Synthesis and characterization of magnetite (Fe₃O₄) nanoparticles from iron sand in Batanghari Beach

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Abstract. The utilization of sand is still limited as a building material, so development is needed to increase the use-value of iron sand from the Batanghari River. No one study was found to improve iron sand in this field into magnetic material. This paper informs a case study of the synthesis and characterization of Fe₃O₄ nanoparticles from the Batanghari Jambi river iron sand using the coprecipitation method. Sintering temperature variations were carried out to see the effect of sintering temperature on crystal size, crystal structure, and optical properties of the sample. Sintering temperature variations used are 300°C, 400°C, and 500°C. The synthesis results showed that the sintering temperature of iron sand extract did not affect the crystal structure formed. However, the sintering temperature affects the size of the crystal; the higher the sintering temperature, the size of the crystal will be even greater. At a temperature of 300°C, a Fe₃O₄ crystal size was 6.94 nm, at a temperature of 400°C a Fe₃O₄ crystal size was 8.29 nm and at a temperature of 500°C a crystal size of 10.15 nm was obtained. The synthesis results also show that the higher the sintering temperature, the optical properties of the iron sand extract, the better. The decreasing energy gap value indicates this. At a temperature of 300°C, a gap energy value of 2.0 eV was obtained, at a temperature of 400°C a gap energy value of 1.9 eV was obtained and at a temperature of 500°C, the energy gap obtained was 1.8 eV.

1. Introduction
Sand is one of the abundant materials throughout the world. Indonesia, as an island, is one of the countries which has abundant sand reserves. Nowadays, sand is one of the materials that get special attention from many researchers in the world; this is caused by the unique characteristics possessed by sand in the nanoscale [1]. The unique characteristics of sand include high surface area, non-toxic, high surface energy, good biocompatibility, high absorption, superparamagnetic, and electron transfer [2]. The latest trend in utilizing sand is converting sand into metal oxide nanostructure [3]. This material is known to have a high surface area so it will be more sensitive in its use as sensors, gene delivery, cell therapy, magnetic scaffolds, magnetic resonance imaging, cell labeling, hyperthermia and drug delivery [4].

Various studies have reported the use of sand in the industrial world. One of the uses of iron sand is to produce Fe₃O₄ (Magnetite) nanoparticles. Fe₃O₄ is a form of iron oxide in nature besides maghemite (γ-Fe₂O₃) and hematite (α-Fe₂O₃) [5]. Fe₃O₄ is known as black iron oxide, which is the metal oxide with the most magnetic properties. A recent study also informs that sand can be used as a photocatalyst [6].
photocatalyst is a material that can increase the rate of oxidation and reduction reactions induced by light [7]. The use of photocatalysts is considered an efficient method of separating pollutant compounds. The photocatalyst material is usually a semiconductor with a gap energy range of 1 to 3 eV. Synthesis of Fe₃O₄ with percolators FeCl₃·6H₂O and FeCl₂·4H₂O has also been carried out by observing the optical properties of the material [8]. Characterization using UV-Vis with a wavelength of 559 nm produces an energy-gap of 2.22 eV [9], it shows that Fe₃O₄ has the potential to be applied as a photocatalyst. Fe₃O₄ can be obtained from iron sand by the coprecipitation method. Coprecipitation is based on the deposition through organic compounds used so that this method becomes simpler, can be done at room temperature, and synthesis time is shorter than the sol-gel method, solvothermal method, hydrothermal method, sonochemical method, microemulsion method, and molten salts method.

Coprecipitation is one of the methods used to make nanoparticle material preparations. The working principle of this method is to convert metal salts into precipitates using a hydroxide or carbonate alkaline precipitant which is then converted to its oxidized form by heating. The coprecipitation method is the most effective because this method can be used in normal environmental conditions. In the synthesis, this method uses acid and base pairs. Acids function as solvents and bases carry solutes down to form the desired precipitate. The synthesis of magnetite nanoparticles by the coprecipitation method is expected to have monodispersive properties. Monodispersive properties mean that the magnetite particles are evenly or uniformly distributed.

The Batanaghari river sand iron in Jambi Province, Indonesia is thought to contain Fe₃O₄. No studies were found explaining the characteristics of the iron sand deposited in this field. Thus, this material could be improved into magnetic material. This paper will explain the synthesis and characterization of the Batanahgari River iron sand material using the coprecipitation method with different temperature variations. This study is important to improve the utilization of iron sand into nanomaterials that have better functions and selling points.

