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Evaluation of the physical, electrical, and magnetic properties of iron sand and its potential applications for advanced technology

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Abstract: This study examines the physical, electrical, and magnetic properties of iron sand from Bayuran Beach to evaluate its potential as a functional material in advanced technology applications. Iron sand samples with particle sizes between 100 and 300 mesh were analyzed using the two-point method, LCR meter, and X-ray Diffraction (XRD). The XRD results indicate that the samples are dominated by the magnetite phase (Fe_3O_4). The 150 mesh sample showed the highest resistivity of 3.38×10^9 Ω·m and a maximum capacitance of 0.16 nF. The magnetic susceptibility value reached 3.34×10^{-4} m^3/kg, with a magnetic mineral content of 79.80% and a density of 2.52 g/cm^3. These findings indicate that Bayuran iron sand has strong potential as a soft magnetic material for inductor cores and magnetic field sensors, microwave absorbers for electromagnetic applications, and dielectric substrates in electronic systems. The capacitance variation between dry and wet conditions also indicates its potential as a humidity sensor. Furthermore, the presence of the Fe_3O_4 phase opens up opportunities for further development as an electrode material in supercapacitors or other energy storage devices through morphological engineering. Overall, this local iron sand is a promising candidate for development into a natural resource-based functional material.

Keyword : Advanced Technology, Fe_3O_4, Functional Materials, Iron Sand

1. Introduction

Metal oxide-based functional materials have become a major focus in the development of modern technology that includes the fields of energy storage, sensors, flexible electronics, and electromagnetic shielding. In addition, iron oxide materials have recently been developed as raw materials for the development of defense component materials, especially radar absorber materials (Aritonang et al., 2024; Hidayat et al., 2024). Among the various types of metal oxides, iron-based compounds such as magnetite Fe_3O_4 and hematite (α-Fe_2O_3) stand out because they have multifunctional properties, including adjustable conductivity, high magnetic ability, thermal stability, and the ability to engineer complex crystal structures according to needs (Ulfa, 2021; Yulianto, 2007). Natural mining commodities that contain a lot of iron oxide are iron sand.

Iron sand is natural sand formed from the weathering of rocks and other iron materials (Kotarumalos et al., 2023; Lopes et al., 2016). Central Java has the potential for iron sand with special characteristics compared to other regions (Yulianto et al., 2019). Its long stretch of coastline makes the potential for mining and processing iron sand into high-value economic materials in Central Java very large. Unfortunately, iron sand has been mined and sold to users in the form of raw materials, making this utilization ineffective (Aji et al., 2019). Bayuran Beach is one of the beaches with black sand in the Jepara area. Bayuran Beach is geologically located in a coastal sedimentation zone that is influenced by river dynamics and sea abrasion, so it tends to produce black sand deposits with significant iron mineral concentrations (Anggraeni et al., 2008; Saputra et al., 2016). The abundant iron sand in Indonesia, especially at Bayuran Beach, needs to be studied further to determine the potential use of this iron sand in various fields of advanced material technology.

Important characteristics that need to be evaluated include electrical resistivity, as an indicator of conductivity or insulation in electronic devices; capacitance, to see potential as a dielectric filler or sensor; density, which influences mechanical stability and mass efficiency; and magnetic susceptibility, as a measure of the material's interaction with an external magnetic field. In addition, the crystal structure determined through x-ray diffraction (XRD) provides in-depth information about the dominant phase of Bayuran Beach iron sand.

This research focuses on a basic study of the electrical, magnetic, physical, and crystal phase properties of the material. These parameters are used as a reference for determining the suitability of Bayuran Beach iron sand as a raw material for developing advanced materials. This study does not utilize iron sand as a raw material for advanced materials, which is a limitation of the research.

2. Method

Sand taken from Bayuran Beach in Jepara Regency was then washed until clean and dried. The dried sand was then separated from impurities using a solid permanent magnet. The sand that had been separated with a bar magnet was then refined using a ball mill for 6-10 hours to obtain the desired particle size. The refined iron sand was then sieved into various sizes, namely 100 mesh; 150 mesh; 200 mesh; 250 mesh; and 300 mesh. Furthermore, the iron sand samples were characterized by x-ray diffraction (XRD) to determine the structure and crystal phase, the resistivity and capacitance values were measured with an LCR multimeter DT9205A. Meanwhile, to determine the susceptibility value of the iron sand, it was measured with a Bartington Magnetic Susceptibility meter, the density value was measured by measuring the volume and mass of the iron sand and to determine the concentration of Fe_3O_4, the iron sand was characterized by Energy Dispersive X-ray Spectroscopy (EDX).

