Attribution-ShareAlike 4.0 International (CC BY-SA 4.0)
Vol. 04, No. 02, February 2024
e-ISSN: 2807-8691 | p-ISSN: 2807-839X

Fe_2O_3 Review: Nanostructure, Synthesis Methods, and Applications

Novita[1], Ramlan[2], Marzuki Naibaho[3], Masno Ginting[4], Syahrul Humaidi[5], Tulus Na Duma[6]
Department of Physics, Universitas Sumatera Utara, Indonesia[1,5,6]
Department of Physics, Universitas Sriwijaya, Indonesia[2]
Research Center for Advanced Materials, National Research, and Innovation Agency (BRIN), Indonesia[3,4]
Email: novita.ichsanbasuki@gmail.com[1], ramlan@unsri.ac.id[2], sinaibahomarzuki@gmail.com[3], masno.ginting@gmail.com[4], syahrul1@usu.ac[5], tulusnaduma@students.usu.ac.id[6]

Keywords
Fe_2O_3, Nanostructures, Synthetic Methods, Applications.

ABSTRACT
Iron sand, which contains magnetite iron ore, exhibits unique magnetic properties when exposed to magnetic fields. Iron ore content, including α-Fe2O3, FeTiO3, Magnetite (Fe3O4), and others, provides potential uses in various industries such as electronics, energy, chemical, ferrofluids, catalysts, and biomedicine. The location of the discovery of iron sand can affect its mineral characteristics and geological conditions. This research aims to develop innovative synthesis methods to produce hematite nanomaterials from iron sand. Nano-size hematite nanoparticles exhibit unique characteristics, including an increase in specific surface area that is beneficial in applications such as gas sensors, catalysts, lithium-ion batteries, and the manufacture of permanent magnets. Through a literature review, this article presents comprehensive insights into the characteristics of iron sand, variations in synthesis methods, and the structure of hematite nanoparticles. Applications of hematite nanoparticles in water treatment, catalysis, and energy storage are also detailed. This article is expected to contribute to the development of innovative nanomaterial technologies as well as explore the potential of iron sand resources for wider industrial applications.

INTRODUCTION

Iron sand is one type of sand containing magnetite iron ore. The iron ore content in this sand gives it unique properties in the form of magnetic properties. When exposed to external magnetic fields, iron sand can exhibit magnetic behavior and even attract metal objects. This phenomenon makes iron sand not only an object of geological exploration, but also a valuable resource in industrial contexts such as, electronics, energy, chemistry, ferrofluids, catalysts, and biomedicine (Aziz, 2021; Basavegowda et al., 2017; Fatih et al., 2021; Mulyani et al., 2022; Nengsih et al., 2023; Puspitaningrum et al., 2017; Susilawati et al., 2018; Tadic et al., 2021; Widodo et al., 2020).

Iron sand contains various magnetic minerals such as α-Fe2O3, FeTiO3, SiO2, Magnetite (Fe, Maghemite) γ-Fe_{2O3}, Alumina (Al_2O_3), and Rutile (TiO_2). Iron sand can also contain impurities such as clay, non-metallic minerals, or organic material. Iron sand generally has a black or dark brown

https://doi.org/10.46799/ijssr.v4i02.728

color, reflecting a significant magnetite content. The size and shape of iron sand grains can vary this is due to deposition processes such as erosion or transport by water. The characteristics of iron sand may vary depending on the mineral composition and geological conditions in which iron sand is found Kandungan Senyawa Ki (Abdel-Karim & Barakat, 2017; Ibrahim et al., 2022; Tan et al., 2024).

Iron sand can be found in various locations around the world. Iron sand mines are often located in coastal areas, rivers, or lakes that are places of deposition of sedimentary material. In its use, iron sand found in nature needs to be synthesized first to produce pure hematite content (Sismanto et al., 2019).

Current research highlights an innovative synthesis method that can produce nanomaterials from pure hematite. Hematite in the nanoscale has shown unique and distinct characteristics compared to its bulk form. With nanosize, the specific surface area of hematite can increase significantly while maintaining its magnetic properties. The wider surface provides benefits in a variety of applications such as gas sensors, catalysts, lithium-ion batteries, and pigments, and can also be utilized in the manufacture of permanent magnets (Kiswanto et al., 2023; Meijer & Rossi, 2021).

