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Experimental investigation for developing a new model for the thermal conductivity of Silica/Water-Ethylene glycol (40%–60%) nanofluid at different temperatures and solid volume fractions

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ABSTRACT

In this study, thermal conductivity of Silica and Water-Ethylene glycol as the base nanofluid, was measured within the temperature range of 25–50 °C for samples with volume fractions of 0.1, 0.5, 1, 1.5, 2, 3, and 5%. According to our measurements, thermal conductivity increased with increasing temperature and volume fraction. In comparison, volume fraction showed a greater incremental effect on thermal conductivity. Measurements showed that the highest thermal conductivity (45.5%) occurred in the volume fraction of 5% at 50 °C. Due to the lack of a precise and appropriate equation for the prediction of thermal conductivity of Silica/Water-Ethylene glycol nanofluid, an equation was provided based on the measurement results, which was a function of volume fraction and temperature. Investigations showed that maximum value for the margin of deviation for the proposed equation was equal to 2.2%, which is acceptable for an experimental equation.

1. Introduction

A nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer. Since metal oxide nanoparticles and carbon nanotubes have greater thermal conductivity than the base fluid, suspension of these nano-materials in the base liquid increases thermal conductivity [1–15].

Shamaeil et al. [16] performed an experimental study on the effects of temperature and volume fraction of double-walled carbon nanotubes (DWCNTs) on the thermal conductivity of ethylene glycol (EG). Their results showed that the thermal conductivity of nanofluids enhances strangely with increase in volume fraction and temperature. Amiri et al. [17] measured the thermal conductivity of the SiO_2-Cu/Water and SiO_2-Cu/EG nanofluids. One of the most important features of this work is that this type of nanofluids contains particles which have a density close to SiO_2 but a thermal effect similar to copper. Kumar and Sonawane [18] used Water based CuO and TiO_2 based nanofluids with 0.02%, 0.04% and 0.06% volume fraction as working fluids for different flow rates of nanofluids. Their nanofluids showed an enhancement. Sarbolookzadeh Harandi et al. [19] presented an experimental study on the effects of temperature and concentration on the thermal conductivity of f-MWCNTs–Fe_3O_4/EG hybrid nanofluid. Their thermal conductivity measurements also showed that the maximum thermal conductivity ratio was 30%, which occurred at temperature of 50 °C for solid volume fraction of 2.3%. Tahani et al. [20] studied the thermal conductivity of Graphene oxide nano platelets/deionized Water in different temperatures and weight fractions using artificial neural network (ANN) and experimental data. Their results indicate that the proposed model by ANN can precisely predict the thermal conductivity of the nanofluid. Karimi Darvanjooghi and Nasr Esfahany [21] investigated the effects of particle size, temperature and volume fraction of SiO_2 nanoparticles on thermal conductivity of nanofluid. Comparison between their measurements showed that the deviation of calculated data from experimental results is within −9.5% to 5.4%. The literature results agree well with the predictions by correlation proposed. Sundar et al. [22] estimated the thermal conductivity and viscosity of ND nanofluids at different particle concentrations and temperatures. Based on their results, the thermal conductivity enhancements are 18.8%, 16.8% and 14.1% at 1.0 vol% of 20:80%, 40:60% and 60:40% PG/W based nanofluids. Gaweł Zyła and Jacek Fal [23] presented the results of experimental research studies carried out on basic physical properties of aluminum nitride–ethylene glycol nanofluids. They concluded that this material exhibits non-Newtonian nature and thermal conductivity increases linearly with the concentration of nanoparticles in suspension. Abdolbaqi et al. [24] prepared nanofluids by dispersing TiO_2 nanoparticles in different base fluids such as 20:80% and 30:70% by volume of BioGlycol/Water mixtures. The maximum thermal conductivity

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enhancement among all the nanofluids was observed for 20:80% BG: W nanofluid about 12.6% in the volume concentration of 2.0% at a temperature of 80 °C. Dongliang et al. [25] measured the thermal conductivity of a system of tetrahydrofuran clathrate hydrate-nanoparticles (carbon nanotubes and copper nanoparticles) under different temperatures, different nanoparticle mass fractions with and without dispersant (sodium dodecyl sulfate), and different nanoparticle dimensions. Their results indicated that thermal conductivity of the system increases with the increasing mass fractions of nanoparticles. Wei et al. [26] studied TiO_2 nanoparticles dispersed in diathermic oil to form nanofluids. Their results showed that the thermal conductivity of nanofluids increased with increasing volume fractions of TiO2 nanoparticles and increasing of temperature. Pryazhnikov et al. [27] presented the results of systematic measurements of the thermal conductivity coefficient of nanofluids at room temperature. They showed that there is no direct correlation between the thermal conductivity of the nanoparticle material and the thermal conductivity of nanofluid containing these particles. Vafae et al. [28] predicted the thermal conductivity ratio of MgO-MWCNTs/EG hybrid nanofluids by an optimal artificial neural network at different solid volume fractions and temperature. The comparison between four optimal ANN results and experimental showed that the ANN with 12 neurons in hidden layer was the best model. Moreover, the results obtained from the best ANN indicated the maximum deviation margin of 0.8% in effective thermal conductivity, and overall heat transfer coefficient. Afrand [29] presented experimental investigation on the effects of hybrid nano-additives, composed of magnesium oxide (MgO) and functionalized multi-walled carbon nanotubes (FMWCNTs), on the thermal conductivity of ethylene glycol (EG). He concluded that the thermal conductivity of EG considerably increased with increasing temperature, while thermal conductivity of hybrid nanofluid slightly enhanced. Ahmadi Nadooshan [30] presented the effects of temperature ($20\ ^\circ C < T < 50\ ^\circ C$) and volume fraction ($0 < \varphi < 4\%$) on the thermal conductivity of zinc oxide/ethylene glycol-Water nanofluid. Their results revealed that the thermal conductivity of nanofluids significantly increases with increasing solid volume fraction at higher temperatures.

