Journal of Magnetism and Magnetic Materials 428 (2017) 457–463

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Experimental study on viscosity of spinel-type manganese ferrite nanofluid in attendance of magnetic field

Mohammad Amani[a], Pouria Amani[b], Alibakhsh Kasaeian[c,*], Omid Mahian[d], Fazel Kasaeian[e], Somchai Wongwises[f]

[a] Mechanical and Energy Engineering Department, Shahid Beheshti University, Tehran, Iran
[b] Department of Chemical Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran
[c] Department of Renewable Energies, Faculty of New Science & Technologies, University of Tehran, Tehran, Iran
[d] Young Researchers and Elite Club, Mashhad Branch, Islamic Azad University, Mashhad, Iran
[e] Faculty of Material Science and Engineering, Sharif University of Technology, Tehran, Iran
[f] Fluid Mechanics, Thermal Engineering and Multiphase Flow Research Lab (FUTURE), Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi (KMUTT), Bangmod, Bangkok, Thailand

ARTICLE INFO

Keywords:
Viscosity
$MnFe_2O_4$/water nanofluid
Magnetic field
Nanoparticle volume fraction

ABSTRACT

In this paper, an experimental evaluation on the viscosity of water-based manganese ferrite nanofluid with and without magnetic field with 100, 200, 300, and 400 G intensities has been conducted. The Brookfield DV-I PRIME viscometer is implemented to measure the $MnFe_2O_4$/water nanofluid viscosity and to evaluate the influence of different volume concentrations (from 0.25% to 3%) and various temperatures (from 20 to 60 °C) on the viscosity. According to the measurements, viscosity incrementally increases with the augmentation of nanoparticles concentration while it remarkably decreases at higher temperatures under absence and attendance of magnetic field. The maximum viscosity ratio of 1.14 is achieved at 3 vol% of nanoparticles and 20 °C under no magnetic field, whereas it increments to maximum viscosity ratio of 1.75 at 3 vol% of nanoparticles and 40 °C under 400 G magnetic field. Furthermore, new correlation is proposed for determination of viscosity of $MnFe_2O_4$/water nanofluids in terms of magnetic field intensity, volume concentration and temperature.

1. Introduction

Nowadays, the incrementing demand of heat transfer fluids has led to development of a fluid with desirable properties, while most of conventional fluids have their deficiencies. To provide superior heat transfer in different applications, Choi [1] introduced such a fluid by stabilizing the colloidal nanosuspension of particles including Al, Al_2O_3, CuO, SiO_2, ZnO, and carbon nanotubes in conventional base fluid including engine oil, ethylene glycol, water, etc. Nanofluids have become the most desirable cooling and heating fluids due to their small dimension and consequently huge ratio of surface to volume which have led to long-term stability, high heat transfer rate, less clogging in flow channel and therefore higher thermal conductivity.

The knowledge of thermophysical properties of nanofluids (i.e., thermal conductivity, density, viscosity, and heat capacity) is required before designing a thermal system with the working fluid consisting of nanoparticles. Viscosity is one of the substantial properties since it demonstrates the fluid's resistance and directly influences the convection heat transfer, pressure loss for laminar and turbulent flows, and pumping power. In the literature, numerous investigations have been implemented on analysis of the viscosity of nanofluids to determine the rheological behavior of heat transfer fluids and there is various work on studying the influence of parameters including temperature, volume concentration, particle shape and dimension on the viscosity of nanofluids [2,3].

Magnetic nanofluids—widely known as ferrofluids—are a type of nanofluids that has recently gained significant attention of many researchers [4–6]. Ferrofluids comprise of colloidal magnetic nanoparticles prepared in diverse diameters and morphologies from ferromagnetic materials (i.e., iron, cobalt, nickel etc.) and their oxides (i.e., spinel-type ferrites, magnetite [Fe_3O_4], etc.) and dispersed inside a base fluid, which can be affected under magnetic field. Regarding the measurement of viscosity of ferrofluid, various studies have been conducted [7,8]. An experimental evaluation of viscosity along with

