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Electrical conductivity, viscosity, and density of different nanofluids: An experimental study

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ABSTRACT

In this study, the thermophysical properties of water based nanofluids were investigated. Electrical conductivity, density and viscosity are the main important parameters which must be investigated before performance analysis for industrial application. The amount of these thermophysical properties considerably depends on the types of the nanofluids. The results showed a considerable enhancement in electrical conductivity and viscosity of the base fluid with the addition of nanoparticles. For all nanofluids except Multiwall Carbon Nanotube (MWCNT), the linear trends were observed between electrical conductivity and concentration. Sodium dodecyl sulfate (SDS) was applied as the surfactant and with the surfactant addition to water, the electrical conductivity was increased significantly while nanofluid density and viscosity are mostly constant. Based on the experimental results obtained, the Maxwell model cannot predict the enhancement in the electrical conductivity, thus correlations were developed for this condition. Viscosity of the nanofluid agreed well with the Einstein equation in low concentrations while as the concentration increased, this equation under predicted the experimental viscosity which may be attributed to the changes in behavior of the nanofluid. The experimental density of the nanofluid can also be predicted accurately by the mixture law.

1. Introduction

Nanofluids are creased from dispersion of the solid particles in different base fluids like water and organic liquids [1–4]. These nanofluids entered in different micro and nanofluidic devices and cooling systems [5,6]. Thermophysical properties of nanofluids [7–9] have significant effects on the performance of a system. In this area, experimental studies that consider nanofluid thermophysical properties at different concentrations and temperatures are scarce. However, experimental data related to the thermophysical properties are required for variety of engineering applications.

One of the most important thermophysical properties is the electrical conductivity of nanofluids. The results reveal considerable enhancement of this property [10,11] with the addition of nanoparticles to the base fluid. Shen et al. [10] used ZnO as a nanoparticle and insulated oil as the base fluid. They observed 973 times enhancement in the electrical conductivity in a volume fraction of about 0.75%. Glover et al. [11] observed that with the addition of about 0.5% (by weight) functional sulfonated carbon nanotube, electrical conductivity increased 13 times. White [12] reported 100 times enhancement in the electrical conductivity with the addition of 7% (by volume) of nanoparticles. They also observed that the electrical conductivity increased with reducing the particle size. Pastoriza-Gallego et al. [13] investigated the electrical conductivity of ZnO nanofluids in propylene as the base fluid. They observed enhancement of about 100 times in a volume fraction of about 7%. Electrical conductivity is affected by different parameters such as: Brownian motion, agglomeration, and stability [14]. Bordi et al. [15] observed that with particle aggregation, the number of particles reduced and the size of particles increased. This matter reduces Brownian motion of particles and then electrical conductivity dropped. Literature review revealed that, the Maxwell model cannot predict this enhancement in the electrical conductivity. For example, Shen et al. [10] reported that the Maxwell model underestimates the measured experimental data of the electrical conductivity. Based on this underestimation, they reported two mechanisms of dynamic and static for the electrical conductivity of nanofluids. Sarojini et al. [16] observed an unsatisfactory agreement between the experimental data and theoretical results of Maxwell model and they attributed this difference to the polarization effect.

Another important factors that can be affected in different parameters including Reynolds number, pump efficiency and

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friction factor are nanofluid viscosity and density. Vajjha and Das [17] investigated the density of Al_2O_3 nanofluids and observed that density increased with the addition of nanoparticles and decreased with temperature. Mahbubul et al. [18] observed that the density and viscosity of nanofluids increased with increasing concentration and decreased with increasing temperature. Yiamsawas et al. [9] measured viscosity of Al_2O_3/water and TiO_2/water at high temperature and high concentrations of nanofluids. They observed that in the theoretical models, the size and shape of nanoparticles, and temperature are important factors beside the volume fraction. Chandrasekar et al. [19] observed that the viscosity of nanofluids increased with the nanoparticles addition. Nguyen et al. [20] reported that the viscosity of nanofluids increases significantly with concentration and decreases with temperature. Timofeeva et al. [21] reported that when the enhancement in viscosity is less than four times the increase in thermal conductivity of nanofluids is useful. Nguyen et al. [22] investigated the effect of particle size of Al_2O_3 nanoparticles and reported that the effect of particle size on viscosity is more significant at higher nanoparticle concentrations. Kulkarni et al. [23] investigated the effect of temperature for CuO, Al_2O_3 and SiO_2 ethylene glycol and water based nanofluids and observed that viscosity decreases exponentially with temperature increase. Mahian et al. [8] measured the density of ZnO nanoparticles in an ethylene glycol–water mixture. They reported that, at higher temperatures the density is more sensitive to the increase in concentration of nanoparticles.

