




## Original Article

# Effect of Different Temperatures in Magnetite Synthesis on Methylene Blue Adsorption

Dea Dwi Ananda<sup>1</sup>, Sultan Napoleon<sup>1</sup>, Thessa Octavia Joyetta Tarigan<sup>1</sup>, Tiara Rizki Yulita<sup>1</sup>, Latisa Stefi Alivia<sup>1</sup>, Bagas Kusuma<sup>1</sup>, M. Rizki Fajri<sup>1</sup>, Kayla Sophia Putri<sup>1</sup>, Nayantaka Virsa Artdero<sup>1</sup>, Nurwanto<sup>1</sup>, Rudi Hartono<sup>1</sup>, Rahmat Basuki<sup>1\*</sup> 

<sup>1</sup>Department of Chemistry, The Republic of Indonesia Defense University, Kawasan IPSC Sentul, Bogor 16810, Indonesia

<https://doi.org/10.55749/ss.v1i2.84>

Received: 2 Jul 2025; Revised: 20 Aug 2025; Accepted: 2 Sep 2025; Published online: 23 Sep 2025; Published regularly: 31 Dec 2025

This is an open access article under the CC BY-SA license (<https://creativecommons.org/licenses/by-sa/4.0/>).

**Abstract—** This study aims to synthesize magnetite ( $\text{Fe}_3\text{O}_4$ ) particles using the coprecipitation method, with variations in temperature ( $70^\circ\text{C}$  and  $90^\circ\text{C}$ ) and reaction system (open and closed) to evaluate their effects on product quality. Characterization was conducted using FTIR, XRD, and organoleptic observation to confirm the formation of  $\text{Fe}_3\text{O}_4$ . Additional tests included magnetic attraction measurements through mass response and adsorption capacity (Q) analysis using methylene blue. FTIR analysis showed absorption bands at  $3417.00\text{ cm}^{-1}$ ,  $1627\text{ cm}^{-1}$ ,  $1404\text{ cm}^{-1}$ , and  $578\text{ cm}^{-1}$ , indicating the presence of O–H, C=O, and Fe–O functional groups. XRD patterns revealed diffraction peaks at  $2\theta$  values of  $30.27^\circ$ ,  $35.23^\circ$ ,  $43.22^\circ$ ,  $53.71^\circ$ ,  $57.43^\circ$ , and  $62.11^\circ$ , confirming the spinel crystal structure of  $\text{Fe}_3\text{O}_4$ . The sample synthesized at  $90^\circ\text{C}$  under closed conditions exhibited a darker black color and higher mass yield, suggesting improved crystallinity and phase purity. The closed system also showed higher adsorption capacities of  $0.0008\text{ mmol}\cdot\text{g}^{-1}$  at  $70^\circ\text{C}$  and  $0.0018\text{ mmol}\cdot\text{g}^{-1}$  at  $90^\circ\text{C}$ , along with stronger magnetic response. The open system produced a black precipitate with lower yield and weaker magnetic response, suggesting oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  due to direct contact with oxygen, leading to the formation of compounds such as hematite or maghemite with lower magnetic properties. These results confirm that higher reaction temperatures and closed conditions optimally enhance the quality and stability of magnetite.

**Keywords—** Ammonia; Close System; Coprecipitation; Magnetite; Methylene Blue; Open System.

## 1. INTRODUCTION

Magnetite ( $\text{Fe}_3\text{O}_4$ ) is a form of iron oxide that is included in the group of ferromagnetic minerals. This material has strong magnetic properties because its structure consists of a mixture of  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  ions arranged in a spinel lattice [1]. Various types of magnetic materials have been developed, including hematite ( $\alpha\text{-Fe}_2\text{O}_3$ ) [2], maghemite ( $\gamma\text{-Fe}_2\text{O}_3$ ) [3], and ferrite ( $\text{MxFe}_3\text{-xO}_4$ , where M is a divalent metal such as Co, Mn, Zn) [4]. However, magnetite is the most widely used because of its chemical stability, strong magnetic properties at room temperature, and its ability to be synthesized in nanometer sizes with a narrow size distribution [5].

