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Experimental investigation on thermal conductivity of water based nickel ferrite nanofluids

Amir Karimi [a,*], Mohamad Amin Abdolahi Sadatlu [b], Behzad Saberi [c], Hamed Shariatmadar [a], Mehdi Ashjaee [a]

[a] *Department of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran*
[b] *Department of Engineering and Science, Sharif University of Technology, International Campus, Kish Island, Iran*
[c] *Department of Materials Science and Engineering, K.N. Toosi University of Technology, Tehran, Iran*

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ABSTRACT

Experimental investigations are performed in order to determine the thermal conductivity of $NiFe_2O_4$ nanoparticles dispersed in deionized water. The magnetic nanoparticles are synthesized using a microemulsion method. The X-ray diffraction (XRD), transmission electronic microscopy (TEM), and vibration sample magnetometer (VSM) are used to characterize the structure, the size and the magnetic properties of the nanoparticles. The VSM results disclose that the $NiFe_2O_4$ nanoparticles are ferromagnetic at room temperature. Experimental measurements on thermal conductivity of the prepared nanofluids are conducted at different volume concentrations between 0% and 2% and in the temperature range of 25–55 °C. The experimental results show that the thermal conductivity of nanofluids increase with an increase in volume concentration and temperature. The Maximum enhancement in thermal conductivity of nanofluids is 17.2% at 2% volume concentration and in temperature of 55 °C. Finally, the experimental results of thermal conductivity are fitted with a new correlation to predict the thermal conductivity of nanofluids.

1. Introduction

The low thermal conductivities of traditional heat transfer fluids such as water, ethylene glycol, and engine oil limit their heat removal performance in many thermal systems. Therefore, a great deal of investigation has been performed to resolve this problem. The addition of a small amount of metallic or nonmetallic nanometer-sized particles in base fluid can improve the thermal conductivity of conventional heat transfer fluids [1–4]. The advent of research studies on heat transfer in a fluid mixture of nanoparticles returns to a few decades ago [5]. In recent years, the investigations into nanofluids have been progressed rapidly due to its importance in cooling systems, mechanical engineering and bioengineering [4,5]. The investigators have been carried out wide analyses on the transport properties of nanofluids [5].

A special group of nanofluids is so-called ferrofluids, which are stable colloidal mixture including magnetic nanoparticles such as Fe_3O_4, Fe_2O_3, $CoFe_2O_4$, Fe, and Co suspended in carrier liquid [6]. Magnetic nanofluids have been found as a smart fluid which are capable of changing rheological and thermal properties under an external magnetic field. The magnetic nanofluids are attractive for many researchers owing to their potential benefits for numerous scientific applications such as mechanical engineering, thermal engineering and drug delivery [7–9].

The nanosized spinel ferrites of the type MFe_2O_4 (M = Fe, Co, Ni, Zn, Mg, Mn), the magnetic materials with cubic spinel structure, have been used in wide range of applications and fundamental studies over the past few years. Dispersions of such magnetic nanoparticles are easy to manipulate with an external magnetic field and hence greatly utilized for modern industrial and widespread applications [10,11]. Magnetic ferrite nanoparticles are used in biomedical purposes because they are chemically stable, and their surfaces are very reactive to attach biological molecules under influence of a high magnetic moment [12].

$NiFe_2O_4$ is utilized in various applications containing high-density information storage media, ferrofluid technology, magnetic refrigeration, electronic devices, drug delivery, medical diagnostics, catalysts and sensor technology [11].

The thermal conductivity and the viscosity of nanofluids are the most important thermophysical properties, which affect the

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[*] Corresponding author.
E-mail address: amir.karimi@ut.ac.ir (A. Karimi).

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convective heat transfer performance of nanofluids. Comprehensive investigations corresponding to the transport properties measurement of either nonmagnetic [13–16] or magnetic nanofluids [17–27] have been conducted by researchers over the last few decades. Research works related to the thermal conductivity of non-magnetic type nanofluids are given below: Ghalambaz et al. [13] considered Al_2O_3 dispersed in water, Choi et al. [14] considered CNTs suspended in engine oil, ZnO nanoparticles were considered by Singh [15]. Eastman et al. [16] performed experimental investigations on the thermal conductivity of Al_2O_3, Cuo and Cu nanoparticles dispersed in water and HE-200 oil, when the volume fractions were varied between from 0% to 5%. A 60% enhancement of thermal conductivity compared to the base fluid was reported, by addition of copper oxide at volume concentration of 5%.

Some earlier studies exhibited that the thermal conductivity of magnetic nanofluid increases with increasing volume concentration [17–20]. Wang et al. [17] studied the effect of nanoparticle size on the thermal conductivities of heat transfer oils by using iron oxide nanoparticles. They indicated that the thermal conductivity enhancement increases with a decrease in particle size. Hong et al. [18], Abareshi et al. [19] and Zhu et al. [20] experimentally investigated the effect of magnetic nanoparticles on the thermal conductivity of nanofluids by using transient hot wire method in absence of magnetic field. Fertman et al. [21] considered hydrocarbon based magnetic fluids consisting of colloidal Fe_3O_4 particles coated with oleic acid as surfactant. They discussed temperature dependent thermal conductivity at 0.01% to 0.2% and in the temperature range of 20 °C to 80 °C. Yu et al. [22] considered kerosene based nanofluid including colloidal Fe_3O_4 particles with an average size of 155 nm. They found a 34% thermal conductivity enhancement at volume fraction of 1% in the temperature range of 10 °C to 60 °C. Pastoriza-Gallego et al. [23] measured the thermal conductivity of Fe_3O_4 and α-Fe_2O_3 nanoparticles dispersed in ethylene glycol at different mass fractions between 0% and 25%. Their results show that the thermal conductivity of the nanofluids increased with increasing the volume fraction and temperature. Philip et al. [24] investigated Fe_3O_4 nanoparticles with 6.7 nm particle diameters which were dispersed in kerosene at the volume fraction of 7.8%. They discovered a 23% enhancement in thermal conductivity of nanofluid in absence of magnetic field, while they observed a 300% thermal conductivity enhancement at volume concentration of 6.3% under the influence of an applied magnetic field. Djurek et al. [25] measured the thermal conductivity of γ-Fe_2O_3 and $CoFe_2O_4$ nanoparticles with an average particle size of 8–15 nm, which were suspended in water and *n*-decane. They found that the thermal conductivity of nanofluids increases with increasing volume concentration. Sundar et al. [26] experimentally studied the thermal conductivity of Fe_3O_4 nanoparticles dissolved in different concentrations of ethylene glycol/water mixture in the particle volume concentration range from 0.2% to 2% and temperature ranging from 20 to 60 °C. Sundar et al. [27] presented the thermal conductivity correlation for Fe_3O_4 water based nanofluid with particle size of 13 nm in the temperature range of 20 –60 °C. The experimental results exhibited a 48% improvement in thermal conductivity of nanofluid with volume concentration of 2% at 60 °C.