Hemmat Esfe et al. [31] studied the effects of solid volume fraction and temperature on thermal conductivity of DWCNT (inner diameter of 3 nm)-ZnO (diameter of 10–30 nm)/Water-ethylene glycol (60:40) nanofluids. Based on experimental results and using of non-linear regression on results of experiments, they proposed a correlation as a function of temperature and solid volume fraction. In the present study, the nanofluid thermal conductivity composed of Silica/Water-Ethylene glycol (40%–60%) is examined experimentally. To the author's knowledge, there is no comprehensive and thorough investigation to predict the thermal conductivity of the supposed nanofluid.

2. Methodology

2.1. Statement of the problem

In the present study, Silica suspended in a Water-Ethylene glycol (40%–60%) solution was used for experiments. An ethylene glycol and Water mixture, the nearly universally used automotive coolant, is a relatively poor heat transfer fluid compared to Water alone. This nanofluid also has a high boiling point, which is desirable for maintaining single-phase coolant flow. This nanofluid is stabilized using the combination of chemical and mechanical methods in different volume fractions. Minimum 5-hour ultrasonic wave was used to stabilize the nanofluid. This nanofluid was prepared in seven different volume fractions at various temperatures (≤50 °C). After suspending nanoparticles in the base fluid, thermal conductivity was measured by using of KD2 device. It is worth noting that temperature was constant during the experiment. To this end, the temperature calibration bath and other temperature regulation mechanisms were used. Results of this experiment were presented in descriptive and comparative charts.

2.1.1. Hypotheses

- ✓ Different mechanical and chemical methods will be employed to suspend nanoparticles.
- ✓ The nanofluid is completely stable.
- ✓ Duration of exposure to ultrasonic waves depends on suspension conditions of nanoparticles.
- ✓ Solid particles are dispersed evenly through the base fluid.
- ✓ Temperature is constant throughout the thermal conductivity measurement container.
- ✓ Temperature calibration bath and/or other temperature regulation mechanisms are used to control the temperature.
- ✓ The volume fractions are calculated completely and accurately.
- ✓ Nanofluid is incompressible.

2.2. Preparation of nanofluid

The most important step in testing nanofluid properties is the preparation of a suitable nanofluid. To perform experiments with minimal error, availability of stable and homogeneous samples is the most important prerequisite. The aggregation or the lack of proper suspension of nanoparticles in the base fluid can cause several measurement errors. There are many methods for preventing this phenomenon from happening. In this experiment, a mixture of Water and Ethylene glycol (40:60) was used as the base fluid. Silica nanoparticles were suspended in a specific amount of Water-Ethylene glycol mixture (Merked, Germany). The physical and chemical properties of Ethylene glycol, Water and Silica nanoparticles were presented in Tables 1, 2, and 3, respectively. To identify nanoparticle structures, XRD images of Silica nanoparticles were used (Fig. 1).

To prepare the samples, a two-step procedure was used and different volume fractions of the nanofluid (0.5%, 0.5%, 1.5%, 2%, 3%, and 5%) were prepared. Eq. (1) was used to calculate the values of nanoparticle and base fluid, and required amounts of them for preparation of different volume fractions,

$$\phi = \left[\frac{\left(\frac{w}{\rho}\right)_{SiO_2}}{\left(\frac{w}{\rho}\right)_{SiO_2} + \left(\frac{w}{\rho}\right)_{Water} + \left(\frac{w}{\rho}\right)_{EG}} \right] \times 100 \quad (1)$$

In this equation, φ, ρ, and w stand for the volume fraction, density, and material weight, respectively. The weight of materials was measured using a sensitive digital scale. Table 4 presents the required Silica for different volume fractions.

According to previous experiments, after the preparation of nanofluids with different volume fractions, each sample was visually monitored for three days, and no sedimentation and agglomeration was observed.

2.3. Measurement of thermal conductivity

2.3.1. Measurement with KD2

The KD2 prob uses the THW method for the measurement of thermal properties of solid and liquid conductors. In this technique, a thermal pulse is sent to a wire and response time of temperature during

Table 1
Physical and chemical information of Ethylene glycol.

Characteristic	Value
Combustion temperature	197.6 (°C)
Freezing temperature	− 13 (°C)
Molar mass	62.07 (gr/mol)
Density	1.11 (gr/cm^3)
pH	6–7.5
Boiling point	197.6 (°C)