As mentioned before, there is a lack of comprehensive experimental investigations related to thermophysical properties of nanofluids. In order to contribute to determining nanofluid theromophysical properties, some of parameters were investigated as functions of concentration and temperature. The thermal conductivity of nanofluids, in spite of its electrical conductivity, was investigated considerably. Electrical conductivity, similar to density and viscosity, is a basic conception for nanofluids that has not been widely studied. In this study, the electrical conductivity, viscosity and density of CuO, TiO_2, MgO, MWCNT, Al_2O_3 and ZnO water based nanofluids were investigated as functions of concentration and temperature and then the results were compared with the theoretical models. As scare experimental data are available for these thermophysical properties of nanofluids in literature, detailed studies in this field are required. The results of this study can be applied for better understanding of the concepts of transport properties in nanofluids.

2. Experiment and procedure

2.1. Preparation of nanofluid

Different types of nanoparticles including CuO (Sigma–Aldrich), MgO (Sigma–Aldrich), CNT (Neunano), TiO_2 (Neunano), Al_2O_3 (US research nanomaterial, Inc) and ZnO (US research nanomaterial, Inc) were used in this study (see Fig. 1). All of the nanofluids were produced by the two step method. In this method, nanofluids were dispersed into the base fluids in powder form. The nanoparticles were mixed into the base fluid using a mechanical mixer for about one hour and then dispersed into the base fluids using ultrasonic Homogenizer for about 4 h. More details about the preparation of the nanofluids can be found in the previous works [24,25] of the author. All of the nanofluids can be dispersed without the addition of surfactants, except carbon nanotubes (CNTs). CNTs were dispersed using surfactant, since CNTs are hydrophobic and inorganic solids [11] and cannot be dispersed in water in the absence of surfactant. Different concentrations (0.01%, 0.02%, 0.03%, 0.04%, 0.05%, 0.1%, 1% and 2% by weight) of nanofluid were prepared and the effect of surfactant (SDS) addition was investigated. FE-SEM, TEM and SEM images of these nanoparticles were obtained in order to confirm the nanoparticles sizes and obtain the morphological characteristic of the nanoparticles.

2.2. Measurements of electrical conductivity, density and viscosity of nanofluids

The electrical conductivity, density and viscosity of the nanofluids and surfactant solution were measured by the JENWAY 4520 conductivity meter, DMA-35N portable density meter devices and Ostwald method, respectively. These parameters were measured as a function of concentration of the both nanoparticles and surfactant solution. For measurements of thermophysical properties, 100 ml nanofluid was poured in a beaker and the temperature was kep constant in a bath water. Immediately after the preparation of nanofluid, thermophysical properties were measured. In

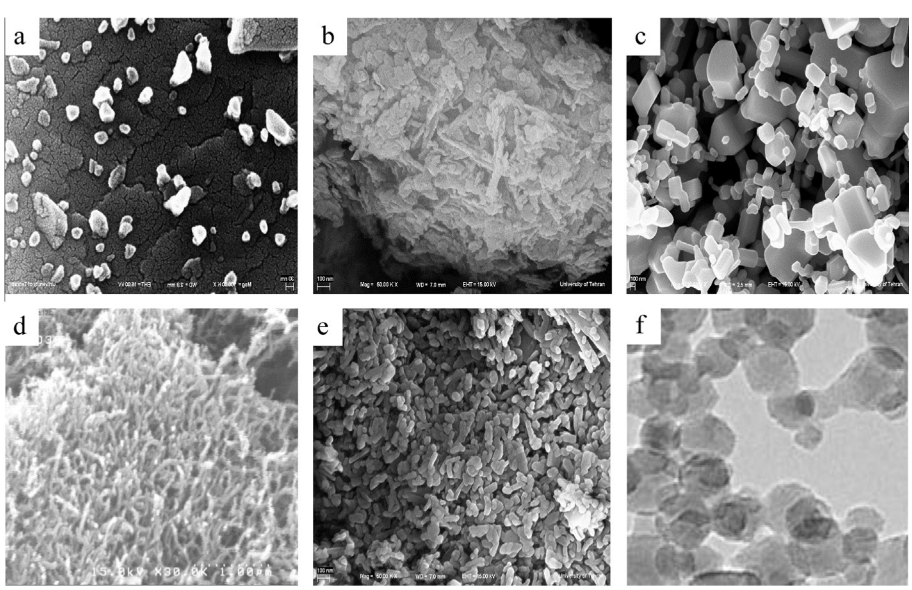

Fig. 1. FE-SEM (a, b, c, e), SEM (d) and TEM (f) pictures of (a) Al_2O_3, (b) MgO, (c) ZnO, (d) MWCNTs, (e) CuO and (f) TiO_2 nanoparticles.