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Electro- and thermophysical properties of water-based nanofluids containing copper ferrite nanoparticles coated with silica: Experimental data, modeling through enhanced ANN and curve fitting

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ABSTRACT

A new homogeneous nanofluid of copper ferrite nanoparticles coated by silica dispersed in distilled water as the base fluid is prepared in a way to avoid settling and agglomeration. The values of dynamic viscosity and electrical conductivity at various temperatures and nanoparticles concentrations are experimentally measured. In addition, two empirical correlations are provided for them by the curve fitting approach. Moreover, the sensitivity analysis beside an enhanced artificial neural network is presented to accomplish the obtained results. The margin of deviations and experimental results versus those of correlations, imply the suitable accuracy of the proposed correlation. It is shown that more temperature corresponds to less dynamic viscosity; it also mildly increases the electrical conductivity. However, the effect of nanoparticle concentrations is more significant.

1. Introduction

Nanomaterials are used in different aspects of sciences these days; hence their applications are being developed in various fields like medicine, HVAC, electrical and thermal industrials. Spinel ferrites nanoparticles with an overall formulation of xFe_2O_4 (x = Cu, Mn, Mg, Zn or similar materials) are generally applied in high-density absorbing mediums such as ferromagnetic fluids, gas sensors, magnetic separation and so on. Copper ferrite plays an essential role as a magnetic substance. In general, copper ferrite is generated from CuO and α-Fe_2O_3 powders by a ceramic processing approach, which comprises several steps like powder homogenization, densification, and prolonged high-temperature heat treatment in several steps. However, the magnetic properties of the copper ferrite are determined by its phase composition and can be tuned by changing the production conditions. Moreover, the magnetic separation would be an attractive alternative to filtration or centrifugation as it avoids a decrease in the catalyst and increases reusability, rendering the catalyst cost-effective and is promising for industrial performances [1–3].

On the other hand, nanofluid is composed of nanoparticles dispersed in a base fluid. Mainly, it was generated to improve the heat transfer rate. However, the new high-tech instruments encourage researchers to propose the new types of nanofluids such as the hybrid ones to have better thermal efficiency at both sides of hydrodynamic and thermally. Two main factors should be noticed whenever a nanofluid is going to be applied: temperature and nanoparticles mass/volume fraction. Each one of these items would affect the nanofluid performance significantly. In this regard, a large number of articles can be addressed which have reported the effects of temperature and nanoparticles concentration on thermophysical properties of nanofluids. It should be mentioned that physical parameters like nanoparticles diameter or the type of the base fluid and nanoparticles can affect the nanofluid performance [4–19].

Investigation the new kinds of nanofluids would lead to knowing their thermo-physical properties like density, viscosity, thermal conductivity and electrical conductivity to have the best choice of nanofluid at various applications. Several papers presented many theoretical equations to predict the thermo-physical properties. However, these approaches might

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Nomenclature

ANN	artificial neural network
$CuFe_2O_4$	copper ferrite
n	number of the network weights and biases
N	number of training input-target samples
RE	relative electrical conductivity
RV	relative viscosity
SiO_2	silica
t	network targets
T	temperature (°C)

Greek symbols

α	network outputs
μ	dynamic viscosity (mPa s)
σ	electrical conductivity ($\mu S\ cm^{-1}$)
φ	concentration of nanoparticles ($gr\ mL^{-1}$)
w	network weights and biases

Subscripts

bf	base fluid
nf	nanofluid

contain some detours in results especially for the hybrid ones [20–25].

As a result, the experimental achievements for each one of nanofluids were presented which in some cases followed by a correlation according to the experimental results. Actual and accurate values of nanofluid viscosity and conductivity were some advantages of the experimental works. Although, the new and most expensive experimental would be needed for the new type ones. Generate, stabilize, disperse, and then the measurement of the properties are some difficulties in the experimental studies to propose a new nanofluid. The electrical conductivity of Al_2O_3, Ag, ZnO, CNT and GNP nanoparticles dispersed in various base fluids were reported in the literature [26–33]. The dielectric properties of more complex nanofluids like SC-TiO_2 nanoparticles based on ethylene glycol, as a function of temperature and frequency, have also been measured and reported [34].