Several methods have been developed for the synthesis of magnetite including coprecipitation, sol–gel [6], hydrothermal, thermal decomposition, and microemulsion. Among these methods, the coprecipitation method is one of the most widely used because of its simple procedure, low cost, no need for organic solvents, and suitable for large-scale production

[7]. This method is carried out by mixing  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  salt solutions in an aqueous medium, then adding a base agent to form  $\text{Fe}_3\text{O}_4$  particle precipitates.

Basic agents play an important role in the coprecipitation process because they function to increase the pH of the solution, thereby triggering the formation of metal hydroxides which are then transformed into magnetite. Some types of bases commonly used in this method include sodium hydroxide (NaOH), potassium hydroxide (KOH), and ammonia ( $\text{NH}_4\text{OH}$ ). The selection of the type of base greatly affects the reaction rate, particle size, and stability of the resulting suspension.

In this study, ammonia solution ( $\text{NH}_4\text{OH}$ ) was used as a basic agent because ammonia has a lower oxidation ability towards  $\text{Fe}^{2+}$  compared to other strong bases. Therefore, ammonia produces a smaller amount of  $\text{Fe}^{3+}$ , which can affect the formation of the final phase such as maghemite. In addition to the type and concentration of base, other factors such as reaction

\*Corresponding author.

Email address: [rhmtbsq@gmail.com](mailto:rhmtbsq@gmail.com)

temperature and stirring rate also have a significant effect on the synthesis results [8]. The reaction temperature affects the rate of nucleation and crystal growth, while the stirring rate affects the distribution of ions in the solution and the homogeneity of the particles formed.

Careful control of these parameters is essential to produce magnetite with optimal particle size, magnetic behavior, and phase purity. However, studies that directly link these synthesis variables to functional properties such as adsorption capacity remain limited. This study aimed to synthesize magnetite ( $\text{Fe}_3\text{O}_4$ ) nanoparticles through the coprecipitation method using ammonia solution ( $\text{NH}_4\text{OH}$ ) as the alkaline agent. It also sought to examine the influence of temperature and environmental conditions on the color and magnetic properties of the synthesized particles. Methylene blue adsorption tests were conducted to evaluate the adsorption capacity of the samples prepared at different temperatures. This study is expected to contribute to the development of an efficient and controlled synthesis method in producing high-quality  $\text{Fe}_3\text{O}_4$  nanoparticles for various functional applications.

## 2. EXPERIMENTAL SECTION

### 2.1. Materials

The chemicals used were  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  (99% purity Merck, Germany),  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  (99% purity Merck, Germany),  $\text{NH}_4\text{OH}$  (25 % purity Merck, Germany), and metilen blue, and aquades.

### 2.2. Instrumentation

This research performed Overhead magnetic stirrer, Erlenmeyer flask, goblet, watch glass, spatula, 100 mL measuring cylinder, stirring rod, spektrofotometer UV-vis, FTIR (Shimadzu Prestige 21), and XRD (BRUKER AXS D8 ADVANCE ECO).

### 2.3. Magnetite Synthesis

Magnetite was synthesized using the coprecipitation method. A total of 4 g of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  and 2 g of  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  were weighed, then put into an Erlenmeyer flask. A volume of 25 mL of distilled water was added, then the mixture was stirred using a stirrer until evenly distributed. After that, the mixture was heated to a temperature variations of 70 °C and 90 °C, and then 25 mL of 25% ammonia solution was added directly. The mixture was allowed to react for 30 minutes, and then filtered to separate the precipitate. Initial tests on magnetic materials were conducted using X-Ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) to ensure the purity and phase identity of the materials used. The precipitate obtained was subjected to physical tests (color) and magnetic tests. Methylene blue adsorption tests were conducted to evaluate the adsorption performance of the synthesized samples. A total of 50 mg of each sample was shaken for 60 minutes in a shaker with methylene