Most of the prior studies pertaining to the measurements of the transport properties of magnetic nanofluids presented until now, focus on Fe_xO_y magnetic nanoparticles such as Fe_3O_4 and γ-Fe_2O_3 which are suspended in base fluid [19,23]. Up to now, only a few studies have been conducted to investigate the heat transfer of spinel ferrite MFe_2O_4 (M = Mn, Co, Ni, and Zn) magnetic nanoparticles dispersed in carrier liquid. To the best of the authors' knowledge, the investigations of the thermal conductivity of water based $NiFe_2O_4$ magnetic nanofluid are scarce. In this work, the $NiFe_2O_4$ nanoparticles are synthesized employing a microemulsion method. The thermal conductivity of nanofluids are measured at different temperatures and volume concentrations. The experimental results are compared with some creditable theoretical models. Finally, new empirical correlation is developed in order to determine the thermal conductivity of nanofluids.

2. Experimental set up

2.1. Materials and synthesis procedure

Among all synthetic routes, the microemulsion method has the capability of controlling the shape, size, and size distribution of nanoparticles [28]. The type and concentration of either iron salts or reducing agent, the molar ratio of water to surfactant, temperature, and the type of surfactants have significant influence on physicochemical properties of obtained nanoparticles. It should be pointed out that the most influential parameters on the particle size are water-to-surfactant molar ratio and molar concentration of metal salts while the effect of reducing agent is insignificant [29]. The size of nanoparticles increases with increasing the water-to-surfactant molar ratio [29]. It is evident that increasing the molar concentration of metal precursors inversely affects the nanoparticle size. Therefore, with increasing the molar concentration of metal salts, the nanoparticles become smaller [30]. Ferric chloride [iron (III) chloride hexahydrate ($FeCl_3{\cdot}6H_2O$ (>99%))], 1-butanol (C_4H_9OH), isooctane (C_8H_{18}), cetyltrimethylammonium bromide (CTAB) and sodium borohydride ($NaBH_4$ (>99%)), tetra methyl ammonium hydroxide ($N(CH_3)_4OH$), and sodium hydroxide (NaOH), which are purchased from MERCK chemicals, are used as received without further purification. Furthermore, Nickel (II) chloride hexahydrate ($NiCl_2{\cdot}6H_2O$ (>99%)) is supplied by MP Biomedicals. High purity of N_2 gas (>99%) is employed to provide an oxygen free environment during the synthesis process. $NiFe_2O_4$ nanoparticles are prepared utilizing water-in-oil microemulsion (reverse micelle) method.

$NiFe_2O_4$ nanoparticles are synthesized by using a quaternary microemulsion system at certain ratios of aqueous phase, surfactant and oil phase. Microemulsion 1 and microemulsion 2 were prepared on the basis of quaternary phase diagram of water/CTAB, 1-butanol/isooctane which was described in the Ref. [31]. Nickel ferrite nanoparticles are prepared by mixing equal volumes of microemulsion 1 and microemulsion 2 including metal salts (Fe: Ni = 2:1) and precipitating agent, respectively. At this experiment water-to-surfactant molar ratio of 37 is used. Also, the sodium borohydride-to-metal salts molar ratio is kept constant at 2 to ensure that all of precursors are reduced completely to corresponding metals. Microemulsion 2 gradually is added into stirring microemulsion 1 by using a dropping funnel under room atmosphere. After mixing of two microemulsions, the precipitate of $NiFe_2$ alloy nanoparticles appeared immediately. After 10 min of reaction, due to oxidation, the precipitate color is changed to dark brown which reveals the formation of $NiFe_2O_3$. The nanoparticles are washed several times with deionized water, then finally with ethanol to remove all residual elements. All reactants are present in the stoichiometric amounts to reduce the portion of unreacted precursors. Any remaining unreacted precursors are properly removed by the mentioned cleaning method. The synthesized nanoparticles are centrifuged for 20 min at 6000 rpm in a rotor with the diameter of 30 cm. All nanoparticles are approximately recovered using the aforementioned centrifugation process. Then, the remaining solid is warmed in a vacuum desiccator at 70 °C to dry the residual moisture. To investigate the thermal conductivity of nanofluid, the $NiFe_2O_4$ nanoparticles are transferred into deionized water as a base fluid with volume fractions of 0.25%, 0.5%, 1%, 1.5% and 2% in order to prepare the magnetic nanofluid. Also, 8 mL of 25% tetra methyl ammonium hydroxide is added into the solution to prevent the magnetic nanoparticles from aggregation. The

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