3. Result and Discussion

3.1. X-Ray Difraction (XRD) Analysis

The results of the Bayuran Beach iron sand sample preparation will then be characterized by XRD (target Cu, λKα = 1.54060 A˚). The XRD test aims to determine the crystal phase that appears and to determine the crystal form formed from the sample.

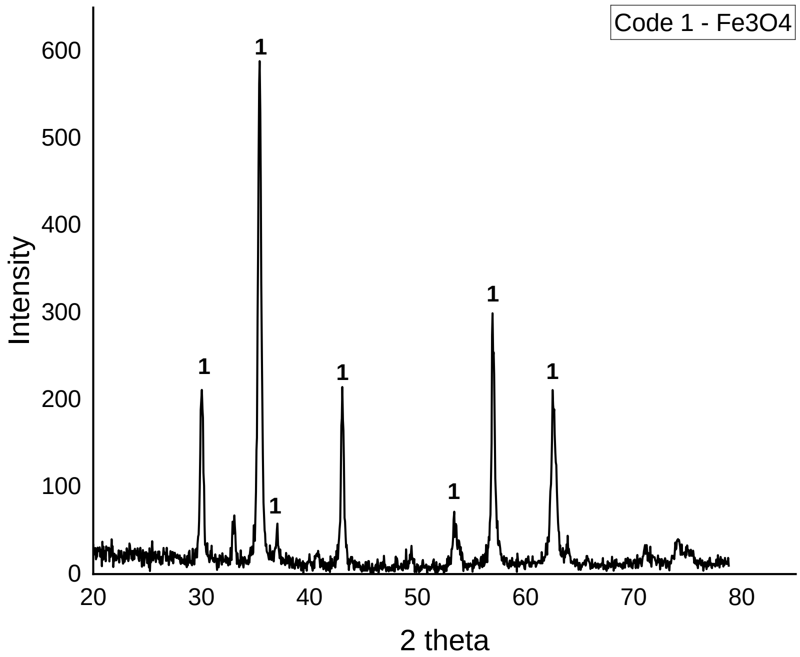

Figure 1.XRD Spectrum of Iron Sand from Bayuran Beach, Jepara

After the XRD characterization test was carried out, the data obtained were then processed using Match Software with the Crystallography Open Database (COD) as a comparison database. The diffraction peaks shown at 2 Theta Ѳ (code 1): 30.2; 35.5; 37.1; 43.2; 53.7; 62.7, are the peaks of the diffraction pattern of Cubic Fe_3O_4 crystals (Figure 1). The match of this diffraction pattern indicates that the analyzed iron sand has a dominant magnetite phase with good crystallinity, indicating a regular lattice structure. The peak at 2θ 35.5° with the highest intensity confirms the presence of the crystal plane (311), which is generally the dominant peak for magnetite. While other peaks such as 43.2° (400) and 62.7° (440) are also characteristics of crystalline magnetite. The presence of sharp diffraction peaks indicates that the formed Fe_3O_4 minerals are crystalline with relatively homogeneous crystal domain sizes. These results are consistent with magnetic susceptibility data and high mineral concentrations, supporting the interpretation that the Bayuran Beach iron sand samples have significant magnetite content and have the potential for further processing such as soft magnetic materials for inductor cores, microwave absorbers for electronic equipment (Kamila et al., 2023; Karbeka et al., 2020; Kiswanto et al., 2021). The Fe_3O_4 compound can be further synthesized into other types of crystal phases such as afe2O3 which has a brownish red color, as well as yfe2O3 with a purple color, so that iron sand from Bayuran Beach can be used as a coloring material with magnetic properties (Chabib et al., 2017; Soekansa et al., 2023). As explained byHutomo, 2017; Hidayat et al., 2024; Yustanti et al., 2024; Aisyah et al., 2015 in their research, iron sand material containing Fe_3O_4 can be further developed for electromagnetic absorber applications, thus opening up opportunities to become Radar Absorbing Material (RAM) materials.