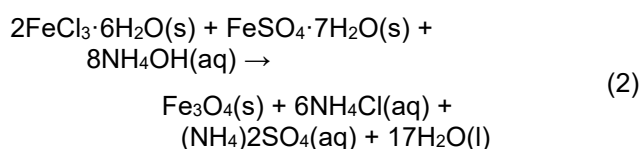
blue solution at concentrations of 2, 4, 6, 8, and 10 ppm to prepare a standard calibration curve. The adsorption capacity is determined from the decrease in concentration after the sample interacts with the substance, using a calibration curve as a reference. Through Equation (1), the amount of methylene blue adsorbed can be calculated.

$$Q = \frac{(c_o - c_e)}{w} V \quad (1)$$

## 3. RESULT AND DISCUSSION

### 3.1. Fulvic Acid Extraction

Magnetite ( $\text{Fe}_3\text{O}_4$ ) was synthesized using the coprecipitation method, which involves the simultaneous precipitation of multiple soluble components in a single phase to form solid particles [9]. The one-pot coprecipitation approach offers high efficiency by reducing the number of reaction steps and enhancing the interaction between components. This allows the material formation to occur either simultaneously or sequentially without the need for intermediate product separation. The magnetite synthesis is based on the interaction between  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ , as the  $\text{Fe}^{3+}$  ion source, and  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , as the  $\text{Fe}^{2+}$  ion source. This precursor mixture was then heated to either 70°C or 90°C. Heating was used to increase the reaction rate and accelerate the crystallization of  $\text{Fe}_3\text{O}_4$ , which exhibits strong magnetic properties [10]. Once the desired temperature was reached, 25 mL of 25% ammonia solution was added directly to trigger the precipitation of iron hydroxides. The mixture was allowed to react for 30 minutes before being filtered to separate the  $\text{Fe}_3\text{O}_4$  precipitate. The reaction of  $\text{Fe}_3\text{O}_4$  formation is as follows Equation (2).

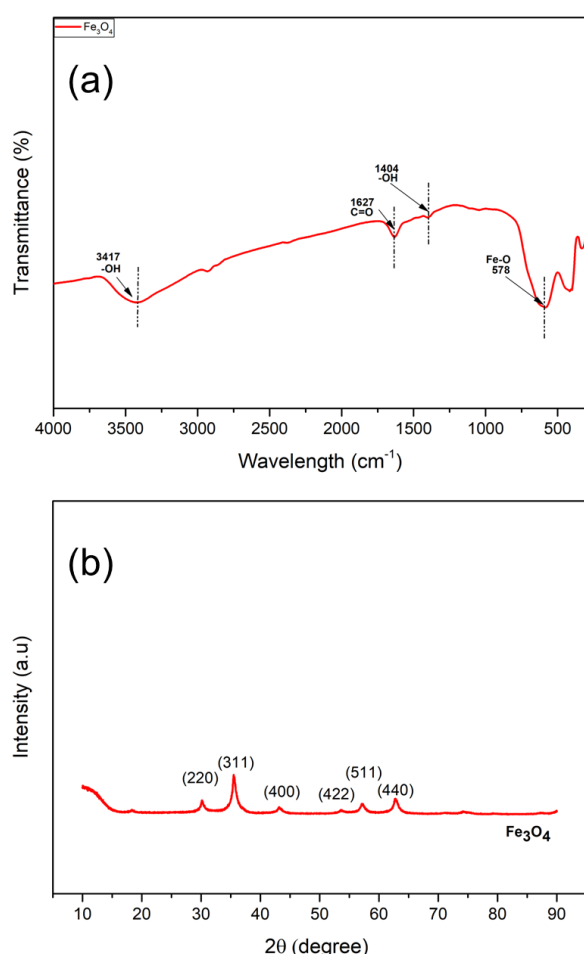


Initial tests on magnetic materials were conducted using X-Ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR) to ensure the purity and phase identity of the materials used. The results of this initial characterization became the basis for the next step, namely varying the reaction conditions in open and closed systems. The experiment was continued at two temperature variations, namely 70°C and 90°C, to emit the effect of the reaction environment and temperature on changes in the properties of the resulting magnetite material.

