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Experimental determination of viscosity of water based magnetite nanofluid for application in heating and cooling systems

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ABSTRACT

In this paper, experimental determination of dynamic viscosity of water based magnetite nanofluid (Fe_3O_4/water) was performed. The viscosity was measured in the temperature range of 20–55 °C for various samples with solid volume fractions of 0.1%, 0.2%, 0.4%, 1%, 2% and 3%. The results showed that the viscosity considerably decreases with increasing temperature. Moreover, the viscosity enhances with an increase in the solid volume fraction, remarkably. The calculated viscosity ratios showed that the maximum viscosity enhancement was 129.7%. Using experimental data, a new correlation has been proposed to predict the viscosity of magnetite nanofluid (Fe_3O_4/water). A comparison between the experimental results and the correlation outputs showed that the proposed model has a suitable accuracy.

1. Introduction

In the recent decades, convective heat transfer and magnetic fluid flow under various external magnetic fields have been widely investigated [1–7]. These works showed that the heat transfer rate is affected considerably by magnetic field.

On the other hand, due to the availability and high heat capacity of water, it is commonly used in engines and other heat transfer applications, such as HVAC chillers and solar water heaters. Despite the many advantages of the water, this fluid has a low thermal conductivity. For this reason, many researchers have attempted to improve the thermal properties of water. In this regard, they found that adding the nanoparticles considerably enhances the thermal conductivity of nanofluids, which leads to improve the heat transfer rate [8–15]. However, by adding the nanoparticles into the water, its viscosity is also affected [16–20]. Because of the effect of viscosity on the pumping power, this parameter should be investigated when nanoparticles is added into the water.

Many researchers experimentally investigated the effects of temperature and volume fraction of nanoparticles on the viscosity of water based nanofluids. A brief review of the previous researches on the viscosity of water based nanofluids is provided in Table 1. In these works, the authors showed that the behavior of nanofluids at some nanoparticle concentrations is non-Newtonian. Moreover, they reported that the viscosity of nanofluids is dependent on temperature, solid volume fraction, nanoparticles size, and the type of base fluid and nanoparticles.

In the recent decades, heat transfer and flow of magnetite nanofluid, consisted of colloidal magnetite nanoparticles suspended in a base fluid, under various external magnetic fields have been widely investigated [35–38]. These works showed that the heat transfer rate is affected considerably by magnetic field. In fact, the control of the fluid flow and energy conveyance processes in the magnetic nanofluids is possible by using an external magnetic field. One of the most widely used nanoparticles to prepare the magnetite nanofluids is iron oxide (Fe_3O_4). Fe_3O_4 occurs in nature as the mineral magnetite. Because of the high use of iron oxide in the industry as well as its interesting thermal properties, the Fe_3O_4 nanoparticles was interested by different researchers. For example, Sundar et al. [39] examined the convective heat transfer coefficient and friction factor characteristics of Fe_3O_4 nanofluid for flow in a circular tube. In another work, Sundar et al. [40] investigated thermal conductivity of Fe_3O_4/water-EG nanofluid, experimentally. Their experiments were performed in the temperature range of 20–60 °C and in the volume concentration range from 0.2% to 2.0%. Results indicated that the thermal conductivity increases with the increase of particle concentration and temperature. They also proposed the experimental correlation to predict the thermal conductivity of nanofluids.

Determination of effective thermal conductivity and viscosity

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Table 1.
Previous researches on the viscosity of water based nanofluids.

Authors	Nanoparticles	Size (nm)	Volume fraction (%)	Temperature (°C)
Putra et al. [21]	Al_2O_3	38	1–4	20–60
Kulkarni et al. [22]	CuO	29	5–15	5– 50
Ding et al. [23]	CNT	NA	0.1–0.5	25–40
Nguyen et al. [24]	Al_2O_3 CuO	36, 47 29	1-12	25–75
Lee et al. [25]	Al_2O_3	30	0.01–0.3	21–39
Duangthongsuk and Wongwises [26]	TiO_2	21	0.2–2	15–35
Turgut et al. [27]	TiO_2	21	0.2–3.0	13–55
Rea et al. [28]	Al_2O_3 Zr	50	3 and 6	20–80
Kole and Dey [29]	Al_2O_3	< 50	0.1–3.5	10–80
Godson et al. [30]	Ag	< 100	0.3–0.9	50–90
Azmi et al. [31]	SiO_2	50	0–4	30
Hemmat Esfe et al. [32]	MgO	40	< 1	24–60
Hemmat Esfe et al. [33]	MWCNT	N/A	0.05–1	25–55
Hemmat Esfe et al. [34]	DWCNT	(2–4) × 50 μm	0.01–0.4	27–67