3.2. Resistivity and Capacitance Test

Measurement results

Table 1. Electrical resistivity of Bayuran Beach Iron Sand, Jepara Regency

	100 Mesh	**150 Mesh**	**200 Mesh**	**250 Mesh**	**300 Mesh**
Resistance 10^6 (Ohm)	18.3	2.55	11.28	8.3	5.2
Resistivity 10^9 (Ohm.M)	24.2	3.39	14.97	11.01	6.9
Capacitance (Nano Farad)	0.06	0.16	0.01	0.01	0.01
Wet State Capacitance (Farad)	0L	0L	0L	0L	0L

The measurement results show a varying resistance trend with particle size. The highest resistance value was found at 100 mesh size, namely $18.3 \times 10^6\ \Omega$, while the lowest value was at 150 mesh, namely $2.55 \times 10^6\ \Omega$ (Table 2). The pattern shown in the graph tends to decrease sharply from 100 to 150 mesh, then increases again at 200 mesh before finally decreasing gradually towards 300 mesh. This phenomenon indicates that the resistance of the material is not only influenced by particle size linearly, but also by other factors such as particle distribution and the possibility of differences in contact between particles due to size variations (Figure 2). The difference in electrical resistance values of each iron sand particle size can be used as a high-value resistor material or even developed as an electrical insulator material and a ferrite ceramic-based semiconductor material (Mulyadi et al., 2022; Rahmawati et al., 2024; M Rafli, 2024; Nuraini et al., 2021).

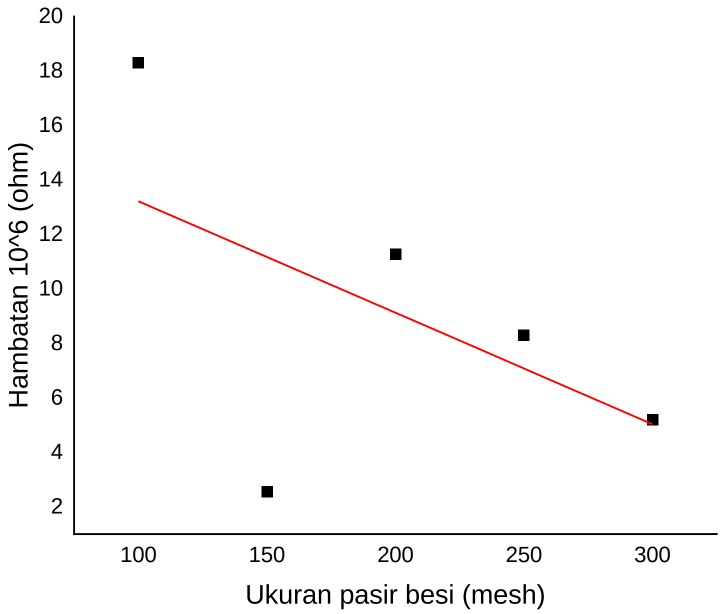

Figure 2. Graph of resistance to iron sand size at Bayuran Beach, Jepara

The resistance value data was then subjected to further analysis to determine the resistivity value of the material with the parameters of a test tube container with a length of 5 cm and a tube radius of 0.34 cm with the resistivity formula as follows:

$$\rho = R\frac{A}{L}$$

Where ρ is the resistivity value of the material (ohm. m), L is the length of the sample tube, R is the electrical conductivity value of the material, and A is the base area of the test sample tube. From the calculations for each size of Bayuran Beach sand particles, the data obtained are as shown in Figure 3.