2. Material and Method

2.1. Preparation sample

An intake of iron sand was carried out using permanent magnets. Sand retrieval utilizes the magnetic properties of magnetite minerals so that it could be separated from impurities (non-iron sand). Intake process was done by filtering dry sand to get smaller and uniform sized sand. Furthermore, filtered sand was placed near the permanent magnet so that the iron sand contained in the sand could be separated from non-iron sand. The process of drawing iron sand that has been obtained can be done ten times to obtain purer iron sand. Iron sand was filtered using 120 mesh sieves prior synthesize to obtain pure iron sand. Forty gram Batanghari Jambi iron sand was dissolved into 38 ml HCl (12 M) at 55 °C and stirred for about 60 minutes using a magnetic stirrer. Chemical processes occurred in the following reactions are:

\[ 3\text{Fe}_3\text{O}_4(s)+8\text{HCl(l)} \rightarrow 2\text{FeCl}_3(l)+3\text{FeCl}_2(l)+3\text{H}_2\text{O(l)}+\text{H}_2(g) \]  

(1)

2.2. Coprecipitation method

After the solution was formed, it was filtered using filter papers. The solution added with 73 ml NH₄OH and placed for 1 hour to obtain a precipitate. Precipitated iron sand formed solid black separated from the solution, which is then washed using distilled water at seven times so that the results obtained are completely clean from impurities. This treatment fulfills the reaction equation:

\[ 2\text{FeCl}_3(l)+\text{FeCl}_2(l)+\text{H}_2\text{O(l)}+8\text{NH}_4\text{OH(l)} \rightarrow \text{Fe}_3\text{O}_4(s)+8\text{NH}_3\text{Cl(l)}+5\text{H}_2\text{O(l)} \]  

(2)

2.3. Preparation of nanoparticle Fe₃O₄

The precipitate was dried in the oven at a temperature of 120 °C for 2 hoursto evaporate its water content. Then sintering process was done with various temperatures, \textit{i.e.} 300, 400 and 500 °C. The characterization of Fe₃O₄ nanoparticles was carried out using an X-ray Diffractometer (XRD), while UV-Vis spectrophotometer was used to determine the energy gap of the Fe₃O₄ nanoparticles.
3. Result and Discussion

3.1. Nanoparticle Fe₃O₄
One of the simplest and oldest methods of synthesis in solid-liquid reactions is the coprecipitation method. The solid produced by the coprecipitation method is stable and insoluble in solvents. The coprecipitation process involves metal cations from a certain medium that are deposited together in the form of hydroxide, carbonate, oxalate, or citrate. The precipitate is calcined at a certain temperature to give a product in powder form. The coprecipitation process involves controlling solvent and precipitating concentrations, temperature, and stirring speed in the manufacture of products. The coprecipitation method uses an acid solution to dissolve the main ingredient. Acid is used as a solvent because ferrous metal can react quickly with HCl to form iron (II) and H₂ gas. The solution that has been stirred until it is homogeneous, it is necessary to add a settling solution in such a way that the precipitate has high homogeneity. NH₄OH solution can be used as a precipitator. The use of NH₄OH which contaminates the precipitate can be removed by heating.

The resulting precipitate is influenced by the concentration of solvent and precipitant, heating temperature, and the duration of stirring. The use of the coprecipitation method with various concentrations of iron salt solutions and settling solutions affects the amount of powder and the magnetic properties of the formed magnetite (Aji, 2008). In this study, the magnetite growth method was carried out by varying the temperature of the iron sand extract dissolving so that it could be seen its effect on the lattice parameters, crystal structure, crystal size, and the magnetic properties that appeared. Synthesis of Fe₃O₄ nanoparticles was carried out by the coprecipitation method. Fe₃O₄ nanoparticles were obtained by utilizing iron sand extract from the Batanghari river iron sand Jambi. The dissolution step of iron sand extract produces a black solution which indicates the presence of iron salt content. When Fe₃O₄ which is still in the form of the iron sand extract is mixed with high concentrated HCl where the iron metal contained in the iron sand extract can react quickly with HCl to form FeCl₂, FeCl₃ and Fe₂O₃ where all three act as precursors to produce Fe₃O₄. The iron salt solution formed is then precipitated using NH₄OH solution. Precipitation of iron salts can occur due to the formation of mixed crystals or by the adsorption of ions during the precipitation process. The precipitate formed is the result of the oxidation process of ferrous metal material contained in the dissolved iron salt, according to the equation. Based on direct observations, it can be seen that the extract of iron sand and the results of the synthesis show a difference. The magnetite nanoparticles that were synthesized appeared to be more concentrated black compared to iron sand extract. The synthesized grains also look smoother than iron sand extracts.