**Figure 1a** shows the absorption spectrum of functional groups of  $\text{Fe}_3\text{O}_4$ . The absorption at wave number  $3417.00 \text{ cm}^{-1}$  indicates the presence of O–H stretching, while the absorption at  $1627 \text{ cm}^{-1}$  indicates the vibration of the C=O bond. In addition, the absorption at  $1404 \text{ cm}^{-1}$  is also related to the O–H stretching vibration. The typical absorption band for the Fe–O bond is detected at wave number  $578 \text{ cm}^{-1}$ , which

indicates that the Fe ions are in tetrahedral and octahedral positions in the crystal structure of magnetite ( $\text{Fe}_3\text{O}_4$ ).

The crystal structure of the nanoparticles was analyzed using X-ray diffraction (XRD) technique. The XRD patterns of both samples are shown in **Figure 1b**, which show six typical diffraction peaks of  $\text{Fe}_3\text{O}_4$  at  $2\theta$  angles around  $30.27^\circ$ ,  $35.23^\circ$ ,  $43.22^\circ$ ,  $53.71^\circ$ ,  $57.43^\circ$ , and  $62.11^\circ$ , respectively. These peaks correspond to the (220), (311), (400), (422), (511), and (440) crystal planes based on the Miller indices. The results of the diffraction pattern analysis and lattice parameters have been confirmed with reference data from the Crystallography Open Database (COD) with entry number 9006920 for the  $\text{Fe}_3\text{O}_4$  phase. After further synthesis with variations in temperature and system, a simple organoleptic test was carried out to ensure initial identification.



**Figure 1.** (a) Functional groups characterization and (b) diffractogram pattern of magnetite

The synthesized magnetite was characterized through an organoleptic test to assess its quality. According to Ngatijo [13],  $\text{Fe}_3\text{O}_4$  is physically characterized by its distinctive black powder appearance. **Figure 2** shows a comparison of magnetite produced under four different conditions: (a) heating at  $70^\circ\text{C}$  in an open system, (b) heating at  $70^\circ\text{C}$  in a closed system

system, (c) heating at  $90^\circ\text{C}$  in an open system, and (d) heating at  $90^\circ\text{C}$  in a closed system.



**Figure 2.** Visual characterization of  $\text{Fe}_3\text{O}_4$  at (a)  $70^\circ\text{C}$  in an open system, (b)  $70^\circ\text{C}$  in a closed system, (c)  $90^\circ\text{C}$  in an open system, and (d)  $90^\circ\text{C}$  in a closed system

Observations showed that the magnetite produced at  $90^\circ\text{C}$  had a darker color compared to that synthesized at  $70^\circ\text{C}$ . This is because magnetite particles at higher temperatures have more time and energy to organize themselves into larger and more ordered crystals [11]. These more ordered crystals possess a greater number of active sites and energy pathways, allowing electrons to move more freely between the +2 and +3 oxidation states. The more electrons available to absorb photons across various wavelengths, the greater the light absorption, resulting in a deeper and darker black appearance.

In addition, the samples synthesized under closed conditions exhibited a darker color compared to those produced in open conditions. This is because, in a closed environment, there is no oxidation caused by exposure to atmospheric oxygen, resulting in a purer and more concentrated product. The denser and purer crystal structure of magnetite formed under these conditions enhances its light absorption capability, making the color appear significantly darker than when the reaction occurs in an open system with excess oxygen [12].

