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THERMAL CONDUCTIVITY OF NANOFLUIDS BASED ON γ-Fe_2O_3 NANOPARTICLES

BY

GABRIELA HUMINIC[1,*], ANGEL HUMINIC[1], FLORIAN DUMITRACHE[2] and CLAUDIU FLEACA[2]

[1]Transilvania University of Brașov, Romania
Mechanical Engineering Department
[2]National Institute for Laser, Plasma and Radiation Physics, Măgurele, Romania
Laser Department

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Abstract. Thermal conductivity of γ-Fe_2O_3 nanofluid is reported by few researchers. The current study is focused on the measurement of thermal conductivity of the γ-Fe_2O_3nanoparticles dispersed in distilled water. Experiments were performed for four the weight concentrations 0.5%, 1.0%, 2.0% and 4.0% respectively and the temperature in range 25°C to 50°C. The experimental results were compared to theoretical models and experimental data available in literature.

Keywords: nanoparticles; nanofluids; thermal conductivity.

1. Introduction

The magnetic fluids have remarkable potential for engineering applications being used in different fields such as thermal engineering, electronic packing and bioengineering (Rosensweig, 1985; Odenbach, 2002). Magnetic nanoparticles used in magnetic nanofluids are usually prepared in different sizes and morphologies from metal materials (ferromagnetic materials) such as iron, cobalt, nickel as well as their oxides (ferromagnetic materials)

*Corresponding author; *e-mail*: gabi.p@unitbv.ro

such as maghemite (Fe_2O_3), magnetite (Fe_3O_4), spinel-type ferrites, etc. (Nkurikiyimfura *et al*., 2013).

In the last decade, researchers are focusing on the measurement of thermal conductivities and viscosities of magnetic fluids in the absence or presence of magnetic fields, because of the unique magnetic properties of these nanofluids (Syam Sundar *et al*., 2013a; Syam Sundar *et al*., 2013b; Khedkar *et al*., 2013; Yu *et al*., 2010; Abareshi *et al*., 2010; Hong *et al.*, 2006).

In the work (Syam Sundar *et al*., 2013a) the authors measured the thermal conductivity and viscosity of water based magnetite (Fe_3O_4) nanofluid as a function of particle volume fraction at different temperatures. Their results showed that the thermal conductivity ratio increased with the increase of particle volume fraction and increase of temperature. Maximum thermal conductivity enhancement of 48% was observed with 2.0% volume concentration at 60°C temperature compared to distilled water. Also, same authors (Syam Sundar *et al*., 2013b) investigated the thermal conductivity enhancement of the ethylene glycol and water mixture based magnetite (Fe_3O_4) nanofluids. Experiments were conducted in the temperature range from 20 °C to 60°C and in the volume concentration range from 0.2% to 2.0%.They found that the thermal conductivity for 20:80% EG/W based nanofluid is 46%, 40:60% EG/W based nanofluid is 42% and 60:40% EG/W based nanofluid is 33% at 2.0% particle volume concentration at a temperature of 60°C.

Khedkar (Khedkar *et al*., 2013) measured the thermal conductivity and viscosity of Fe_3O_4 nanoparticles in paraffin as a function of particle volume fraction. The experimental results showed that the thermal conductivity increases with an increase of particle volume fraction, and the enhancement observed to be 20% over the base fluid for a paraffin nanofluid with 0.1 volume fraction of Fe_3O_4 nanoparticles at room temperature.

The effects of particle volume fraction on the thermal conductivity of a kerosene based Fe_3O_4 magnetic nanofluid prepared via a phase-transfer method were investigated by Yu (Yu *et al*., 2010). Their results showed that the thermal conductivity ratios obtained increased linearly with the increase of volume fraction and temperature and the value was up to 34.0% at 1 vol%.