3.2. XRD Characterization
Diffraction is an event that the wave is scattered by a disturbance (for example, a grid), followed by scattering in all directions, which causes strengthening or attenuation under certain conditions. Diffraction occurs when there is an equality of geometric order between the wavelength and the width of the lattice. The result of the amplification of the scattering describes the character of the scatter or the disturbance. If a beam with a wavelength corresponding to the distance between the crystal planes is shot into a crystalline material, there will be crystal diffraction. X-ray diffraction is used to identify the crystal structure of a solid by comparing the value of the d distance (crystal plane) and the intensity of the diffraction peaks with the standard JCPDS data issued by the ICDD (International Center of Diffraction Data).

XRD characterization was carried out to determine the crystal structure, lattice parameters, and crystal size of the synthesized Fe₃O₄ nanoparticles. The output of the characterization results was read using ORIGIN 9.0 software in the form of data 2θ and intensity. From the 20 data and intensity, then plotted so that it forms a diffractogram showing the diffraction peaks that are formed. The results of the overall characterization of the sample data can be seen in figure 2. XRD characterization was carried out on all three samples, namely temperatures of 300, 400 and 500 °C. The control variable used in the characterization is the wavelength used for firing on the sample, Cu Kα wavelength 1.54059 Å, and the
shooting angle from 20.01 ° to 69.99 °. The results of the characterization in the form of diffraction curves are then adjusted to JCPDS number 19-629 for magnetite and JCPDS number 39-1346 for maghemite.

Based on Figure 2, it can be seen that temperatures of 300 °C, 400 °C, and 500 °C have peaks (2 2 0) and (3 1 1). The diffraction pattern that is formed for the maximum intensity representing Fe$_3$O$_4$ is at an angle of 2θ, which corresponds to the Miller index (3 1 1). From the diffractogram, it can be stated that the iron sand used is dominated by Fe$_3$O$_4$ or the iron sand used is magnetite. The presence of these peaks indicates that the crystalline structure of Fe$_3$O$_4$, which is a spinel structure. The results of XRD characterization showed that the higher sintering temperature, the peak from the sample had become narrower. This study informed that the degree of crystallinity and the level of regularity of the arrangement of atoms in the sample increases with increasing sintering temperature. Due to the increase in sintering temperature, an increase in thermal energy that causes crystal growth so that the nucleus grows by attracting other atoms to fill the space in the lattice to be formed. Thus, the increasing temperature sintering crystal growth continues until the final transformation of the crystal. The highest intensity shows that the crystal has a good crystal order or many atoms that are arranged orderly and neat.

**Figure 1.** XRD pattern of Fe$_3$O$_4$ at 300 °C (a), 400 °C (b) and 500 °C (c).

In addition to the XRD results, there is another peak that is maghemite (it-Fe$_2$O$_3$). The presence of the γ-Fe$_2$O$_3$ phase is adjusted to JCPDS data no 39-1346. The appearance of γ-Fe$_2$O$_3$ caused by Fe$_3$O$_4$ material is very easy to change into other phases, wherein principle Fe$_3$O$_4$ undergoes oxidation when interacting with free air. Oxidation during the synthesis of Fe$_3$O$_4$ cannot be avoided so that Fe$_3$O$_4$ will always have oxides or sub-oxides on its surface.

Maghemite oxidation results from Fe$_3$O$_4$ occurs at a sintering temperature of 250 °C and will peak at a sintering temperature of 900 °C [10]. At the same time, the hematite phase will occur at sintering temperatures ranging from 550 to 700 °C [11]. The change in sintering temperature causes an increase in the heat energy that is given so that the atom vibrates and diffuses at the grain boundary, the process of phase transformation begins when the Fe$^{2+}$ ion is oxidized to the Fe$^{3+}$ ion [12]. This Fe$^{3+}$ ion diffuses to form γ-Fe$_2$O$_3$. Also qualitatively, it can be predicted that the presence of γ-Fe$_2$O$_3$ phase in the sample is only in small levels because the sample obtained from this synthesis process is dominated by a deep black color that shows the characteristic Fe$_3$O$_4$. Based on the presence of γ-Fe$_2$O$_3$ phase, phase ratio calculation can be determined using the Hanawalt Method. Figure 1 shows that there are two different big groups of phases, namely the Fe$_3$O$_4$ and γ-Fe$_2$O$_3$ phases.