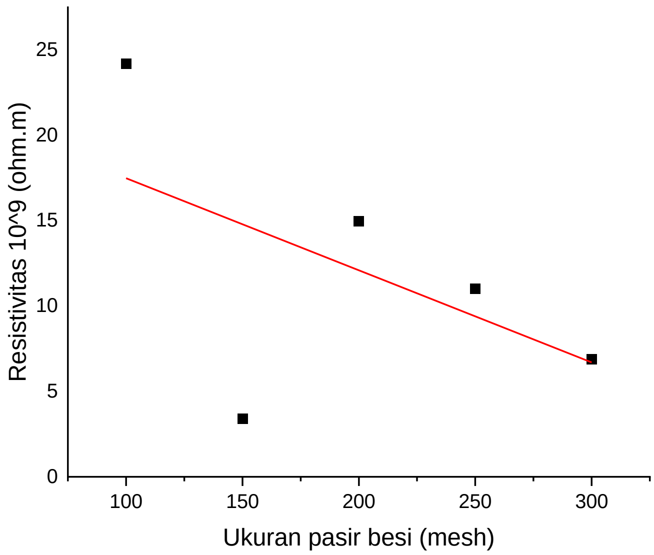

Figure 3. Graph of resistivity against iron sand size at Bayuran Beach, Jepara

The resistivity results show a similar trend to the resistance, as shown in Figure 2. The highest resistivity occurs at 100 mesh at 24.2 $\times 10^9$ Ω·m, while the lowest value is at 150 mesh at 3.39 $\times 10^9$ Ω·m. The resistivity value then increases at 200 mesh and decreases gradually at 250 and 300 mesh. This trend confirms that resistivity is positively correlated with resistance. Research conducted by Ningsih et al., 2019; Didik et al., 2020; Asri et al., 2021.

In general, decreasing particle size (increasing mesh) leads to an increase in specific surface area and the potential for more interparticle connections, thus affecting the electrical conductivity pathway. However, non-uniformity in particle size distribution can cause fluctuating resistivity values, as seen in the increase at mesh 200.

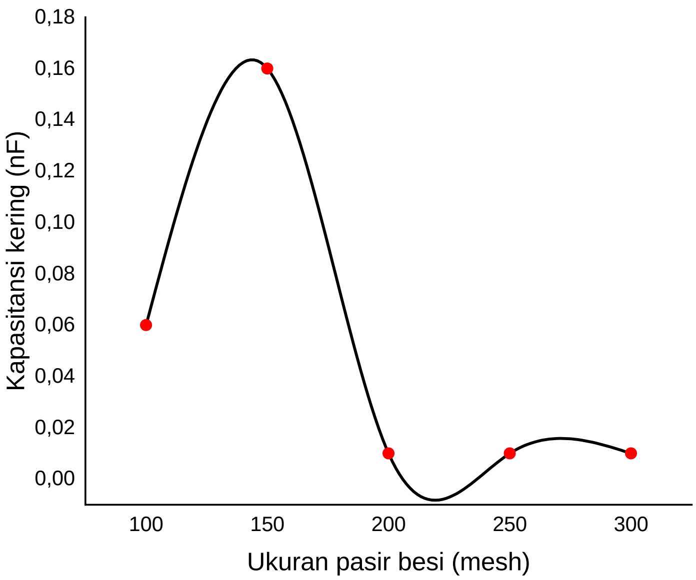

Figure 4. Capacitance graph against iron sand size at Bayuran Beach, Jepara

The samples were then tested for their capacitance values using an LCR multimeter DT-9205A. The capacitance data (Figure 3) showed a drastic increase at the 150 mesh size (0.16 nF), while at other sizes, especially 200 mesh and above, the capacitance value was relatively very low (0.01 nF). This indicates the existence of an optimum condition at a certain size (150 mesh) where the electrical charge storage capacity reaches its maximum, possibly due to the particle configuration that allows the formation of a larger capacitive area. After passing the optimum size, the interaction between particles becomes less effective in forming microcapacitors, so the capacitance value decreases drastically. This indicates that the sand material taken from Bayuran Beach can be further utilized as a raw material for ferrite ceramic-based capacitors. Next, the samples were tested for their capacitance values in a wet state for all mesh sizes, the measurement results showed the same wet state capacitance value, namely 0L. This indicates that humidity or wet conditions do not affect the material's ability to store charge in this measurement. This is likely due to the hydrophobic nature of the material or the experimental design, which prevents water from filling the gaps between particles, thus altering the dielectric properties. The different capacitance values of dry and wet sand could lead to further development of a ferrite-based humidity sensor material.

