Journal of Magnetism and Its Applications, 2 (1) 2022, 14-17

http://www.jourmag.org/index.php/jma

Journal of Magnetism and Its Applications

Received August 17th 2022; received in revised August 31th 2022; accepted September 3rd 2022

Research articles

Magnetite Nanofluids from Natural Sand for Temperature Sensor Application: A Preliminary Study

Putri Fauziah, Arif Hidayat, Ahmad Taufiq*, ST. Ulfawanti Intan Subadra

Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Semarang St., No. 5, East Java, 65145, Indonesia

Article info

Keywords:
Nanofluid
Magnetite
Natural sand
Temperature sensor
Sensitivity

Abstract

In this study, magnetite nanofluids have been developed from natural sand for temperature sensor application. On the basis of the results of XRD data analysis, it was known that the nanoparticles as fillers of the nanofluids had a single phase, namely magnetite with an inverse cubic spinel structure with a crystallite size of 11 nm. The SEM image showed that the nanoparticles were composed of spherical particles and tended to agglomerate with a particle size distribution of 38 nm. The octahedral and tetrahedral Fe-O functional groups were detected at wavenumbers of 506 cm^{-1} and 762 cm^{-1} which confirmed the presence of magnetite. The band gap energy value of the magnetite nanoparticles was 2.797 eV. Furthermore, the temperature sensor test showed that the output laser intensity of the magnetite nanofluids increased with increasing temperature. The best dilution with the volume composition of H_2O:nanofluids (1:4) achieved the best sensitivity for temperature sensor application.

1. Introduction

The COVID-19 pandemic that has hit the world in the last 3 years has one of the common symptoms of flu and fever above normal human temperature [1, 2]. This situation implies the importance of using a high accuracy temperature sensor. In addition, temperature sensors are also used to detect fires both in buildings and in nature [3]. Some of these problems make temperature sensors important to develop and lead many researchers to conduct more in-depth research both in fundamental aspects and aspects of production [4]. Temperature sensors that have been successfully developed by previous researchers, such as CMOS, liquid crystal cholesteric, and fiber optics [5]. Recently, several researchers have succeeded in developing temperature sensors based on liquid or ferrofluid magnets [6,7]. Pathak et al. have reported that ferrofluids have a high temperature sensitivity of up to 3.7 mK [6]. Our previous studies also reported that ferrofluid exhibits a sensitive response as a sensor at temperatures of 27 – 50 °C [8]. In general, ferrofluid consists of a filler, surfactant, and dispersing liquid. In this research, magnetite filler is used, which is proven to have superior properties to be applied as a temperature sensor, such as superparamagnetic [9] and in nano-size it has a high surface area so it has high sensitivity, easy to absorb and desorb the targeted sensor object [10].

In this study, the raw material for making magnetite is iron sand which is widely found in Indonesia. Indonesia is famous for its abundant natural resources, one of which is iron sand. So far, iron sand has only been used as an additional material for cement and steel, which is classified as not optimal. In our previous research, we also succeeded in using iron sand as the main precursor for the manufacture of ferrofluid which was applied as a temperature sensor capable of detecting temperatures from 27 °C [11]. In its application as a temperature sensor, it turns out that the viscosity of ferrofluid is an important thing to note. Therefore, in this study, dilution variations were also carried out to obtain the best formula so that magnetite ferrofluid can be applied as a temperature sensor with maximum performance.

2. Experimental Methods

The preparation of magnetite nanofluids started with the preparation of filler, namely magnetite nanoparticles synthesized by the coprecipitation method following our previous research [11, 12]. Magnetic powder from iron sand was reacted with HCl to get $FeCl_2$ and $FeCl_3$ solution. Then the solution was titrated with NH_4OH to get precipitated magnetite nanoparticles. Then 1 g of magnetite precipitate was mixed with 2 ml of TMAH followed by stirring for one hour and titrated with distilled water until homogeneous to obtain high homogeneity magnetite nanofluids. Then the remaining precipitate was dried at 100 °C to obtain magnetite powder. Magnetite nanoparticles were characterized using an X-ray diffractometer (XRD) type PANalytical X'Pert Pro, Cu-Ka 1.540 to determine the phase, structure, and crystal size of the nanoparticles. The characterization of the fourier transforms infrared (FTIR) spectrophotometer with the Shimadzu brand and IRPrestige-21 type was also carried out to determine the functional groups of the nanoparticles. The morphology of the nanoparticles was also characterized using the FEI scanning electron microscopy (SEM) brand with Inspect-S50 type. The optical value of magnetite nanoparticles was also characterized using UV-Vis spectrophotometer. Furthermore, temperature sensor testing was carried out using magnetite nanofluids samples with various dilutions using composition of nanofluids: H_2O (1:0, 1:1, 1:2, 1:3, and 1:4).