* Corresponding author.
E-mail addresses: m_amani@sbu.ac.ir (M. Amani), pouria.amani@ut.ac.ir (P. Amani), akasa@ut.ac.ir (A. Kasaeian), omid.mahian@mshdiau.ac.ir (O. Mahian), f.kasa92@student.sharif.edu (F. Kasaeian), somchai.won@kmutt.ac.th (S. Wongwises).

http://dx.doi.org/10.1016/j.jmmm.2016.12.129
Received 5 November 2016; Received in revised form 24 December 2016; Accepted 28 December 2016
Available online 30 December 2016
0304-8853/

thermal conductivity of Fe_3O_4/ethylene glycol nanofluid has been done by Sonawane and Juwar [9]. They also developed a multi-response optimization of conditions for minimum viscosity of nanofluid and maximum thermal conductivity. Bahiraei and Hangi [10] investigated the influence of nanofluid concentration and temperature on the viscosity and thermal conductivity of Fe_3O_4/water nanofluids. They revealed that thermal conductivity and viscosity improved with incrementing the volume fraction from 0% to 4%. However, increasing temperature from 25 to 60 °C, increased the thermal conductivity and decreased the viscosity. In their study, a nonlinear relationship was reported between the thermal conductivity and viscosity against the volume fraction of nanoparticles. Moreover, by applying neural network, they proposed new models of viscosity and thermal conductivity as a function of volume concentration and temperature. In an investigation on the viscosity of Fe_3O_4/water nanofluids by Toghraie et al. [11], it was observed that the viscosity remarkably declined with the increment of temperature (20–55 °C) and significantly augmented by increasing the volume concentration of nanoparticles 0.1–3 vol%). They reported the maximum viscosity increment of approximately 130% at volume fraction of 3% and 20 °C. They also derived new correlation for measurement of the viscosity of Fe_3O_4/water nanofluids. Atashrouz et al. [12] studied the rheological behavior of Fe_3O_4/ethylene glycol/water nanofluids and evaluated the influence of shear rate on the viscosity. According to their results, the nanofluid showed shear-thinning behavior in which by increasing the shear rate, viscosity decreased. Moreover, they proposed a correlation for prediction of viscosity by using a hybrid group method of data handling polynomial neural network. Esfe et al. [13] evaluated the influence of different nominal dimensions of nanoparticles (about 98, 71 and 37 nm) along with the effect of nanoparticle concentrations on the viscosity and thermal conductivity of Fe/water nanofluid. It was observed that thermal conductivity varies directly relative to volume fraction and inversely relative to nominal dimensions of nanoparticles. They also showed that the nanofluid viscosity ratio was higher at high nanoparticle concentration and/or nanoparticle diameter. Abareshi et al. [14] studied the viscosity of α-Fe_2O_3/glycerol nanofluid and revealed that these nanofluids were non-Newtonian shear-thinning fluids and temperature strongly affected the shear viscosity. They also reported that the viscosity of these nanofluids was inversely proportional to the temperature and directly proportional to the nanoparticles concentration. Sundar et al. [15] examined the rheological behavior of Fe_3O_4 nanoparticles dispersed inside three different weight fractions of ethylene glycol and water mixture (60:40, 40:60 and 20:80 wt%) and observed that the 60:40 wt% ethylene glycol/water-based nanofluids is approximately 3 times more viscous in comparison with the other base fluids. Sundar et al. [16] theoretically and experimentally evaluated the influence of particle volume concentration and temperature on viscosity and thermal conductivity of Fe_3O_4/water ferrofluid. They reported that the increment of viscosity was greater than that of thermal conductivity at identical temperature and volume concentration. They also proposed a correlation for measurement of viscosity and thermal conductivity of nanofluid without using the Einstein and Maxwell models. In another study, Sundar et al. [17] examined the viscosity along with the thermal conductivity of nanodiamond attached with magnetite nanoparticles at different temperatures and particle loadings and proposed new correlation for predicting their experimental data.