By reviewing the latest literature and research, this review article will compile a comprehensive understanding of the characteristics of iron sand based on the location of its discovery, explore various methods that can be used to produce hematite nanoparticles, and decipher the structure of hematite nanoparticles. Various applications of hematite nanoparticles will also be discussed to determine their development. This article is expected to provide new insights into the potential of iron sand resources and contribute to the development of innovative nanomaterial technologies.

METHODS

This literature research method review will begin by investigating the various literature sources that have been presented to understand the characteristics of iron sand based on the location of its discovery. Consideration will be given to the content of magnetic minerals and impurities in iron sand, as well as variations in grain size and shape affected by the deposition process. Next, research will focus on innovative synthesis methods to produce hematite nanomaterials from iron sand. The analysis will cover the unique characteristics of hematite at the nanoscale, with an emphasis on increasing the specific surface area and maintaining its magnetic properties. This article will compile a comprehensive understanding of the structure of hematite nanoparticles and present various applications of hematite nanomaterials, such as gas sensors, catalysts, lithium-ion batteries, and permanent magnet manufacturing. This literature review is expected to provide new insights into the potential of iron sand resources and contribute to the development of innovative nanomaterial technologies, especially in the context of water treatment, catalysis, and energy storage.

RESULTS

Coastal Areas

Coastal areas are known as places where the process of material deposition by seawater occurs. The deposition of material by seawater will affect the concentration of iron minerals. Therefore, iron sand in coastal areas has a high iron content. In addition to iron minerals, iron sand in coastal areas can also contain additional minerals such as ilmenite, magnetite, or other metal minerals. Comparison of iron sand characteristics of coastal areas in Indonesia can be seen in Table 1 (Bahfie, 2022; Kotarumalos et al., 2023).

Iron sand in coastal areas occurs due to rocks containing iron minerals eroded by sea waves and carried to the coast. In addition, the process of weathering and erosion also plays a role in forming iron mineral particles that are free from the original rock. The accumulation of iron sand along the coast or coastline occurs with the help of tides (Setiady et al., 2020).

Table 1. Comparison of iron sand characteristics of coastal areas in Indonesia

Location Name	Dominant Minerals	Additional Minerals	Physical, Mechanical, and Chemical Properties	Reference
Sunur Beach, West Sumatra	Magnetite, Hematite, and Ilmenite	Quartz, and anapit	Magnetic granules are large, multidomain, and mineral growth modes form lamellae.	(Fatni Mufit et al., 2006)
South Coast of West Java	Magnetite, Hematite	Silicon, Graphite, Clinoferrosilite	Not explained further	(Setianto et al., 2017)
Sampulungan Beach, South Sulawesi	Magnetite	Titanium, Chromium, Vanadium, and Manganese	It is ferrimagnetic, multidomain magnetic grain, and fine magnetic fraction.	(Tiwow et al., 2018)
Keumumu Beach, Aceh	Magnetite	Silica, Calcium, Aluminum, Potassium, and Titanium	The sand fraction is very fine, rounded and well rounded.	(Purnawan et al., 2018)
Puntaru Beach, East Nusa Tenggara	Magnetite	Aluminum, Silica, and Potassium	Softmagnetic, and ferrimagnetic	(Karbeka et al., 2020)
Ivory Coast, East Nusa Tenggara	Magnetite, and Hematite	Aluminum, Silica, Potassium, and Titanium	Not explained further	(Fithriyani et al., 2018)
North Coast, Central Java	Hematite, maghemite	Titanomagnetite, and titanohematite	Fine grain, and pseudo-single domain (PSD)	(Yulianto et al., 2003)
Kata Beach, West Sumatra	Hematite	Carbon, Aluminum, Silica, Calcium, and Manganese	Black, Difficult to reduce, and softmagnetic.	(Rianna et al., 2018)

River

Iron sand in rivers generally has varying grain sizes, depending on the process of transportation and deposition by water. The size of sand grains in rivers is usually smaller than the size of sand grains in coastal areas. This can occur due to the process of transportation by water until it arrives at the river can break the grain. The color of iron sand in rivers can vary, but usually has a brighter color than the color of iron sand in coastal areas (Didik et al., 2020; Nugroho & Basit, 2014).