3. Results and Discussion

The diffraction pattern of the magnetite nanoparticles is shown in Figure 1. The diffraction peak was identified at the 2θ position = 30.1°, 35.5°, 43.3°, 47.6°, 53.7°, 57.3°, 62.9°, 71.3°, and 74.4° represented Bragg planes (2 2 0), (3 1 1), (4 2 2), (1 3 3), (5 1 1), (4 4 0), (5 3 3), (0 2 6), and (3 3 5). The results obtained in this study are consistent with previous research [14]. In addition, there is a match between the black sphere and the red line, which indicates that the formed nanoparticles have a single-phase magnetite with an inverse spinel cubic structure and a crystal size of 11 nm. The structure of magnetite nanoparticles is the inverse spinel magnetite structure is based on the face centered cubic concept of O^{2+} cations where Fe^{3+} cations occupy half the tetrahedral gap or 50:50 mixture composition between Fe^{2+} and Fe^{3+} occupies 1/8 of the octahedral site.

*Corresponding author
Email: ahmad.taufiq.fmipa@um.ac.id

DOI: 10.53533/JMA.v2i1.21

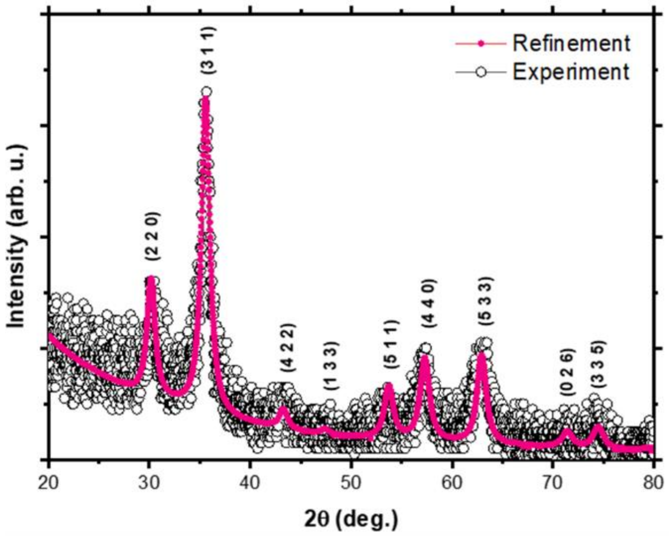

Fig. 1. X-ray Diffraction Pattern of Magnetite Nanoparticles

The morphology of magnetite nanoparticles has been characterized using SEM with the results shown in Figure 2. By using SEM at a magnification of 100,000x, virtually the characterization results can be seen that magnetite nanoparticles are composed of spherical-shaped particles with a size distribution of 38 nm. Based on the figure, it is also known that the particles that make up magnetite tend to clump together to form secondary particles, according to previous research [15].