The results of this study indicate that particle size significantly influences the electrical properties of materials. Resistance and resistivity show similar patterns, confirming their interrelated relationship, while capacitance exhibits non-linear behavior with a peak value at 150 mesh size. This supports the hypothesis that the distribution and contact between particles are key in controlling the electrical properties of granular materials. Lower resistance and resistivity values at smaller mesh sizes (finer particle size) indicate increased conductivity due to the larger contact area between particles.

3.3. Density, Suceptability and Mineral Content Test

Measurement results

Table 2. Density, susceptibility, and concentration of iron sand minerals in Bayuran Beach

The material being measured	Mass density (g/cm^3)	magnetic susceptibility	magnetic mineral concentration (%)
Bayuran Beach	2.52	3.34	79.80

To enrich the data on Bayuran Beach sand, a density test was conducted by taking 50 cm^3 of sand and weighing it, resulting in a weight of 126 grams. The volume and mass of the iron sand were then calculated using the formula$\rho = \frac{m}{V}$, where ρ is the density, m is the mass of sand, and V is the volume of the mass.The iron sand density obtained from Bayuran Beach, at 2.52 g/cm^3, indicates that this material is classified as a heavy mineral, but has not yet reached the very heavy category like pure magnetite (around 5.2 g/cm^3). This value indicates that the iron sand material at the location is likely a mixture of heavy minerals (such as magnetite or hematite) with lighter fractions (such as quartz or silicate minerals). This mixture is commonly found in coastal alluvial deposits that undergo natural transportation and sorting through wave action.

The high magnetic susceptibility value of 3.34×10^{-4} m^3/kg indicates that the iron sand at this location has a strong response to external magnetic fields. This is an indicator that the content of ferromagnetic minerals, especially magnetite (Fe_3O_4), dominates the magnetic composition in the sample. This value is much higher compared to non-magnetic sedimentary rocks, which usually have susceptibility values below 0.1. This parameter indicates the material's suitability as a soft magnetic material, such as in inductor cores, magnetic field sensors, or microwave absorbers for electromagnetic radiation dampening. Meanwhile, in a study conducted by Mufit et al., 2006, a magnetic susceptibility value of 2.58 m^3/kg was obtained. Tamuntuan et al., 2017 reported in their study that the magnetic susceptibility value of iron sand ranged from 7.7 m^3/kg to 436 m^3/kg. Thus, this value confirms that the iron sand at Bayuran Beach is worthy of consideration in magnetic mineral exploration. Measurement of susceptibility values was carried out using a Bartington Magnetic Susceptibility meter.

After identifying the dominant crystal content in Bayuran Beach sand, Energy Dispersive X-ray Spectroscopy (EDX) characterization was performed. The magnetic mineral concentration reached 79.80%, which is very significant and indicates high economic potential. This value reflects the dominance of magnetic minerals over the total sample mass, and supports the high susceptibility results. In exploration studies, concentrations above 60% are usually considered an indication of rich material and potential for commercial extraction, both for the steel industry and magnetic materials.

Magnetic susceptibility values and mineral concentrations show a direct relationship; the higher the magnetic mineral concentration, the higher the susceptibility value. This indicates that susceptibility parameters can be used as an indirect indicator for rapidly detecting magnetic mineral content in the field. The slightly lower density value for magnetite than the theoretical value can be explained by the presence of non-magnetic impurities in the iron sand.

XRD characterization shows the presence of Fe_3O_4 phase with a cubic crystal structure. Resistivity value measurements show quite diverse values corresponding to the size of the iron sand particles, the highest resistivity value is shown by the 100 mesh particle size. Capacitance values show the difference in value between dry sand and wet sand, the highest capacitance value is in dry iron sand with a size of 150 mesh, namely 0.16 nF. The density of iron sand is 2.52 which is classified as a heavy mineral material. Suceptibility of 3.34×10^{-4} m³/kg indicates that the iron sand at this location has a strong response to a significant external magnetic field. The electrical and magnetic properties identified in the Bayuran Beach iron sand show broad potential in: Soft magnetic materials for electromagnetic devices (sensors, inductors), microwave absorbers, humidity sensor dielectric substrates (based on capacitance variations between dry and wet conditions), supercapacitor electrodes or energy storage systems if further morphological engineering is carried out on the surface structure.