Iron sand is often unevenly distributed along river flows due to the deposition process. The deposition process can lead to the deposition of iron sand in certain areas such as, river bends and prominent plains along the flow. In addition, strong river currents can transport and precipitate different iron particles in different parts of the water flow. The iron sand content in the river has impurities such as clay, non-metallic minerals, or organic material (Kamiludin et al., 2016).

Table 2. Comparison of the characteristics of river iron sand in Indonesia

Location Name	Dominant Minerals	Additional Minerals	Physical, Mechanical, and Chemical Properties	Reference
Batang Kuranji River, West Sumatra	Albite, magnetite	Quartz, halloysite, saponite, and pyrophyllite	Ferromagnetic minerals	(Afdal &; Niarti, 2013)
Central Lampung	Ilmenite, and Potassium Chloride	Not explained further	Antiferromagnetic	(Puspitarum et al., 2019)
Tor River, Papua	Magnesioferrite	Augit-aluminian	Magnetization is high saturation, and coercive field is low.	(Togibasa et al., 2018)
Sompang River, East Lombok	Silica	Aluminum, Carbon, Sodium, and Potassium	It is finely grained, and has a smaller size than river sand	(Meiliyadi et al., 2022)
Bah Bolon River, North Sumatra	Magnetite, Hematite, and Maghemite	Titanium, Aluminum, Copper. Manganese, Silica, Vanadium	It is soft magnet, and high saturation.	(Novita et al., 2023)

Based on research that has been done, the mineral content in iron sand in rivers has a more unique diversity than the mineral content in iron sand in coastal areas. This can occur because the iron sand in the river has mixed with various minerals during the transportation process by water.

Hematite Nanostructure (α-Fe2O3)

Hematite (α-Fe2O3) has properties that are difficult to corrode so it is suitable for applications such as gas sensors, catalysts, lithium-ion batteries, and pigments, it can also be used in the manufacture of permanent magnets. At high temperatures, the α-Fe (Edianta et al., 2021; Gandha et al., 2016; Miftahul Khoiroh et al., 2013; Rostami et al., 2021; Suhendi et al., 2021; Susilawati et al., 2022). (hematite) phase is the most stable phase compared to other phases. This crystal structure is rhombohedral (trigonal) with a crystal type such as corundum (α-Al2O3), has a space group "R-3 c" lattice parameters a = b = 5.036 Å, c = 13.747 Å, α= = 90° (Figure 1). It is antiferromagnetic under ~260 K (Morin transition temperature), and weak ferromagnetic between 260 K and 950 K (Neel temperature). Many factors, such as pressure, particle size, and magnetic field intensity influence its magnetic properties. Fasahematite has curie temperatures above 800 ºC and below 1000 ºC (Song & Pistorius, 2019).

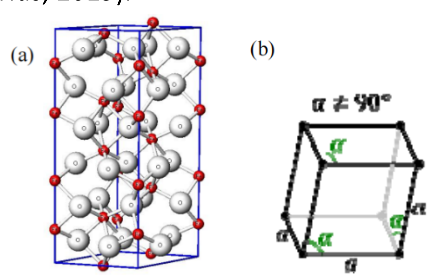

Figure 1. (a) Corundum structure of hematite (α-Fe_{2O3}); (b) Rhombohedral shape of hematite crystal lattice (α-Fe_{2O3})

To produce α-Fe 2O3 nanoparticles is carried out using several methods, including the sol-gel method, from which the particle size of α-Fe2O3 between 10 – 20 nm, the hydrothermal method with a particle size of 30 nm, the ball miling method, with a particle size of 99.14 μm – 93.34 μm, and the coprecipitation method, with a particle size of 22.8899 nm (Dewi & Adi, 2018; Fahlepy et al., 2019; Gandha et al., 2017; Malik & Putra, 2018; Tadic, Panjan, et al., 2019)

Various nanostructures have been studied on hematite by varying the synthesis process. The nanostructures formed during the synthesis and fabrication process also depend on different factors such as synthesis methods, types of precursors, stabilizers, substrates, and not to mention their parameters, for example, temperature and time variations in the synthesis process. Nanostructures are useful for a wide range of applications due to their unique structure and optical and electrical behavior. The nanostructure of α-Fe2O3is nanorods, as shown in Figure 2, micro-cubes, nanowires, nanotubes, nanoflakes, flower-shaped hematite, nanoparticles, and nanorod arrays (W. R. W. Ahmad et al., 2017, 2019; Atabaev, 2015; EmiL-Kaya et al., 2022; Gurudayal et al., 2014; X. Li et al., 2015).

