH range has been done so that the pH of the isoelectric point of nanofluids exists in the studied range. In order to eliminate experimental error and check repeatability, each measurement was repeated 3 times under the same conditions. The average measurements were presented as the final results. Uncertainty in the measurement of the thermal conductivity was estimated based on the accuracy of the tools used. Uncertainty in the thermal conductivity of nanofluids was calculated using equation (1) [4]:

$$U_{knf} = \pm\sqrt{\left(\frac{\Delta k_{nf}}{k_{nf}}\right)^2 + \left(\frac{\Delta w}{w}\right)^2} \qquad (1)$$

That U represents the uncertainty in measurement; w indicates the weight of nanoparticles and Δ indicates the measurement error. The maximum uncertainty in the measured thermal conductivity was calculated as 3.1%.

3- Results and Discussion

Monitoring the stability of ZnO-EG and MgO-W nanofluids at different times and pH levels was done using a continuous visualization method with a high-resolution camera. The results showed that immediately after preparation of nanofluid in different pH, they have good stability. But with the passage of time, the aggregation and sedimentation of nanoparticles in the samples is gradually revealed. The highest amount of sedimentation was observed for ZnO-EG nanofluid at pH=9.5 and for MgO-W nanofluid at pH=10.5.The reason for this is that the mentioned pHs are actually the pH of the isoelectric point of nanofluids [5].At this pH level, the repulsive forces between the particles are zero and as a result, the particles stick together. Therefore, when the pH is close to or equal to the pH of the isoelectric point, the suspension is unstable. However, with the increase of the pH difference relative to this point, the hydration force between the particles increases, the value of the zeta potential of the nanoparticle surface is increased, as a result of which the movement of the nanoparticles in the suspension increases and causes more stability of the nanoparticles[6].

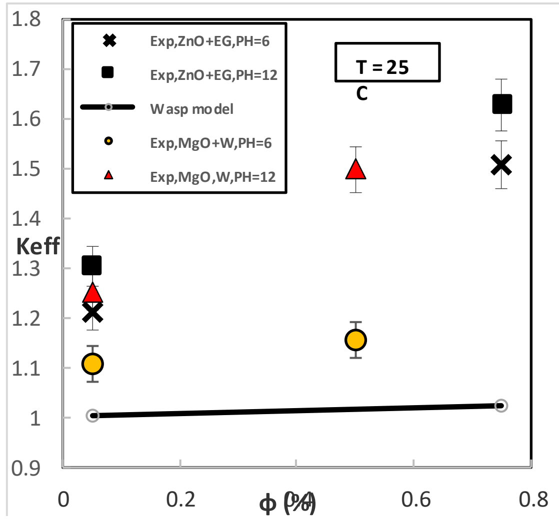

Fig. 2. Comparing the experimental results with the predicted values of the classical model for the thermal conductivity of ZnO-EG and MgO-W nanofluids

The experimental effective thermal conductivity values obtained from ZnO-EG and MgO-W nanofluids were compared with the effective thermal conductivity predicted by classical models, including the Wasp model [7]. Figure 2 shows this comparison. It is evident from the mentioned figure that the classic Wasp model is unable to predict the thermal conductivity of nanofluid.

Therefore, the existing classic models do not provide an accurate prediction of the thermal conductivity of nanofluids. On the other hand, no equation has been provided to predict the effective thermal conductivity of nanofluids with concentration and pH variables. Therefore, using the obtained experimental results and with the aid of the curve fitting method, new correlations were presented. Curve fitting evaluation parameters are presented in Table 2. The parameters include R^2 (regression coefficient), AARD (average absolute relative deviation) and MSE (mean square error). In Table 2, R^2 for the prediction of k_{eff} are very close to 1, and the values of AARD and MSE are very low. Therefore, it can be said that the proposed equations have good predictability.

4- Conclusions

The main results of the research are summarized in the following cases:

Table 2. Regression parameters

Nanofluid / Parameter	MgO-W	ZnO-EG
R^2	0.98	0.94
MSE	3.025×10^{-3}	0.0121
AARD%	0.52	0.53
Max Dev %	-3.12	7.6

-The pH level strongly affected the stability of both nanofluids, so that for both nanofluids at the pH of the isoelectric point, complete sedimentation was observed.

- The highest enhancement in the thermal conductivity of ZnO-EG nanofluid was 63%, which was obtained at a volume fraction of 0.75% and pH = 12. However, the highest enhancement in the thermal conductivity of MgO-W nanofluid was 49%, which was obtained at a volume fraction of 0.5% and pH = 12.

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