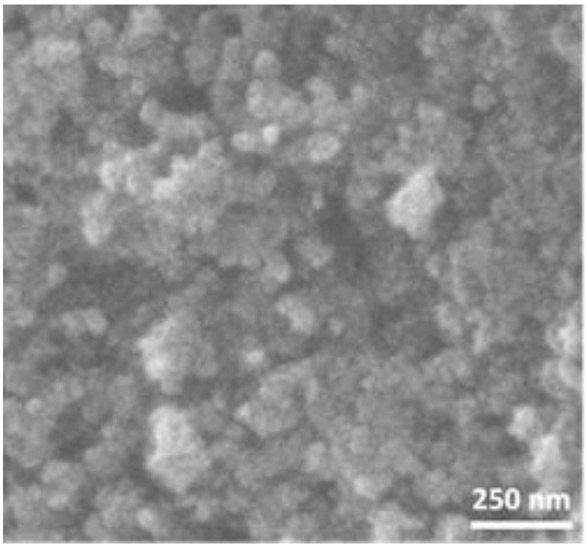

Fig. 2. SEM Image of Magnetite Nanoparticles

Figure 3 is the FTIR spectrum, where valleys are formed due to the vibration of functional groups in the magnetite nanoparticles. Based on figure, it is detected that there are valleys at wavenumbers 506, 762, 1356, 1636, and 2378 cm^{-1}. The first two absorptions at wavenumbers 506 cm^{-1} and 762 cm^{-1} were formed as a result of the vibrations of Fe-O octahedral and tetrahedral. The results in this study are close to our previous studies [16, 17]. The existence of these two bonds also confirms the XRD results, where the magnetite formed has an inverse spinel cubic structure [18]. Furthermore, the vibration of the tetrahedral Fe-O functional group was detected at a wavenumber of 1356 cm^{-1} [19]. While the functional group of O-H bending is found at wavenumbers 1636 and 3500 cm^{-1} and CO_2 is detected at wavenumber 2378 cm^{-1}. Similar results have also reported in previous studies [20]. Furthermore, the optical value described by the energy gap of magnetite nanoparticles was analyzed by the Tauc plot method shown in Figure 4. The results of the analysis show that the magnetite nanoparticles synthesized from iron sand have an energy gap of 2.797 eV. These results are close to the magnetite energy gap value of 2.890 eV and was still classified as a semiconductor [21].

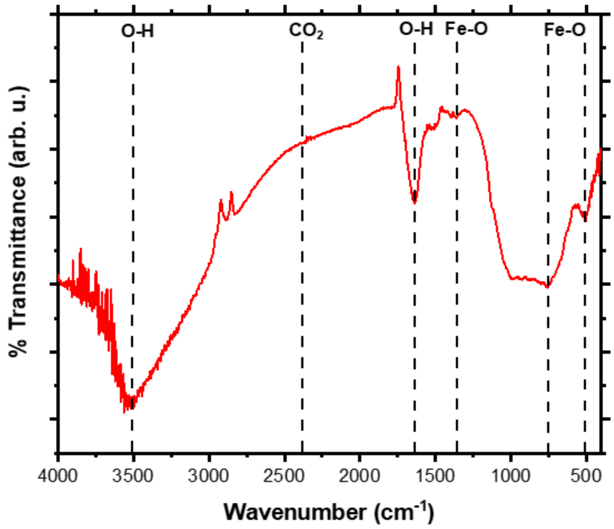

Fig. 3. FTIR Spectrum of Magnetite Nanoparticles

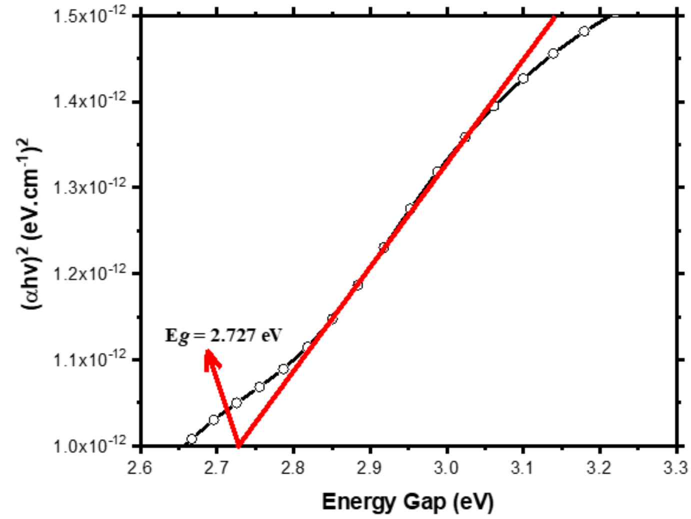

Fig. 4. Energy Gap of Magnetite Nanoparticles

The sensitivity test of magnetite nanofluids to temperature changes has been characterized by looking at the effect of heating on the intensity of the laser fired at the nanofluids. The testing process was carried out by varying the dilution of nanofluids with deionized water in a ratio of 1:0, 1:1, 1:2, 1:3, and 1:4. The test results relationship between temperature and laser intensity, as shown in Figure 5.