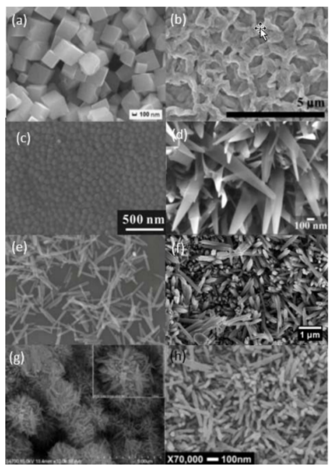

Figure 2. Nanostructure of α-Fe2O3; (a) microcubes, (b) nanowires, (c) nanotubes, (d) nanoflakes, (e) nanorods, (f) microstructure orientation, (g) sea-urchin shaped, and (h) worm-shaped.

Hematite nanostructure synthesis

Coprecipitation

Iron sand is separated by impurities using neodymium magnets. The result is then dissolved into HCl, with the reaction:

$$Fe2O3 + 6HCl \rightarrow 2FeCl3 + 3H2O$$

Stirred and heated at 80oC using a magnetic stirrer at a speed of 350 rpm for 2 hours. Precipitation is carried out by dripping ammonium hydroxide (NH_4OH) dissolved to pH 6 and forming a precipitate by the reaction:

$$2FeCl3 + 3H2O + 6NH4OH \rightarrow 2Fe\ (OH)3 + 6NH4Cl + 3H2O$$

The resulting precipitate is washed with equates and dried in a memmert oven at 100°C for 19 hours, with the reaction:

$$2Fe(OH)_3+6NH_4OH+3H_2O \rightarrow 2FeOOH+6NH_4Cl+5H_2O$$

The dried sample is ground and then calcined. The synthesis process using the coprecipitation method can be seen in Figure 3. The weakness of the coprecipitation method is that the grain size distribution of nanoparticles tends to be large, as well as the polydisversiveness of small particles. Nanoparticles are easily agglomerated the synthesis of nano-hematite using the coprecipitation method has been reported in various studies. A comparison of the results of each study that has been conducted can be seen in Table 3.