**Table 1.** Mass of  $\text{Fe}_3\text{O}_4$

System	$70^\circ\text{C}$	$90^\circ\text{C}$
Opened (g)	1.633	2.066
Closed (g)	1.697	2.398

Based on theoretical calculations, the expected mass of magnetite is 1.665 g. At  $70^\circ\text{C}$ , the magnetite yield in the open system was 1.633 g (**Table 1**), while the closed system produced a slightly higher yield of 1.697 g. At  $90^\circ\text{C}$ , the yields were 2.006 g in the open system and 2.398 g in the closed system. The yields exceeding 100% indicate that the magnetite product was not yet pure, as it still contained ammonia and other contaminants that co-precipitated with the magnetite [14]. To remove these impurities, distilled water was added and the product was repeatedly washed until the pH of the solution reached neutral. This process helped eliminate residual ammonia and other unwanted substances. Additionally, allowing the suspension to

settle for 24 hours further improved the purification by enabling the magnetite particles to settle more completely while separating out impurities. Apart from purification through sedimentation, temperature also plays a crucial role in the synthesis of magnetite [15].

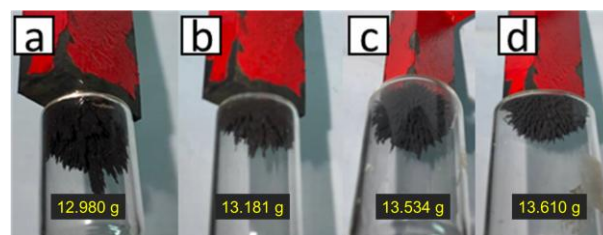
Higher temperatures increase the kinetic energy of molecules in the solution. This elevated kinetic energy accelerates the collision rate between  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  ions and hydroxide anions ( $\text{OH}^-$ ) from the ammonia solution. More frequent and energetic collisions enhance the likelihood of chemical reactions that lead to the formation of  $\text{Fe}_3\text{O}_4$ . Furthermore, at  $90^\circ\text{C}$ , the rate of magnetite crystal formation increases as the activation energy of the reaction is more easily overcome, allowing particles to combine into crystalline structures with higher efficiency. These factors contribute to a higher yield of magnetite, as the reaction proceeds more completely and produces a greater amount of product. While temperature plays a critical role in the reaction, the reaction environment also significantly influences the synthesis outcome. In both open and closed systems, differences in oxygen exposure affect the magnetite formation process and the quality of the final product.

In a closed system, reduced contact with oxygen prevents the unwanted oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$ , allowing the formation of  $\text{Fe}_3\text{O}_4$  to proceed more effectively and resulting in purer magnetite. This stable and controlled reaction environment maintains consistent temperature and pressure, preventing evaporation and fluctuations in solution concentration that could disrupt nucleation and crystal growth. As a result, the magnetite particles formed are more uniform and of higher quality, leading to an increase in product mass and overall yield. Therefore, the closed system supports higher yields by producing magnetite with optimal purity and particle size.

Based on **Figure 3**, the synthesized  $\text{Fe}_3\text{O}_4$  composite exhibits strong magnetic properties, confirming the presence of magnetite ( $\text{Fe}_3\text{O}_4$ ) in the material. This is evident from the strong magnetic attraction observed in all samples, especially under closed reaction conditions. The rapid attachment of the magnet to the material indicates that magnetite was successfully synthesized and possesses strong magnetic characteristics [16]. However, in Figures a and c, the magnetite particles tend to move away from the magnet, suggesting weaker magnetic attraction under open conditions. This indicates that the magnetite formed in open systems may have a less pure crystal structure or smaller particle size, resulting in reduced magnetic strength compared to that synthesized under closed conditions. The qualitative magnetism test shows that the sample heated at  $90^\circ\text{C}$  in a closed system exhibits the strongest magnetic response, indicating a higher degree of purity and more ideal particle size [11].

