Experimental investigation on thermal conductivity and viscosity of maghemite (γ–Fe₂O₃) water-based nanofluids

I Nurdin¹,³, M R Johan² and B C Ang²

¹ Chemical Engineering Department Lhokseumawe State Polytechnic, 24301 Aceh, Indonesia
² Nanomaterials Engineering Research Group, Advanced Materials Research Laboratory, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

Email : irwan@pnl.ac.id; irwan_nurdina@yahoo.com

Abstract. Thermal conductivity and kinematic viscosity of maghemite nanofluids were experimentally investigated at a small volume fraction of maghemite nanoparticles and temperatures. Maghemite nanofluids were prepared by suspending maghemite nanoparticles in water as base fluids. Results show that the thermal conductivity of maghemite nanofluids linearly increase with increasing particle volume fraction and temperature, while kinematic viscosity increase with increasing particle volume fraction and decrease with increasing temperature. The highest enhancement of thermal conductivity and kinematic viscosity are 18.84% and 13.66% respectively, at particle volume fraction 0.6% and temperature 35.

1. Introduction
Nanofluid is a new class of engineering material consisting of solid nanoparticles with sizes smaller than 100 nm suspended in a base fluid. It provides useful applications in industrial fluids system, including as heat transfer fluids, magnetic fluids, and lubricant fluids [1].

Maghemite (γ-Fe₂O₃) nanoparticles are promising magnetic materials that are intensively explored in recent years due to their superparamagnetic behavior [2]. The suspended of these magnetic nanoparticles in a liquid medium generate a new class of liquid called “magnetic fluids.” The uniqueness of this fluid is its superparamagnetic and biocompatibility behavior, and it can be controlled by external magnetic fields.

Due to its unique characteristics, the magnetic fluids act as smart fluids. They have potential applications in a variety of areas including microelectronics as in audio speaker, magnetic seal in motors, energy supply, HVAC, magnetic ink for banking cheques, magnetic recording media, magnetic resonance imaging media, drug delivery or therapeutic agents in cancer therapy and thermal engineering applications [3-7].

For such utilizations, the thermal conductivity and viscosity of magnetic fluids are critical parameters that influenced the performance of the process. Therefore, the measurement of these properties and understanding of these transport parameters become important in the application of the magnetic fluids.

³ To whom any correspondence should be addressed.
It is well-known that the thermal conductivity and viscosity of the nanoparticle in liquids depends on the particles concentration and temperatures. Most research works related to the measurement of thermal conductivity of non-magnetic nanoparticle suspensions show a good thermal conductivity enhancement [8-11]. However, only a few of research associated with the thermal conductivity of magnetic nanofluids, particularly maghemite nanofluids were reported.

Many researchers focus on the measurement of thermal conductivity of magnetite (Fe₃O₄) nanofluids with varying of particle volume fraction and temperature without applying magnetic fields [12-14]. They found that the thermal conductivity of magnetite nanofluids increased with the increase of the particle volume fraction and temperature.

At the same time, lack of data regarding the viscosity of nanofluids measurements particularly magnetic nanofluids in the literature. Most of the investigations available in the literature on the viscosity of nanofluids, concerning the effect of volume fraction agree upon the fact that the viscosity of nanofluids increases with increasing the particle volume fraction. These phenomena also occurred in magnetic nanofluids.

Although significant investigations have been done concerning this material, the amount of data remains very limited. Efforts are still being conducted primarily to characterize the thermal and physical properties of magnetic fluids.

In this study, thermal conductivity and viscosity of water-based maghemite nanofluids were measured at a low particle volume fraction and temperatures.

2. Methodology
The Maghemite nanoparticles used in this experiment have been synthesized using a chemical co-precipitation method and characterized using several characterization techniques.

2.1. Nanofluid preparation
Maghemite nanofluids were prepared by dilution of a known concentration of a stock solution in deionized water at a different percent of the particle volume fraction of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6%.

The concentration of the nanofluids in percent volume fraction can be estimated by Eq. (1).

\[ \phi = \frac{m_p}{\rho_p} \cdot \frac{\rho_f}{\rho_f} \times 100\% \]  

(1)

where \( \phi \) is particle volume fraction, \( m_p \) is mass of nanoparticles, \( \rho_p \) is density of nanoparticles \( m_f \) is mass of base fluids and \( \rho_f \) is density of base fluids.

2.2. Thermal conductivity measurement
Thermal conductivity measurements were conducted by KD2 Pro thermal property analyzer equipment by Decagon Devices Company, USA, which is according to transient hot-wire method. It consists of a handheld controller and sensors that inserted in the medium. The KS-1 single-needle sensor with 1.3 mm diameter and 60 mm length was used. The sensor integrates with its interior a heating element and a thermo-resistor, and it connected to a microprocessor for controlling and conducting the measurements. The measurements were performed using 30 ml sample in a cylindrical glass tube bottle. The needle probe inserted into the sample bottle then placed and exposed to a jacketed vessel that the temperature kept constant with a JEO circulating and refrigerating water bath. The samples were allowed in the bath for 30 minutes to get the desired temperature. The measurements conducted at different temperatures and particle volume fractions. Before measurement, the meter was calibrated using the standard verification solutions of known thermal conductivity. Thermal conductivities data were recorded five times with an interval of 15 minutes for each concentration at given temperature. The average of data measurements was reported.