4. Conclusion

The results of the study indicate the presence of the Fe_3O_4 phase with a cubic crystal structure. Measurement of resistivity values shows quite diverse values corresponding to the size of the iron sand particles, the highest resistivity value is shown by the particle size of 100 mesh. The capacitance value shows the difference in value between dry sand and wet sand, the highest capacitance value is in dry iron sand with a size of 150 mesh, namely 0.16 nF. The density of iron sand is 2.52, which is classified as a heavy mineral material. The susceptibility of 3.34×10^{-4} m³/kg indicates that the iron sand at this location has a strong response to a significant external magnetic field. The electrical and magnetic properties identified in the iron sand of Bayuran Beach show broad potential in: Soft magnetic materials for electromagnetic devices (sensors, inductors), microwave absorbers, humidity sensor dielectric substrates (based on capacitance variations between dry and wet conditions), supercapacitor electrodes or energy storage systems if further morphological engineering is carried out on the surface structure.

References

Aisyah, A. D., & Zainuri, M. (2015). Rekayasa Material Penyerap Gelombang Radar Berbahan Dasar Batuan Besi Laterit Dan Karbon Aktif Kulit Singkong Pada Rentang Frekuensi X Band (Doctoral Dissertation, Institut Technology Sepuluh Nopember).

Aji, M. P., Yulianto, A., & Bijaksana, S. (2019). Sintesis Nanopartikel Magnetit, Maghemit Dan Hematit Dari Bahan Lokal. Jurnal Sains Materi Indonesia, 106-108.

Anggraeni, N.D. (2008). Analisa Sem (Scanning Electron Microscopy) Dalam Pemantauan Proses Oksidasi Magnetite Menjadi Hematite. Seminar Nasional Vii Rekayasa Dan Aplikasi Teknik Mesin Di Industri, Kampus Itenas, Bandung.

Aritonang, S., & Murniati, R. (2024). Material Pertahanan. Cv. Aksara Global Akademia.

Asri, L., Didik, L. A., & Bahtiar, B. (2021). Sintesis Dan Analisis Kandungan Mineral Dan Karakteristik Sifat Listrik Nanopartikel Pasir Besi Pantai Telindung Kabupaten Lombok Timur. Jst (Jurnal Sains Dan Teknologi), 10(1), 85-91.

Chabib, M. A. (2017). Pengaruh Lama Kalsinasi Pada Sintesis Senyawa Pigmen Hematit (A-Fe2o3) Dari Limbah Industri Kerajinan Besi Dengan Metode Rute Presipitasi-Kalsinasi. Angewandte Chemie International Edition, 6(11), 951-952.

Didik, L. A., & Wahyudi, M. (2020). Analisa Kandungan Fe Dan Karakteristik Sifat Listrik Pasir Besi Pantai Telindung Yang Disintesis Dengan Beberapa Metode. Indonesian Physical Review, 3(2), 64-71.

Hidayat, S., Fianti, F., Nurbaiti, U., & Astuti, B., Yulianto, A. (2024). Structure And Morphology Absorber Material Base On Iron Sand With Sio_2 Fortification From Water Hyacinth. Journal Of Natural Sciences And Mathematics Research, 10(2), 189-199.

Hutomo, D. K. (2017). Sintesis Dan Karakterisasi Absorber Gelombang Elektromagnetik Komposit Berbasis Upr Dengan Filler Fe3o4 Dari Pasir Besi Dan Sio2 Dari Sekam Padi (Doctoral Dissertation, Universitas Negeri Jakarta).

Kamila, S. S., Milenia, R., & Royani, T. T. (2023). Analisis Sifat Kemagnetan Pasir Besi Di Indonesia. Humantech: Jurnal Ilmiah Multidisiplin Indonesia, 2(8), 1761-1766.

Karbeka, M., Koly, F. V. L., & Tellu, N. M. (2020). Karakterisasi Sifat Kemagnetan Pasir Besi Pantai Puntaru Kabupaten Alor-Ntt. Lantanida Journal, 8(2), 108-116.

Kiswanto, H., Yuniarto, A. H. P., Istiqomah, N. I., & Suharyadi, E. (2021). Struktur Kristal Dan Sifat Kemagnetan Nanopartikel Mn-Ferrite Yang Disintesis Dari Bahan Alam Pasir Besi. Jurnal Fisika Unand, 10(4), 413-420.