The magnetic test showed that all magnets were lifted perfectly. The mass addition test was conducted to determine the strength of the magnet simply. **Figure 3**

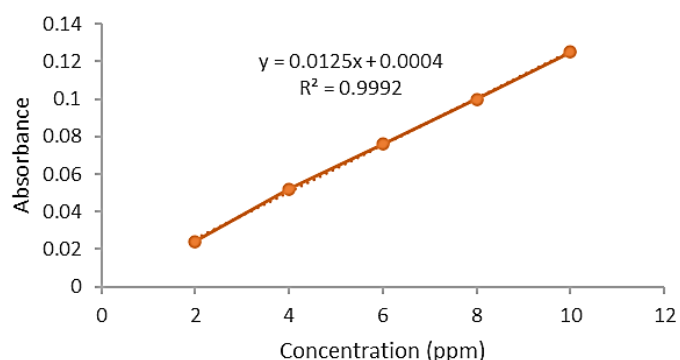
presents the maximum weight that can be held by each magnet based on its magnetic properties.



**Figure 3.** Magnetic attraction test of the sample using magnet

At  $70^\circ\text{C}$ , the maximum weight attracted to the magnet in an open system is 12,980 g, while the closed system yields a slightly higher result of 13,181 g. At  $90^\circ\text{C}$ , the results obtained are 13.34 g in the open system and 13,610 g in the closed system. Figures b and d show larger results because they used a closed system, while figures a and c show smaller results because they used an open system. This shows that a closed system produces stronger magnetic properties than an open system.

The next test involved the use of methylene blue as an adsorbate. Methylene blue was selected due to its well-defined molecular structure, strong chromophore group [17], and ability to interact with active surface sites through electrostatic and  $\pi$ - $\pi$  interactions [18]. A total of 50 mg of each sample was shaken for 60 minutes in a shaker with methylene blue solution at concentrations of 2, 4, 6, 8, and 10 ppm to prepare a standard calibration curve. A 50 mg sample was used because it is the optimal amount to interact with the methylene blue solution without causing saturation or wastage of material. A 60 min shaking time was chosen to allow the adsorption process to reach equilibrium and produce stable data for the construction of a calibration curve.



**Figure 4.** Standard curve of methylene blue adsorption

Based on the standard curve shown in **Figure 4**, the concentration of methylene blue after adsorption can be determined. The initial concentration of 10 ppm showed a noticeable decrease after the adsorption process. This reduction confirms the effectiveness of the magnetic material in adsorbing methylene blue. Decreasing in methylene blue concentration was observed after the addition of magnetite, indicating successful adsorption. At  $70^\circ\text{C}$ , the closed system exhibited a lower final concentration (9.488 ppm) compared to the open



system (9.648 ppm), suggesting a higher adsorption efficiency. Similarly, at 90 °C, the closed system showed a more significant reduction in concentration (8.848 ppm) than the open system (9.808 ppm). These results indicate that both temperature and system conditions influence the adsorption performance, with the closed system consistently demonstrating better methylene blue removal efficiency. Using Equation (1), the amount of adsorbed methylene blue can be calculated that greater magnetic influence contributes to more efficient adsorption of methylene blue.

**Table 2.** Adsorption capabilities (Q)

System	70 °C	90 °C
Opened (mmol.g <sup>-1</sup> )	0.00055	0.0003
Closed (mmol.g <sup>-1</sup> )	0.0008	0.0018

#### 4. CONCLUSION

Magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles were successfully synthesized using the coprecipitation method with ammonia (NH<sub>4</sub>OH) as the base agent. The study demonstrated that both temperature and environmental conditions (open vs. closed systems) significantly affect the quality, color, magnetic properties, and yield of the synthesized magnetite. Higher temperatures (90°C) enhanced particle crystallinity and increased yield due to accelerated nucleation and crystal growth. Furthermore, synthesis under closed conditions produced magnetite with a darker color, stronger magnetic response, and higher yield compared to open systems, attributed to reduced oxidation of Fe<sup>2+</sup> and a more stable reaction environment. The results of the methylene blue adsorption test demonstrated that magnetite effectively reduced dye concentration, confirming its adsorption capability. The best result was obtained at 90°C in a closed system, which yielded magnetite with optimal purity, uniform particle size, and strong magnetic characteristics. The results of this study support the findings of Alibeigi and Vaezi (2008) who stated that magnetite formation is greatly influenced by the molar ratio between Fe<sup>2+</sup> and Fe<sup>3+</sup> ions. In open air conditions, Fe<sup>2+</sup> ions are easily oxidized to Fe<sup>3+</sup>, so that the ideal ratio of 1:2 is difficult to maintain and causes the magnetite phase to not form perfectly. These findings highlight the importance of temperature control and reaction environment in producing high-quality Fe<sub>3</sub>O<sub>4</sub> for potential applications in magnetic materials.