The Fe$_3$O$_4$ phase increases with increasing sintering temperature from 300 to 400 °C. However, it was seen that at a temperature of 500 °C, the phase ratio of Fe$_3$O$_4$ decreased. Due to Fe$_3$O$_4$ being very easily oxidized to γ-Fe$_2$O$_3$. The phase ratio of γ-Fe$_2$O$_3$ decreases from the sintering temperature of 300 °C to
400 °C due to the increased growth of Fe$_3$O$_4$ crystals, so that it can suppress the presence of γ- Fe$_3$O$_4$. Whereas at the sintering temperature of 500°C, an increase in the phase ratio γ- Fe$_3$O$_4$ is due to the angle of 20 (32.23), a new phase appears as γ- Fe$_3$O$_4$ phase. The tendency of the Fe$_3$O$_4$ phase to change to the γ- Fe$_3$O$_4$ phase is quite high at a sintering temperature of 500°C. Besides, have the same structure, namely cubic, so they cannot be distinguished through simple structural analysis [13]. Characterization of Fe$_3$O$_4$ nanoparticles based on XRD results can not only be used to identify the crystal structure but also can be used to determine the lattice parameters and crystal size. From figure 1 at the maximum peak that is (3 1 1), we can know the value of parameters and crystal size. The material showed the width of the Fe$_3$O$_4$ lattice, which is 0.251 nm. Calculation of lattice parameters and crystallite size of Fe$_3$O$_4$ nanoparticles synthesized can use ORIGIN 9.0 software.

The results of quantitative data analysis using the ORIGIN 9.0 program indicate that the diffraction pattern formed is two phases, namely, phase 1 (magnetite) and phase 2 (maghemite). High peaks indicate that the sample has high crystallinity and a wide peak indicates that the sample is nanometer size. Furthermore, this can be justified from the results of the fitting using the Scherrer equation which is written in Equation 1, the approximate crystal size is obtained. It should be noted that as the crystal dimension enters the nanoscale, the peak widens with decreasing crystal size. It is known that the width of the diffraction peaks allows the determination of crystal size. In practical terms, the crystal size can be determined by a variant of the Scherrer equation:

$$D = \frac{k\lambda}{B \cos \theta}$$

Where D is the thickness of the crystal, K is a constant that depends on the shape of the crystal, and B is the width of the peak at half the intensity in radians. If the Gaussian function is described to describe the peak of expansion, then the constant K is equal to 0.89, the Scherrer equation is derived from Bragg's law and can be used to determine crystal size when the crystal is smaller than 1,000 Å. This fitting analysis was performed to determine the crystal size using the Scherrer equation. It appears that magnetite has a cubic structure. The distance between atoms in 1 unit cell.

The synthesis results were characterized using XRD to determine the crystal structure, lattice parameters, and crystal size. Characterization using XRD tools. The data obtained from characterization using XRD is a diffractogram. The diffractogram shows the diffraction peaks at a certain angle. Based on the data obtained from the results of characterization using XRD then the data obtained is compared with the data stored in the JCPDS (19-629) as a reference for the correctness of the sample data made and to find out the lattice parameters of a crystal that has cubic symmetry, with $a = b = c$ and $\alpha = \beta = \gamma = 90^\circ$. then the beam angle of the crystal plane (hkl) can be calculated from the relationship between the distances between the fields, you can use the equation:

$$a = d \sqrt{h^2 + k^2 + l^2}$$

The XRD phase ratio calculation can be calculated using the Hanawalt method:

$$\%\text{Phase ratio} = \frac{\text{The desired phase intensity}}{\text{Total of the intensities from all phases}} \times 100\%$$

XRD is an effective method for determining the phase composition of unknown crystals. The analysis is performed by comparing the position of the diffraction peak and the intensity value against data already recorded in the JCPDS standard data (19-629). The output of characterization using XRD is in the form of 20 data and intensity. From this data, it is plotted in a graphical form (diffractogram) so that the peaks of the diffraction resulting from the material crystals can be seen. By using ORIGIN 9.0 software, the peak of the diffraction peaks can be seen in which phase corresponds to it.