The thermal conductivity of a water based magnetite nanofluid as a function of particle volume fraction at different temperatures was measured by (Abareshi *et al*., 2010). The thermal conductivity increased with the increase of the particle volume fraction and temperature. The maximum thermal conductivity ratio was 11.5% at a particle volume fraction of 3% at 40°C.

Hong (Hong *et al.*, 2006) investigated the thermal conductivity of nanofluids with different volume fractions of Fe nanoparticles in ethylene glycol. Their results confirmed the intensification of thermal conductivity with the particle volume fraction. In the comparison of the copper and iron nanoparticles dispersed in ethylene glycol, the thermal conductivity enhancement in iron- based nanofluids was higher than that in copper-based nanofluid.

The main goal of the present study is to investigate the effects of the temperature and of the weight concentration on thermal conductivity of γ-Fe_2O_3 /water nanofluids.

2. Experimental Procedure

2.1. Preparation of the Nanofluids

In this study, the nanofluids in 0.5, 1.0, 2.0 and 4.0 wt.% concentrations were prepared. 3,4-Dihydroxy-L-phenylalanine (L-DOPA) product no. D9628 was used as surfactants for γ-Fe_2O_3 nanoparticles. The concentration of surfactant for each type of nanofluid is 3g/l. In order to obtain homogeneous suspensions with size aggregates as small as possible was used a double ultrasonication: 10 h at Elmasonic S40H bath followed by 3 h under Hielscher UIP 1000hd sonotrode). In all cases we maintained a 70°C temperature during ultrasonication. No settlement of nanoparticles was observed after 6 months.

2.2. Thermal Conductivity Measurements

Thermal conductivity was measured using a KD 2 Pro thermal properties analyzer. The device consists of a probe with 1.3 mm in diameter and 60 mm in length, a thermo-resistor and a microprocessor to control and measure the conduction in the probe. The instrument has a specified accuracy of ±5%. Before measurements, the calibration of the sensor needle was carried out first by measuring thermal conductivity of distilled water.

Before measurements, the calibration of the sensor needle was carried out first by measuring thermal conductivity of distilled water and glycerin. Thus, the measured value for distilled water and glycerine were 0.600 W/mK and 0.287 W/mK respectively, which were in agreement with the literature values of 0.596 W/mK and 0.285 W/mK respectively at a temperature of 293K.

In order to maintain a prescribed constant temperature during the measurement process, a thermostat bath (Haake C10 - P5/U with an operating range of 25-100°C) was used with an accuracy of ±0.04°C.

3. Results and Discussions

Iron oxide nanoparticles have been characterized using TEM (transmission electron microscopy) analysis (Fig. 1). The iron oxide nanoparticles have two distinct features:

− the small nanoparticles are the most common, having a spherical shape, 5.5 nm mean diameter and are arranged in chain like superposed agglomerates;

− the big particles have polyhedral with round corners shape, are less agglomerated or cross-linked and their sizes vary between 12 to 20 nm.

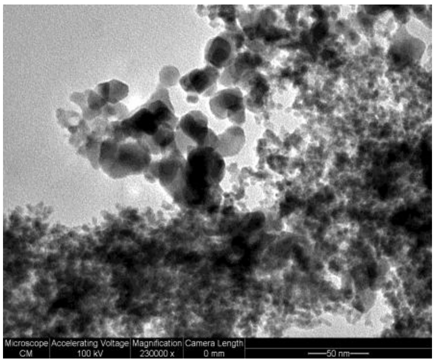

Fig. 1 − TEM image of iron oxide based sample.

In order to prevent particle aggregation and the obtain of the stable nanofluids in time different surfactants were used. Most used surfactants in the preparation of the nanofluids were sodium dodecylsulfate (SDS) (Zhou *et al*., 2012; Saleh *et al*., 2014; Haitao *et al.,* 2013; Hwang *et al*., 2007), sodium dodecylbenzenesulfonate (SDBS) (Zhou *et al*., 2012; Li *et al*., 2008; Zhu et *al.,* 2009; Wang *et al*., 2009) and salt and oleic acid (Yu *et al.,* 2009; Hwang *et al.,* 2008; Ding *et al*., 2007), cetyltrimethylammoniumbromide (CTAB) (Pantzali *et al*., 2009), polyvinylpyrrolidone (PVP) (Zhu *et al*., 2007). In this study, γ-Fe_2O_3/water nanofluids were mixed with L-DOPA surfactant. From our knowledge these surfactants were not used until present of researchers.