The present article tries to generate a new nanofluid composed of copper ferrite nanoparticles coated by silica nanoparticles dispersed in water in the homogeneous shape. That is the first time to produce the nanoparticles of $CuFe_2O_4$ which they are coated with silica. In this way, the hydrophilic surface is manufactured around the nanoparticles. Then, the values of dynamic viscosity and electrical conductivity of $CuFe_2O_4/SiO_2$-water nanofluid are measured experimentally. Moreover, the suitable correlations are provided for each of them. These two last points, give the present work a nice novelty in comparison with other reported papers in this field. The electrical conductivity of a nanofluid plays a vital role in the cases of magneto-hydro-dynamic performances. Moreover, as it was seen in the literature review [35–37], several papers used ANN to present an optimization through the experiment results. However, this work aims to represent the "enhanced artificial neural network" approach for the first time.

2. Problem statement

To prevent settling and agglomeration and of the nanofluid, a novel approach for preparing $CuFe_2O_4/SiO_2$-water nanofluid was employed to achieve a homogeneous mixture. Copper ferrite nanoparticles are covered with a silica coating, and the base fluid is distilled water.

Electrical conductivity (σ) along with dynamic viscosity (μ) of the nanofluid was measured in laboratory for different values of ϕ (nanoparticles concentration with units of gr nanoparticles per mL of water) of 0, 0.005, 0.01 and 0.02 and different T (temperatures with units of °C) of 30, 45, 60 and 75. The results are shown in the figures. Two empirical formulas are obtained via curve fitting for prediction of σ and μ, as a function of nanoparticles concentration and temperature. Sensitivity analysis beside an enhanced artificial neural network was performed to understand the model better.

3. Experiments

3.1. Prepare the nanofluid sample

Distilled water was chosen as the base fluid while the nanoparticles of $CuFe_2O_4/SiO_2$ were synthesized by the solvothermal method in Razi Chemistry Research Center (RCRC), Shahreza Branch, Azad University, Isfahan, Iran. The measurements of the structural properties of the dry $CuFe_2O_4/SiO_2$ nanoparticles by X-ray (XRD) and TEM images are presented in Fig. 1 to achieve the characterizations of nanoparticles. The mean size of nanoparticles is achieved by applying XRD pattern (Bruker-D8 Germany) and Debye–Scherrer equation ($d = 0.9\lambda/(\beta\ \cos\theta)$); where d shows the size of particle's diameter and $\lambda = 0.154$ nm represents the X-ray wavelength. Moreover, β and θ imply to the full width at half maximum and the diffraction angle; which is derived from Fig. 1(a) in the range of 5–70°. 2.5 h of magnetic stirring generated the stable homogeneous sample of nanofluid; then the mixture was exposed to the ultrasonic wave of a homogenizer (Hielscher UP200St, Germany) for 2 h at the frequency of 50 Hz to avoid any agglomeration and adherence of nanoparticles.

3.2. Measurement devices for viscosity and electrical conductivity

Dynamic viscosity is measured by a ULA spindle of cylindrical viscometer of LVDV III Ultra from Brookfield, U.S.A with an accuracy of ∓1%. The sample temperature is kept fixed during the process by continues rotating water between the cylinder sidewalls through a circulator bath (MA series form Julabo, U.S.A). Besides, the electrical conductivity is examined by an RS232 conductivity meter.

With the intention of validating the measurements, the results from this work were contrasted against those obtained by Mehrali et al. [33]. They measured the thermo-physical properties of Nitrogen-doped graphene (NDG) nanofluid at various concentrations of 0.01–0.06 wt%. A 0.025 wt% Triton X-100 (as the surfactant) and distilled water as the base fluid were used to prepare the nanofluid above. Tables 1 and 2 show the viscosity and electrical conductivity measurements of base fluid versus Mehrali et al. [33]; where the reasonable agreements can be seen. The difference between results can be due to nanofluids preparation methods: Mehrali et al. [33] have used Triton X-100 as a surfactant in their research, but present study has been done without using any surfactant/additives.

3.3. Examined values of dynamic viscosity (μ) and electrical conductivity (σ)

Fig. 2 illustrates the effects of temperature on nanofluid dynamic viscosity as well as electrical conductivity at different