This research informed about the crystal size from each sample used. Through XRD diffractogram data, the crystal size can be determined by calculating FWHM (Full Width at Half Maximum) from the peak of the diffraction plane, which is the peak width of the diffraction peak of Fe$_3$O$_4$ samples. FWHM is
used to determine crystal size using the Scherrer equation. From the calculation using the Scherrer equation the crystal size obtained at a sintering temperature of 300°C obtained a crystal size of 6.94 nm when the sintering temperature was enlarged to 400°C the crystal size was obtained which increased by 8.29 nm and the sintering temperature enlarged again to 500°C obtained the size crystal of 10.15 nm. Theoretically, the size of the crystal will increase along with the increase in sintering temperature, due to the crystal growth. At high temperatures, the constituent atoms have enough thermal energy for atomic diffusion so that the atoms move past the grain boundary causing an expansion of the area of the intersection between crystals that will increase the size of the grain. The larger grain size influences the shape and size of the crystals

Result of 2θ at the highest diffraction peak at the peak (311) for all three samples, were at a temperature of 300°C, an angle of 2θ = 35.73°, a temperature of 400°C at an angle of 2θ = 35.78°, and a temperature of 500°C at an angle of 2θ = 35.72°. It can be seen that the three samples have an angle of 2θ, which did not change significantly. Following the Bragg equation, the width of the lattice is inversely proportional to the diffraction angle. The absence of angular shift means that there is no widening of the lattice distance in Fe₃O₄ with increasing sintering temperature [14]. Thus, in table 3, it can be seen that the lattice parameter values and lattice width are the same and do not change for the three samples. This phenomenon showed that the increase in sintering temperature in the sample does not change the crystal structure of Fe₃O₄. Based on the data, the three samples obtained indicate that magnetite has a cubic structure with a lattice parameter of 0.832 nm.

3.3. UV-VIS Characterization

When radiation interacts with a material, information about the characteristics of the material can be obtained. The interaction between radiation and matter can be in the form of scattering, absorption, and transmittance depending on the properties of the material. Characterization of optical properties was carried out using a UV-Vis spectrometer, where when light is passed through a material some of the light is reflected, scattered, absorbed, and partially transmitted. When light is passed from one medium to another, such as from air to solid material, several possibilities can occur. Some of the light radiation is transmitted across the medium, some are absorbed and some is reflected on the surface between the two mediums. The intensity of the incident rays towards the surface of the solid medium must be the same as the amount of light intensity that is transmitted, absorbed, and reflected.

Characterization using a UV-Vis Spectrophotometer to see the optical properties of Fe₃O₄ processed using the Touc Plot method. The determination of the energy gap is obtained by processing the transmission data, by plotting the correlation of the absorption coefficient to the photon energy given to the sample through the Touc Plot equation. The bandgap graph is a graph of the relationship between photon energy and the square of the transmission coefficient. The size of the bandgap can be generated by drawing a linear extrapolation line from the end of the absorption coefficient curve intersecting the x-axis.

\[ a\nu = A (h\nu - E_g)^n \]  

By being the absorption coefficient of a material, h is the Plank Kostanta (6.626x10³⁴ Js), is the frequency, where c is the speed of light (3x10⁸ m/s), Eg is the energy band gap width (energy gap), A is a constant depending on the material, and the values are n=2 for direct transitions and n=1/2 for indirect transitions. Determining the energy gap can be determined using the touc plot method by extrapolation of the linear graph of the Eg (eV) relationship as the abscissa on the x-axis and \((a h \nu)^2\) as the ordinate on the y-axis. Calculation using ORIGIN.9.0 software with extrapolation from the graph relationship Eg and \((a h \nu)^2\) to cut the energy axis to obtain the energy gap value. The result of the extrapolation is in the form of a graph where the intersection of abscissa and ordinate is obtained, which is the energy gap of Fe₃O₄. The optical properties of Fe₃O₄ are determined based on the measurement of the transmittance spectrum obtained from a UV-Vis spectrometer. Figure 3 is the result of transmittance to the wavelength of each sample. The transmittance graph shows the wavelength transmitted by the semiconductor material. The graph shows that the value of transmittance will continue to increase with increasing wavelength.
The graph shows that the photon energy that continues to occur in the range of ultraviolet light that is 200 to 400 nm and also occurs in the range of visible light that is 400 to 800 nm [15].