Kotarumalos, S. H., Limehuwey, R., & Multi, W. (2023). Genesa Dan Karakteristik Endapan Pasir Besi. Tanah Goyang: Jurnal Geosains, 1(1), 26-37.

Lopes, V. C., & Wibowo, H. T. T. (2016, October). Pemetaan Potensi Pasir Besi Di Desa Umbulsari Dan Sekitarnya Kecamatan Tempursari Kabupaten Lumajang Propinsi Jawa Timur. In Prosiding Seminar Nasional Sains Dan Teknologi Terapan (Pp. 159-168).

Ningsih, F., Fitrianingsih, F., & Didik, L. A. (2019). Analisis Pengaruh Lama Penggerusan Terhadap Resistivitas Dan Konstanta Dielektrik Pada Pasir Besi Yang Disintesis Dari Kabupaten Bima. Indonesian Physical Review, 2(3), 92-98.

Nuraini Saprianti, L. A., & Zohdi, A. (2021). Analisa Sifat Listrik Dan Kandungan Fe

Nano Partikel Pasir Besi Berbasis Pasir Besi Sungai Untuk Mengetahui Kualitas Air Sungai.

M Rafli, A. (2024). Ekstraksi Hematit (A-Fe2o3) Dari Pasir Besi Pesisir Barat Sebagai Nanopartikel Dengan Metode Kopresipitasi.

Mufit, F., Fadhillah, H. A., & Bijaksana, S. (2006). Kajian Tentang Sifat Magnetik Pasir Besi Dari Pantai Sunur Pariaman Sumatera Barat. Jurnal Geofisika, Bandung.

Mulyadi, A. (2022). Analisis Resistansi Material Semiconductor Menggunakan Wheatstone Bridge. Journal Zetroem, 4(2), 14-17.

Rahmawati, E., & Putri, N. P. (2024). Sintesis Dan Karakterisasi Pani/Fe3o4 Menggunakan Fe3o4 Dari Pasir Besi Gunung Galunggung Jawa Barat. Inovasi Fisika Indonesia, 13(2), 45-50.

Saputra, F. M. A., Puspitarini, Y., Rizaldi, P. D., Firdaus, M. S. A., & Sujarwata, S. (2016). Sintesis Nanopartikel Magnet Zn-Ferrite (Znfe2o4) Berbahan Dasar Pasir Besi Menggunakan Metode Kopresipitasi. Journal Of Creativity Student, 1(1).

Soekansa, A. F., Sudirman, N., & Aini, S. (2023). Sintesis Dan Karakterisasi Pigmen Merah Hematit (A-Fe2o3) Dari Pasir Besi Kabupaten Sijunjung, Sumatera Barat, Indonesia. Chemistry Journal Of Universitas Negeri Padang, 12(1), 9-13.

Tamuntuan, G., Tongkukut, S. H., & Pasau, G. (2017). Analisis Suseptibilitas Dan Histeresis Magnetik Pada Endapan Pasir Besi Di Sulawesi Utara. Jurnal Mipa, 6(2), 105-108.

Ulfa, H. (2021). Pembuatan Magnetit (Fe3o4) Menggunakan Metode Elektrokimia Dengan Variasi Tegangan (Doctoral Dissertation, Uin Ar-Raniry).

Yulianto, A., Bijaksana, S., Loeksmanto, W., & Kurnia, D. (2019). Produksi Hematit (A-Fe2o3) Dari Pasir Besi: Pemanfaatan Potensi Alam Sebagai Bahan Industri Berbasis Sifat Kemagnetan. Jurnal Sains Materi Indonesia, 5(1), 51-54.

Yulianto, A. (2007). Fasa Oksida Besi Untuk Sintesis Serbuk Magnet Ferit. Indonesian Journal Of Materials Science, 9(1), 487136.

Yustanti, E., Trisdian, A., & Noviyanto, A. (2024). Pengaruh Amplitudo Dan Waktu Sonikasi Terhadap Penurunan Reflection Loss Pada Sintesis Material Absorber Berbasis Pasir Besi Banten Untuk Aplikasi Pesawat Anti Radar. Jurnal Integrasi Proses, 13(1), 13-20.