The thermal conductivity was measured for different temperature (25°C, 30°C, 35°C, 40°C, 45°C and 50°C) and various weight concentrations (0.1%, 0.5%, 1.0%, 2.0% and 4.0%). As it is observed in Fig. 2 the thermal conductivity ratio of nanofluids defines as the ratio of the thermal conductivity of the nanofluids and the thermal conductivity of the base fluid increases both with the temperature and the weight concentration of nanoparticles. A similar trend is observed by (Syam Sundar *et al.*, 2013a; Yu *et al*., 2010; Abareshi *et al*., 2010).

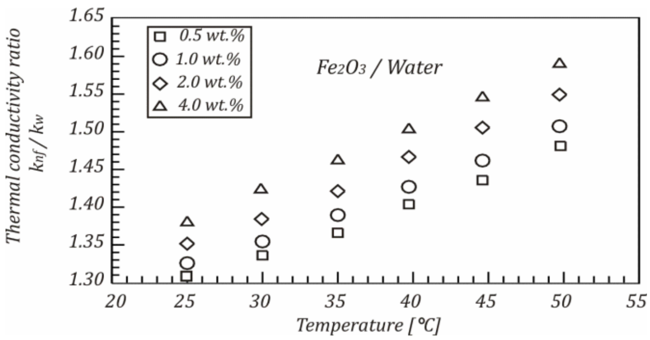

Fig. 2 − The thermal conductivity ratio versus temperature at different weight concentrations of γ-Fe_2O_3 nanoparticles.

Fig. 3 shows comparisons between the measured data and the predicted values using existing correlations from literature at 25°C. For the comparison experimental data concerning the thermal conductivity of γ-Fe_2O_3/water nanofluids were chosen two models: Murshed and Sundar models.

The model for predicting the effective thermal conductivity of nanofluids developed by (Murshed *et al.*, 2006) is:

$$k_{eff,Murshed}=\frac{k_{bf}\left[1+0.27\phi^{4/3}\left(\frac{k_s}{k_{bf}}-1\right)\right]\left[1+\frac{0.52\phi}{1-\phi^{1/3}}\left(\frac{k_s}{k_{bf}}-1\right)\right]}{1+\phi^{4/3}\left(\frac{k_s}{k_{bf}}-1\right)\left(\frac{0.52\phi}{1-\phi^{1/3}}+0.27\phi^{1/3}+0.27\right)}. \quad (1)$$

Recently, Syam Sundar (Syam Sundar *et al.*, 2013a) has developed a new model to predict the effective thermal conductivity of nanofluids, valid for Fe_3O_4/ water nanofluids in the range 0 < ϕ < 2.0 vol.% and 20°C < T <60°C:

$$k_{eff,Syam\ Sundar}=k_{bf}\left(1+10.5\phi\right)^{0.1051} \quad (2)$$

where k_{bf} is thermal conductivity of base fluid, k_s − thermal conductivity of solid particles and ϕ − the volume concentration of nanoparticles.