2.3 Viscosity measurement
The viscosity of the maghemite nanofluids were measured by Cannon Fenske calibrated glass capillary viscometer. The measurement conducted at different particle volume fractions and temperatures. The temperatures were kept constant with a JEO circulating and refrigerating water bath. The samples were placed in the viscometer and allowed for immersion for 30 minutes to get the desired temperature. Viscosity measurements were conducted five times at each particle volume fraction of the maghemite nanofluids at a given temperature. The average of data measurements was reported.

3. Results and Discussion
The sizes and form of the maghemite nanoparticles from TEM image is shown in figure 1. It observed that the shape of the particles is spherical and the size around 9.5 nm.

![Figure 1. TEM image of maghemite nanofluids.](image)

Figure 2 shows the thermal conductivity of maghemite nanofluids as a function of volume fraction of maghemite nanoparticles. Overall, the thermal conductivities of the maghemite nanofluids increase linearly with particles volume fraction and significantly higher than that of the base fluids. The mixture of the nanofluids contains three components, namely nanoparticle, interfacial layer, and liquids [8, 15, 16]. When the nanoparticles suspended in base fluids, interaction occurred between nanoparticles, the interfacial layer, and base fluids. These interactions caused by a random movement of the particles in the base fluids due to collisions with the molecules of base fluids [17]. Besides that, there is also consideration towards the effect of the interfacial layer between fluids and particles as the increase of layer thickness increases the thermal conductivity of nanofluids [18].

At the same time, the conductivity increased as the temperature increases due to the rise of maghemite nanoparticles Brownian motion. The highest enhancement of thermal conductivity of maghemite nanofluids is 18.84% that obtained at a particle volume fraction of 0.6% and temperature of 35 °C. These results are in good agreement with other’s work [12].
Figure 2. Thermal conductivity of maghemite nanofluids as a function of particle volume fraction at different temperatures.

The effect of temperature on the thermal conductivity of maghemite nanofluids shown in figure 3. Generally, the thermal conductivities are nonlinearly increased with the rise of temperature. When the temperature rises, the intensity of Brownian motion augments significantly, which leads to a corresponding enhancement of thermal conductivity. The thermal conductivity of high volume fraction of maghemite become larger than that with lower volume fraction due to the difference in intensity of Brownian motion at elevated temperature [8].

Figure 3. Temperature dependent thermal conductivity of maghemite nanofluids with the different volume fraction of maghemite nanoparticles.

The effect of the particle volume fraction of maghemite nanoparticles on the kinematic viscosity of maghemite nanofluids is presented in figure 4. It can be seen that the increase of a particle volume fraction of maghemite nanoparticles improve linearly with the kinematic viscosity of maghemite nanofluids.

As a nanofluids is a mixture of nanoparticle and base fluids, there is an interaction between particles and its surrounding. The flow of nanofluids created frictions between nanofluids and its surrounding that resist the flow of nanofluids. The more concentrated of nanoparticles in the fluids
will enhance the resistance of nanofluids flow, and this will increase the viscosity of nanofluids. The highest enhancement of kinematic viscosity of maghemite nanofluids is 13.66% for a particle volume fraction of 0.6% and temperature of 35 °C.

The influence of temperature on kinematic viscosity of maghemite nanofluids is presented in figure 5. It can be seen that the kinematic viscosity of maghemite nanofluids decreased with increasing temperature. The liquid molecules are tightly bonded together by attractive intermolecular forces (e.g. Van der Waal forces) at low temperature. These attractive forces are responsible for the viscosity since the individual molecules are difficult to move because they are firmly bound to their neighbors. Therefore, the kinematic viscosity is larger at low temperature.

The impact of increasing temperature will be weakening of inter-particle and inter-molecular adhesion forces hence accelerate the movement of the particles in liquids [19]. The increase in temperature causes the enhancement of kinetic or thermal energy of particles in the solutions that make the molecules more mobile. Therefore, the viscosity is reduced.
4. Conclusions

The influence of low particle volume fraction of maghemite nanoparticles and temperature have been studied on the thermal conductivity and viscosity of maghemite nanofluids.

The thermal conductivity of maghemite nanofluids increases linearly with increasing of a particle volume fraction of maghemite nanoparticles and temperature. The highest enhancement of thermal conductivity is 18.84% at a particle volume fraction of 0.6% and temperature of 35 °C. The kinematic viscosity of maghemite nanofluids increase linearly with increasing of particle volume fraction and decrease with increasing temperature. The highest enhancement of kinematic viscosity of maghemite nanofluids is 13.66% that obtained at a particle volume fraction of 0.6% and temperature of 35 °C.

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