A few researchers have evaluated the influence of external magnetic field on the viscosity of ferrofluids. Paul et al. [18] studied the rheological behavior of the magnetite ferrofluid and observed shear-thinning behavior and an improvement in the viscosity under the attendance of applied magnetic field. They explained that the formation of chain-like aggregates of particles in the fluid caused the viscosity improvement. Shahsavar et al. [19] studied the viscosity and thermal conductivity of a hybrid nanofluid comprising carbon nanotubes and Fe_3O_4 nanoparticles under magnetic field. They found that the viscosity and thermal conductivity of the nanofluid increased by intensifying magnetic induction and it reduced with increment of temperature. Moreover, it was observed that rheological behavior of hybrid nanofluid was shear thinning at low shear rates, whereas with further increase in shear rates, the nanofluid showed Newtonian behavior. Malekzadeh et al. [20] and Wang et al. [21] revealed that the viscosity of Fe_3O_4/water ferrofluids incremented with augmentation of nanoparticles concentration and reduction of temperature in the attendance and absence of magnetic field. Malekzadeh et al. [20] reported that the viscosity varies directly relative to the strength of magnetic field and consequently it could be inferred that the flow behavior of ferrofluid can be controlled by the magnetic field intensity. Wang et al. [21] also proposed a correlation to calculate the viscosity of Fe_3O_4/water ferrofluid in terms of temperature, volume concentration and intensity of magnetic field. The influence of different orientations of an applied magnetic field including perpendicular and parallel on the viscosity and thermal conductivity of γ-Fe_2O_3/water ferrofluid was investigated by Nurdin et al. [22] at different nanoparticle concentrations. The maximum thermal conductivity and viscosity improvement was observed to be about 39.09% and 31.91% at 0.6 vol% of nanoparticles and 30 °C under parallel magnetic field with 300 G intensity. An overview of the discussed experimental works have been presented in Table 1.

Lately, the spinel-type ferrite nanoparticles including MFe_2O_4 (M = Co, Ni, Zn, Mn) have gained significant interest due to their notable magnetic, electronic, and optical properties, and consequently their remarkable thermal conductivity [24,25]. In this type of nanoparticles, there is no preferred direction of magnetization that offers high saturation magnetization and permeability. Also, they are being simply magnetized and demagnetized due to their electrical-insulating properties [26]. These ferrite nanoparticles have broaden new horizons in catalysis, environmental remediation, biomedicine and heat transfer

Table 1
A summary of experimental studies on the viscosity of magnetic nanofluids.

Author	Nanoparticle	Base fluid	Size (nm)	φ (vol%)	T (°C)	B (G)
Sonawane and Juwar [9]	Fe_3O_4	EG	100	0.2 – 0.8	20 – 80	–
Bahiraei and Hangi [23]	Fe_3O_4	water	–	0.25 – 4	25 – 60	–
Toghraie et al. [11]	Fe_3O_4	water	20 – 30	0.1 – 3	20 – 55	–
Atashrouz et al. [12]	Fe_3O_4	EG/water	167	0.22 – 0.55	15 – 70	–
Sundar et al. [17]	Nanodiamond / Fe_3O_4	water	5 – 13	0.05 – 0.2	20 – 60	–
Esfe et al. [13]	Fe	water	37 – 98	0.0313 – 1	25	–
Sundar et al. [16]	Fe_3O_4	water	13	0.2 – 2	20 – 60	–
Sundar et al. [15]	Fe_3O_4	EG/water	5 – 70	0.2 – 1	0 – 50	–
Abareshi et al. [14]	α-Fe_2O_3	glycerol	5	0.125 – 0.75	30 – 70	–
Wang et al. [21]	Fe_3O_4	water	7.5	0.5 – 5	20 – 60	0 – 300
Paul et al.	Fe_3O_4	water	11	1.135 – 4.54	25	0 – 5000
Malekzadeh et al. [20]	Fe_3O_4	water	–	0 – 1	25 – 45	0 – 550
Nurdin et al. [22]	γ-Fe_2O_3	water	9.5	0.1 – 0.6	25 – 30	0 – 300
Shahsavar et al. [19]	Fe_3O_4/CNT	water	13	0.1 – 0.9	25 – 55	0 – 4800