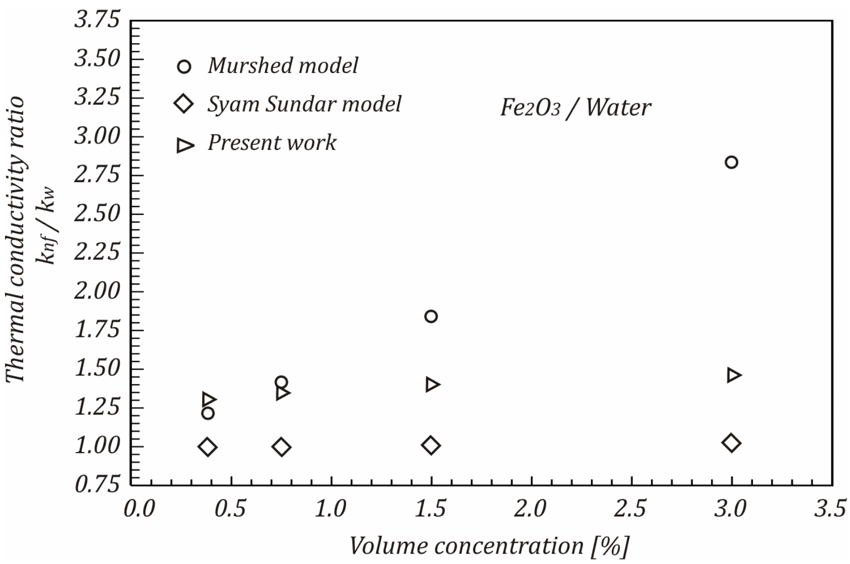

Fig. 3 − Comparison between experimental data and correlations available in literature.

As shown in Fig. 3, at lower volume concentrations of nanoparticles the experimental data were in agreement with Murshed model. The difference between our results and Sundar model can be explained by used different factors such as surfactant (in the Sundar model the used surfactant was Cetyl trimethyl ammonium bromide (C-TAB)), the particle size as well the preparation method.

4. Conclusions

In this paper, the thermal conductivity of nanofluids based on γ-Fe_2O_3 nanoparticles were experimentally investigated. Nanopowders were synthesized laser pyrolysis technique from iron pentacarbonyl vapors carried by ethylene who also acts as laser energy transfer agent. Their aqueous suspensions in presence of the additive L-DOPA were prepared by double ultrasonication. Thermal conductivities of γ-Fe_2O_3 nanoparticles in distilled water were determined experimentally as a function of weight concentration and temperature. The experimental results showed that the thermal conductivity of nanofluids is much higher than the thermal conductivity of base fluid. Also, the thermal conductivities of the γ-Fe_2O_3/water nanofluids increase linearly both with the weight concentration and the temperature.

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CONDUCTIVITATEA TERMICĂ A NANOFLUIDELOR
BAZATE PE NANOPARTICULE DE γ-Fe_2O_3

(Rezumat)

Nanofluidele magnetice au un potenţial remarcabil pentru aplicaţii în inginerie şi medicină. În ultimul deceniu, cercetătorii s-au concentrat pe măsurarea conductivităţii termice, în absenţa sau prezenţa câmpurilor magnetice, datorită proprietăţilor magnetice unice ale acestor nanofluide. În acestă lucrare se prezintă un studiu referitor la conductivitatea termică a nanofluidelor γ-Fe_2O_3/apă. Conductivitatea termică a nanofluidelor a fost măsurată cu ajutorul aparatului KD 2 Pro a cărui principiu de măsurare se bazează pe metoda firului cald. Intervalul de temperatură în care conductivitatea termică a nanofluidelor a fost măsurată este cuprins între 25°C şi 50°C. De asemenea, conductivitatea termică a nanofluidelor γ-Fe_2O_3/apă a fost măsurată pentru diferite concentraţii masice (0.5%, 1.0%, 2.0% şi 4.0%) de nanoparticule. Rezultatele obţinute au scos în evidenţă că aceste nanofluide prezintă o conductivitate termică mult mai ridicată decât conductivitatea termică a apei. Raportul dintre conductivitatea termică a nanofluidelor şi conductivitatea termică a apei creşte semnificativ cu creşterea temperaturii şi, de asemenea, cu creşterea concentraţiei masice de nanoparticule. În final, rezultatele experimentale au fost comparate cu modelele teoretice şi datele experimentale disponibile în literatură.