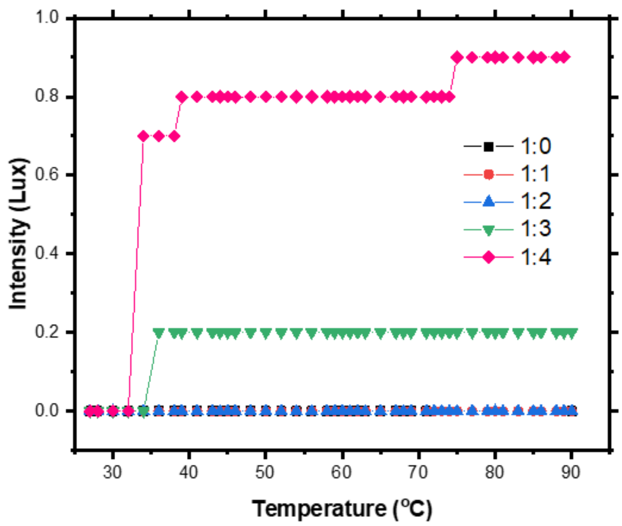

Fig. 5. Intensity versus Temperature of Magnetite Nanofluids

The room temperature as the initial temperature is indicated by a digital thermometer, which is around 27-28 °C at the time of measurement. At samples 1:0, 1:1, and 1:2, there was no increase in the intensity of the luxmeter. This shows that the laser cannot penetrate the nanofluids because the viscosity is still high. However, after a 1:3 dilution, there was an increase in the laser intensity from 0 to 0.2 lux at 36 °C and after that the laser intensity tended to remain constant. Furthermore, when nanofluids were diluted in a ratio of 1:4 it was found that there were 3 increases in intensity, namely from 0 to 0.7 at 36 °C, from 0.7 to 0.8 at 39 °C, and 0.8 to 0.9 at 75 °C. On the basis of these results, it is known that the laser transmittance is affected by the nanofluids viscosity. Nanofluids with high viscosity cause the laser to have little or no transmittance, so that the lux intensity is low. Furthermore, good sensor sensitivity was obtained in samples with a 1:4 dilution, where the higher the temperature, the higher the lux intensity obtained.

4. Conclusions

Nanofluids with magnetite filler have been successfully synthesized by the coprecipitation method from natural sand. Structural analysis showed that the magnetite nanoparticles had an inverse cubic spinel structure with a crystallite size of 11 nm. The magnetite nanoparticles were spherical in shape and tended to agglomerate in nanometric size. The success of magnetite synthesis was also indicated by the presence of functional groups of Fe-O octahedral and tetrahedral at wavenumbers of 506 cm^{-1} and 762 cm^{-1}. Furthermore, magnetite nanoparticles had a energy gap of 2.797 eV as semiconductor material. The results of the optical properties of the magnetite nanofluids showed that the effect of the temperature increased the intensity of the laser. The thermo-optical effect has been demonstrated in magnetite nanofluids, where the lower the nanofluids viscosity, the higher the transmitted light, and the higher the intensity of light.

Acknowledgments

This work was supported by Universitas Negeri Malang for AT through a research grant in 2021-2022.

References

[1] N. Zhu *et al.*, "A Novel Coronavirus from Patients with Pneumonia in China, 2019," *N Engl J Med*, vol. 382, no. 8, pp. 727–733, Feb. 2020, doi: 10.1056/NEJMoa2001017.

[2] Y. Hu *et al.*, "Clinical Characteristics of Coronavirus Disease 2019 in China," *N Engl J Med*, vol. 382, no. 18, pp. 1708–1720, Apr. 2020, doi: 10.1056/NEJMoa2002032.

[3] T. Sutikno, W. S. Aji, and R. Susilo, "Perancangan Alat Pendeteksi Kebakaran Berdasarkan Suhu Dan Asap Berbasis Mikrokontroler AT89S52," *TELKOMNIKA*, vol. 4, no. 1, p. 49, Apr. 2006, doi: 10.12928/telkomnika.v4i1.1244.

[4] F. Wiekhorst, U. Steinhoff, D. Eberbeck, and L. Trahms, "Magnetorelaxometry assisting biomedical applications of magnetic nanoparticles," *Pharmaceutical Research*, vol. 29, no. 5, pp. 1189–1202, 2012, doi: 10.1007/s11095-011-0630-3.

[5] W. Elyani, A. Hidayat, A. Taufiq, and S. Sunaryono, "Sintesis Kromium Ferit Dari Pasir Pantai dan Karakterisasi Awal Sensor Suhu," *JPSE (Journal of Physical Science and Engineering)*, vol. 3, no. 1, pp. 1–7, 2018, doi: 10.17977/um024v3i12018p001.

[6] S. Pathak, K. Jain, Noorjahan, V. Kumar, and R. Prasad Pant, "Magnetic Fluid Based High Precision Temperature Sensor," *IEEE Sensors Journal*, vol. 17, no. 9, pp. 2670–2675, May 2017, doi: 10.1109/JSEN.2017.2675440.

[7] D. Zhang, Z. Di, Y. Zou, and X. Chen, "Temperature sensor using ferrofluid thin film," *Microfluidics and nanofluidics*, vol. 7, no. 1, pp. 141–144, 2009.