![Graph showing wavelength relationship with transmittance](image)

**Figure 2.** Wavelength relationship with transmittance.

The optical properties of Fe$_3$O$_4$ are determined based on the measurement of the transmittance spectrum obtained from a UV-Vis spectrometer. Figure 3 is the result of transmittance to the wavelength of each sample. The transmittance graph shows the wavelength transmitted by the semiconductor material. The graph shows that the value of transmittance will continue to increase with increasing wavelength. The graph shows that the photon energy that continues to occur in the range of ultraviolet light that is 200-400 nm and also occurs in the range of visible light that is 400 to 800 nm. The transmittance curve above also shows that the sample transmits visible light, which is larger than UV light. From several treatments with variations in sintering temperature, it can be seen the difference in transmission values. At a wavelength of 736 nm, the sample has a different transmittance value. At a temperature of 300 ºC, the transmittance value obtained was 0.980%, 400 ºC, the transmittance value was obtained at 0.976%, and at 500 ºC, the transmittance value obtained was 0.777%.

Adding the sintering temperature to the sample will cause a decrease in the percentage of transmittance. According to the mechanism of sintering, where the higher the sintering temperature, there will be a process of compacting a group of powders, and there is a strong bond between the granules and pores contained between the grains so that the light of photons given is more absorbed [16]. Besides, a decrease in the energy gap can be related to figure 1, which shows a decrease in the percentage of transmittance in all three samples. The decrease in the percentage of transmittance shows that the light of photons given to the sample is more absorbed. The lighter the photons absorbed means that the valence-banded electrons will have more additional energy. Thus, valence-banded electrons will more easily move to the conduction band.

The gap energy value is determined by the Touc’s Plot method. Gap energy is the energy needed by electrons to break covalent bonds so that they can move from the valence band to the conduction band. In a semiconductor material, because the energy gap is narrow, then if the temperature rises, some electrons in the valence band go up to the conduction band by leaving a hole in the valence band. Electrons that are already in the conduction band or hole in the valence band will act as charge carriers for the occurrence of electric current. The determination of the gap energy starts from determining the transmittance value of Fe$_3$O$_4$. The energy gap can be determined by processing the transmittance data using the software. Transmittance measurements are carried out at wavelengths, ranging from ultraviolet light to visible light. So we get the wavelength value at each transmittance value, which is then used to get the gap energy value.
The energy gap can be seen in figure 3 a, b, and c by drawing a linear line on the curve so that it intersects with the x-axis (eV axis), then the gap energy value is obtained from the point of intersection. In figure 3(a) the temperature is 300 ºC has an energy gap value of 2.0 eV, then with an increase in figure 3(b) the temperature is 400 ºC. The energy gap value becomes 1.9 eV, and figure 3(c) temperature of 500 ºC, the gap energy needed is increasingly decreased by 1.8 eV. The following is the value of each sample, which can be seen in Table 1 below.

| No | Temperature (ºC) | GAP energy (eV) |
|----|------------------|-----------------|
| 1. | 300              | 2.0 eV          |
| 2. | 400              | 1.9 eV          |
| 3. | 500              | 1.8 eV          |

Table 1 shows that the higher the sintering temperature, the gap energy value decreases. The size of the temperature affects the shape and size of the energy bandgap. The difference in the energy band gap produced in the sample is caused by differences in the size of the particles formed. The higher sintering temperature will cause a smaller pore size between particles and will make the crystal size bigger. The electron will make it easy to move from the valence band to the conduction band so that the energy gap obtained will be smaller where the optimum energy band gap is around 2.0 eV.
4. Conclusion

Based on the research that has been done, it can be concluded that the difference in sintering temperature in the Fe₃O₄ nanoparticles affects the diffraction peaks formed and the size of the crystals formed. Crystal size obtained for the temperature of 300, 400, and 500 °C were 6.94, 8.29 and 10.15 nm, respectively. The difference in sintering temperature in Fe₃O₄ nanoparticles also affects the gap energy obtained, where the greater the sintering temperature, the gap energy results obtained are also smaller. The gap energy obtained from the temperature of 300 °C is 2.0 eV, temperature of 400 °C 1.9 eV, and at the temperature of 500 °C 1.8 eV. Adding the sintering temperature to the sample will cause a decrease in the percentage of transmittance. Following the mechanism of sintering, where the higher the sintering temperature, there will be a process of compacting a group of powders, and there is a strong bond between the granules and pores contained between the granules so that the light of the photons given is more absorbed.

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