#### SUPPROTING INFORMATION

There is no supporting information in this paper. The data supporting this research's findings are available on request from the corresponding author (R.Basuki).

#### ACKNOWLEDGEMENT

The authors sincerely acknowledge the financial support provided by the Department of Chemistry, Republic of Indonesia Defense University. The authors

also extend their gratitude for the facilities and laboratory resources made available by the BRIN.

#### CONFLICT OF INTEREST

There was no conflict of interest in this study.

#### AUTHOR CONTRIBUTIONS

DDA & SN performed the conceptualization, investigation, methodology, writing original draft, review & editing. RB supervise the experiment, data calculations, and revise the manuscript. TOJT, TRY, LSA, BK, MRF, KSP, NVA, Nurwanto, and RH collaborated on writing and revising the manuscript. All authors approved the final version of the manuscript.

#### REFERENCES

- [1] Santos, L.G.D., Buelvas, D.D.A., Valezi, D.F., Vicentin, B.L.S., Rocha, C.M.M., Mauro, E.D., & Porta, F., De A.L. 2025. Microstructural and magnetic properties of polyamide-based recycled composites with iron oxide nanoparticles. *Magnetism*. 5(1).1–16. <https://doi.org/10.3390/magnetism5010005>
- [2] Duglet, R., Sharma, D., Singh, V., Sharma, D., & Singh, M. 2025. Temperature-driven evolution of hematite (α-Fe<sub>2</sub>O<sub>3</sub>) nanoparticles: a study on structural, morphological and magnetic properties. *Solid State Commun.* 396. 115761. <https://doi.org/10.1016/j.ssc.2024.115761>
- [3] Dhahri, R., Benamara, M., Bouzidi, S., Ben Moussa, S., Alzahrani, A.Y.A., Nassar, K.I., Zahmouli, N., Elkenany, E.B., & Al-Syadi, A.M. 2024. Effect of Gd doping on the microstructure and electrical characteristics of maghemite (γ-Fe<sub>2</sub>O<sub>3</sub>) ceramics. *J. Sol-Gel Sci. Technol.* 113. 225–242. <https://doi.org/10.1007/s10971-024-06598-0>
- [4] Chowdhury, M.Z.B., Islam, M.T., Alqahtani, A., Alshammari, A. S., Soliman, M.S., Alamri, S., & Samsuzzaman, M. 2024. Synthesis and characterization of Mn–Zn ferrite-based flexible penta-band metamaterial for sensing applications. *Opt. Laser Technol.* 175. 110744. <https://doi.org/10.1016/j.optlastec.2024.110744>
- [5] Lin, C.C., Wu, Y.C. and Wu, K.Y. 2024. Feasibility of using chemical co-precipitation and a high-gravity reactor with blade packings for continuous production of magnetite nanoparticles. *J. Taiwan Inst. Chem. E.* 162. 105620. <https://doi.org/https://doi.org/10.1016/j.jtice.2024.105620>
- [6] Zulfikar, T.M. and Viena, V. 2024. March. Application of sol-gel method and co-precipitation in the material synthesis process of magnetite fe3o4 nanoparticles. In *Psroceeding of International Conference on Multidisciplinary Research*. 6(2). 311-316.
- [7] Ognjanović, M., Bošković, M., Kolev, H., Dojčinović, B., Vranješ-Đurić, S., & Antić, B. 2024. Synthesis, surface modification and magnetic properties analysis of heat-generating cobalt-substituted magnetite nanoparticles. *Nanomaterials*. 14(9). 782. <https://doi.org/10.3390/nano14090782>
- [8] Kustomo, K. 2020. Uji Karakterisasi dan mapping magnetit nanopartikel terlapisi asam humat dengan Scanning-Electron-Microscope-Energy Dispersive X-Ray (SEM-EDX). *Indonesian Journal of Chemical Science*. 9(3). 148-153.
- [9] Saragi, T., Permana, B., Saputri, M., Safrani, L., Rahayu, I., & Risdiana, R. 2018. Sintesis nanopartikel magnetik dengan metode kopresipitasi. *Jurnal Material dan Energi Indonesia*. 7(2). 17. <https://doi.org/10.24198/imei.v7i02.15393>
- [10] Nkurikiyimfura, I., Wang, Y., Safari, B., & Nshingabigwi, E. 2020. Temperature-dependent magnetic properties of magnetite nanoparticles synthesized via coprecipitation method. *J. Alloys Compd.* 846. 156344. <https://doi.org/10.1016/j.jallcom.2020.156344>
- [11] Kumar, P., Khanduri, H., Pathak, S., Singh, A., Basheed, G.A., & Pant, R.P. 2020. Temperature selectivity for single phase hydrothermal synthesis of peg-400 coated magnetite nanoparticles. *Dalton Trans.* 49(25). 8672–8683. <https://doi.org/10.1039/d0dt01318h>