[8] D. F. Aprita, A. Taufiq, A. Hidayat, and R. E. Saputro, "Development of temperature sensor using TMAH surfactant based $MnFe_2O_4$ ferrofluid," *AIP Conference Proceedings*, vol. 2687, no. 1, p. 050019, May 2023, doi: 10.1063/5.0121707.

[9] Q. Wu, M. Chen, K. Chen, S. Wang, C. Wang, and G. Diao, "Fe_3O_4-based core/shell nanocomposites for high-performance electrochemical supercapacitors," *Journal of Materials Science*, vol. 51, no. 3, pp. 1572–1580, 2016, doi: 10.1007/s10853-015-9480-4.

[10] N. Saprianti, L. A. Didik, and A. Zohdi, "Analisa Sifat Listrik Dan Kandungan Fe Nano Partikel Pasir Besi Berbasis Pasir Besi Sungai Untuk Mengetahui Kualitas Air Sungai Analysis of Electricity Properties and The Content of Fe Nano Particle of Iron Sand Based on River Sand to Know The Quality of ," vol. 7, no. 1, pp. 103–113, 2021.

[11] A. Hidayat, W. Elyani, A. Taufiq, and S. T. Wicaksono, "A Preliminary Study on the Thermo-optics Characteristics of Chromium Ferrite Ferrofluids," *IOP Conference Series: Materials Science and Engineering*, vol. 515, no. 1, 2019, doi: 10.1088/1757-899X/515/1/012087.

[12] A. Taufiq *et al.*, "Effects of the Annealing Temperature on the Structure Evolution and Antifungal Performance of TiO_2/Fe_3O_4 Nanocomposites Manufactured from Natural Sand," *Nano*, vol. 16, no. 02, p. 2150017, 2021, doi: 10.1142/S179329202150017X.

[13] ST. U. Intan Subadra *et al.*, "Preparation and Characterization of Magnetite Nanoparticles Combined with Polyaniline and Activated Carbon," *IOP Conference Series: Earth and Environmental Science*, vol. 276, p. 012041, Jun. 2019, doi: 10.1088/1755-1315/276/1/012041.

[14] S. Bahtiar, A. Taufiq, and Sunaryono, "Preparasi dan Karakterisasi Struktur Nanokomposit Fe_3O_4/ZnO dengan Menggunakan Metode Kopresiptasi," pp. 318–322, 2017.

[15] A. Taufiq *et al.*, "Studies on Nanostructure and Magnetic Behaviors of Mn-Doped Black Iron Oxide Magnetic Fluids Synthesized from Iron Sand," *Nano*, vol. 12, no. 09, Art. no. 09, Sep. 2017, doi: 10.1142/S1793292017501107.

[16] A. N. Hasanah, A. Taufiq, A. Hidayat, and S. T. U. I. Subadra, "Investigation of nanostructure and morphology of $MnFe_2O_4$/MWCNT/ZnO nanocomposite," *AIP Conference Proceedings*, vol. 2687, no. 1, p. 050008, May 2023, doi: 10.1063/5.0121814.

[17] S. U. I. Subadra *et al.*, "Synthesis and characterisation of Fe_3O_4/MWCNT/ZnO nanocomposites covered by a soft template as a new antibacterial agent," *Adv. Nat. Sci: Nanosci. Nanotechnol.*, vol. 13, no. 3, p. 035010, Sep. 2022, doi: 10.1088/2043-6262/ac8de8.

[18] A. Taufiq *et al.*, "Eco-Friendly Fabrication of Fe_3O_4/MWCNT/ZnO Nanocomposites from Natural Sand for Radar Absorbing Materials," *International Journal of Nanoscience and Nanotechnology*, vol. 17, no. 1, pp. 41–53, Mar. 2021.

[19] S. Ahmad, U. Riaz, A. Kaushik, and J. Alam, "Soft Template Synthesis of Super Paramagnetic Fe_3O_4 Nanoparticles a Novel Technique," *Journal of Inorganic and Organometallic Polymers and Materials*, vol. 19, no. 3, Art. no. 3, Sep. 2009, doi: 10.1007/s10904-009-9276-6.

[20] A. Taufiq *et al.*, "Synthesis of magnetite/silica nanocomposites from natural sand to create a drug delivery vehicle," *Heliyon*, vol. 6, no. 4, Art. no. 4, 2020.

[21] H. El Ghandoor, H. M. Zidan, M. M. H. Khalil, and M. I. M. Ismail, "Synthesis and some physical properties of magnetite (Fe_3O_4) nanoparticles," *International Journal of Electrochemical Science*, vol. 7, no. 6, pp. 5734–5745, 2012.