of magnetic Fe_3O_4/water nanofluid were investigated theoretically and experimentally by Sundar et al. [41]. They used magnetic Fe_3O_4 nanoparticles with average diameter of 13 nm. Their experiments were carried out in the volume concentration range 0.0% to 2.0% and the temperature range 20–60 °C. They showed that the thermal conductivity and viscosity enhance with increasing the volume concentration. Sundar et al. [42] also investigated the convective heat transfer coefficient and friction factor for fully developed turbulent flow of MWCNT–Fe_3O_4/water hybrid nanofluids. They prepared the nanofluid samples with volume concentration of 0.1% and 0.3%. Recently, Karimi et al. [43] investigated the thermal conductivity of magnetic nanofluid (Fe_3O_4/water) in the absence and the presence of uniform magnetic field. The thermal conductivity of magnetic nanofluid was measured at various volume concentrations between 0% and 4.8%. Their experimental results showed that the thermal conductivity of magnetic nanofluid increases with increasing the volume concentration and magnetic field intensity. Moreover, they suggested the new correlations to estimate the thermal conductivity of magnetic nanofluid in both the absence and the presence of magnetic field.

Literature survey showed that the thermophysical properties of magnetic nanofluids have been considered by many researchers. However, only a few works have been performed on viscosity of magnetite nanofluid. Therefore, in this work, the dynamic viscosity of Fe_3O_4/water magnetite nanofluid is examined for solid volume fractions up to 3.0% under various temperatures (20–55 °C). Moreover, a new correlation is proposed to predict the dynamic viscosity of Fe_3O_4/water magnetite nanofluid for engineering applications.

2. Nanofluid preparation and viscosity measurement

In the current work, magnetite nanoparticles (Fe_3O_4) were dispersed into water. The specifications of Fe_3O_4 nanoparticles are presented in Table 2. To obtain a characterization of the magnetite nanoparticles, the structural properties of the dry Fe_3O_4 nanoparticles were measured by X-ray diffraction as depicted in Fig. 1. The magnetite nanofluids with the solid volume fractions of 0.1%, 0.2%, 0.4%, 1%, 2% and 3% were prepared using a two-step method. In order to make the stable sample nanofluids, the suspensions

Table 2.
Specifications of Fe_3O_4 nanoparticles.

Parameter	Value
Purity	+98%
Color	Dark Brown
Size	20–30 (nm)
Morphology	Spherical
Bulk density:	0.84 (g/cm^3)
True density	4.8–5.1 (g/cm^3)
Specific surface area (SSA)	40–60 (m^2/g)

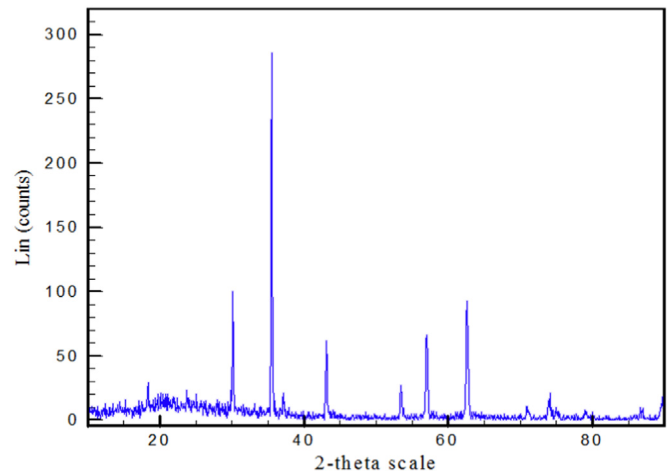

Fig. 1. XRD pattern for the magnetite nanoparticles (Fe_3O_4).

were exposed to an ultrasonic processor (Hielscher Company, Germany) for 7 h. No nanoparticles sedimentation was observed up to 15 days.

The viscosity of the magnetite nanofluids was measured at the temperatures of 20 °C, 25 °C, 35 °C, 45 °C and 55 °C. The Brookfield Viscometer with an equipped temperature bath (Brookfield engineering laboratories of the USA) was used to measure the viscosities of Fe_3O_4/water magnetite nanofluids. The range of accuracy and repeatability of Brookfield Viscometer are ± 1.0% and ± 0.2%, respectively. All experiments were repeated at various rotational speeds for each solid volume fraction and temperature to make sure its repeatability, and then the average of measured data was recorded.

Based on the measurements, the "dynamic viscosity ratio" is defined as the ratio of the dynamic viscosity of the magnetite nanofluids to dynamic viscosity of water.

3. Results and discussion

In this work, the viscosity measurements were performed at the temperature ranges from 20 °C to 55 °C for solid volume fractions of 0.1%, 0.2%, 0.4%, 1%, 2% and 3%. Fig. 2 shows a comparison between the experimental viscosity ratios and results predicted by Batchelor [44] and Wang [45] models. It can be observed that, theoretical models are unable to predict viscosity of the magnetite nanofluids. Moreover, this figure demonstrates that the measured data for the magnetite nanofluid are much higher than both theoretical models. These differences indicate the need for a new correlation to predict the viscosity of the magnetite nanofluid.

Fig. 3 shows the dynamic viscosity of Fe_3O_4/water nanofluids versus solid volume fraction for various temperatures. It can be seen that the viscosity of the magnetite nanofluid increases with