- [12] Cursaru, L.M., Piticescu, R.M., Dragut, D.V., Morel, R., Thébault, C., Carrière, M., Joisten, H., & Dieny, B. 2020. One-step soft chemical synthesis of magnetite nanoparticles under inert gas atmosphere: magnetic properties and in vitro study. *Nanomaterials*. 10(8). 1500. <https://doi.org/10.3390/nano10081500>
- [13] Ngatiyo, N., Gusti, D., Fadhillah, A. and Khairunnisah, R. 2020. Adsorben magnetit terlapis dimerkaptosilika untuk adsorpsi anion logam  $[\text{AuCl}_4^-]$  dan  $[\text{Cr}_2\text{O}_7^{2-}]$ . *Jurnal Riset Kimia*. 11(2). 113-120. <http://dx.doi.org/10.1016/j.jmmm.2020.166408>
- [14] Sani, S., Adnan, R., & Mohamed Iqbal, M.A. 2021. One-step statistical design of experiment for the screening and optimization of magnetite nanoparticles yields from solvothermal synthesis. *Microporous And Mesoporous Mater.* 312. 110775. <https://doi.org/10.1016/j.micromeso.2020.110775>
- [15] Dubey, V., & Kain, V. 2018. Synthesis of magnetite by coprecipitation and sintering and its characterization. *Mater. Manuf. Process.* 33(8). 835–839. <https://doi.org/10.1080/10426914.2017.1401720>
- [16] Novoselova, L.Y. 2021. Nanoscale magnetite: new synthesis approach, structure and properties. *Appl. Surf. Sci.* 539. 148275. <https://doi.org/10.1016/j.apsusc.2020.148275> ss
- [17] Mashkoo, F., & Nasar, A. 2020. Magsorbents: potential candidates in wastewater treatment technology—a review on the removal of methylene blue dye. *J. Magn. Magn. Mater.* 500. 166408. <https://doi.org/10.1016/j.jmmm.2020.166408>
- [18] Nitsae, M., Solle, H.R., Martinus, S.M., & Emola, I.J. 2021. Studi adsorpsi metilen biru menggunakan arang aktif tempurung lontar (*Borassus flabellifer* L.) asal nusa tenggara timur. *Jurnal Kimia Riset*. 6(1). 46-57. <https://doi.org/10.20473/jkr.v6i1.24525>