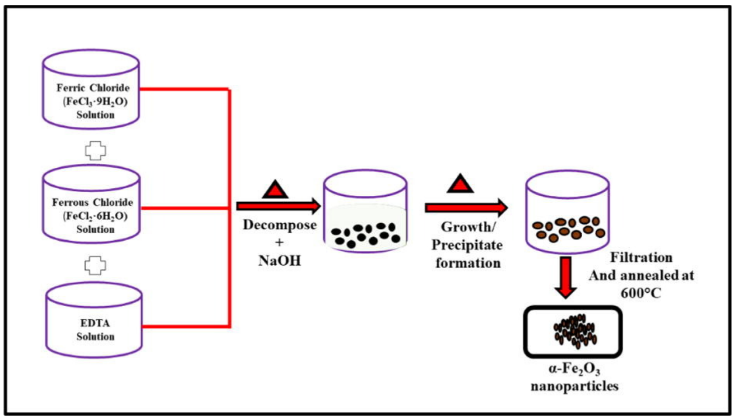

Figure 3. Flow of the coprecipitation method*(Kushwaha &; Chauhan, 2021)*

Table 3. Comparison of research results using the coprecipitation method

Coprecipitation Variation	Particle Size and Shape	Physical, Mechanical, and Chemical Characteristics	Influence of Process Parameters	Ref.
FeCl precursor3and NH4OH precipitator	Hexagonal crystal structure, polygonal morphology, average particle size 10-25 nm. The surface area of the particle is about 17.937 m2/g.	The average pore diameter is 85.67 nm, and the total pore volume is 0.2699 cm^3/g. It has a band gap of 1.8 eV.	This method promises to narrow the band gap in the iron oxide system.	(Parvathy Namboothiri &; Vasundhara, 2023)
FeCl precursors3and NaOH precipitators	The crystal measures 41.7 nm, the average particle size of 50-150 nm is spherical.	Agglomeration occurs, and it is chemically stable.	Temperature affects the formation of nanophases.	(Gobinath et al., 2015)
FeCl precursor3and NH4OH precipitator	The rhombohedral/hexagonal crystal structure measures 16-44 nm.	Agglomeration occurs, has seven phonon modes, crystals are formed at low temperatures.	The concentration of precursors affects the size, crystallinity, morphology, and formation of clots.	(Fouad et al., 2019)
FeCl precursor3and NH4OH precipitator	The particles are 30 nm in size, shaped like a ball with the formation of clusters, hexagonal crystal structure.	Bandgap energy 2.58 eV.	Nano-hematite powder has a uniform size when calcined at 500oC.	(Farahmandjou &; Soflaee, 2015)

FeCl precursor$_3$and NH4OH precipitator	The smallest particle size is 21 nm, spherical.	It has a band gap of 2.09 eV.	An increase in the concentration of precursors leads to an increase in nanoparticle size.	(Lassoued et al., 2017)

Gel Insoles

The sol-gel method is a synthesis method that requires chemical engineering. The term sol-gel comes from two words, namely: 1) sol refers to a precursor solution that will be used as the starting material for the synthesis of Fe2O3 nanoparticles; and 2) gel refers to the form of the final product of synthesized nanoparticles in the form of gels. The sol-gel method is commonly used to synthesize ceramic materials and is not suitable for synthesizing oxide nanoparticles, so additional modifications are needed in using this method. The sol-gel method is a chemical method that has a complex procedure. Many synthesis parameters must be observed (Indrayana, 2019).

Table 4. Process Parameters of Gel Soles

Process Stages	Process Objectives	Process Parameters
Chemical Solutions	Forming Gels	Precursor type, Solvent type, Water content, Precursor concentration, Temperature, and pH
Aging	Let the gel sit to change properties	Time, Temperature, Fluid composition, Aging environment
Drying	Removing water from the gel	Drying method (ovaporative, supercritical, and freeze drying), Temperature, Pressure, Time
Calcining	Changes the physical/chemical properties of solids, often resulting in crystallization and densification	Temperature, Time, Gas (inert or reactive)

The sol-gel method has several disadvantages, namely: 1) it produces a lot of alcohol during the calcination process, 2) it requires additional heat treatment at high temperatures, and 3) the nanoparticle permeability is high, and the bonding power of nanoparticles is weak (Koo et al., 2019)

Hydrothermal

Hydrothermal is formed from the words hydro which means water and thermal which means heat. So the hydrothermal method is a method that uses water and heat whose properties convert solutions into crystals. The hydrothermal method must be performed in a closed system to prevent solvent loss when heated above its boiling point (Jung et al., 2018; Noviyanti et al., 2012; Ou et al., 2018; Qiongyu Li, 2018a; C. Wang et al., 2018; W. Wang et al., 2018; G. T. Zhu et al., 2018).

Hydrothermal synthesis is widely used in the manufacture of metal oxides. Metal oxide synthesis can occur in two stages. The first stage is hydrolysis of the salt solution to produce metal hydroxide. The second stage is that the hydroxide will be dehydrated to produce the desired metal.

Water is the most effective solvent in dissolving ionic compounds at high temperatures and pressures. Water can also act as a pressure transmission and as a precursor solvent, so the resulting powder can be amorphous or crystalline. The advantages of the hydrothermal method include being able to produce crystalline products that can be achieved at low enough temperatures with a high degree of crystallity, can reduce agglomeration between particles, can produce a relatively uniform particle size distribution, high product purity, relatively cheaper, directly formed powder from solution, shape and particle sizes can be controlled from the initial material and different hydrothermal conditions, The reactivity of the resulting powder is high, and allows the synthesis of compounds that have oxidation numbers that are difficult to obtain, especially transition groups (Colombo et al., 2015; Fulle et al., 2018; Zarringhadam & Farhadi, 2018).

In addition, hydrothermal also has a drawback, that is, the initial solubility must be known, hydrothermal slurry is corrosive, and the use of high-pressure vessels will be dangerous in case of accidents (Mercier et al., 2018; D. F. Putri et al., 2019).

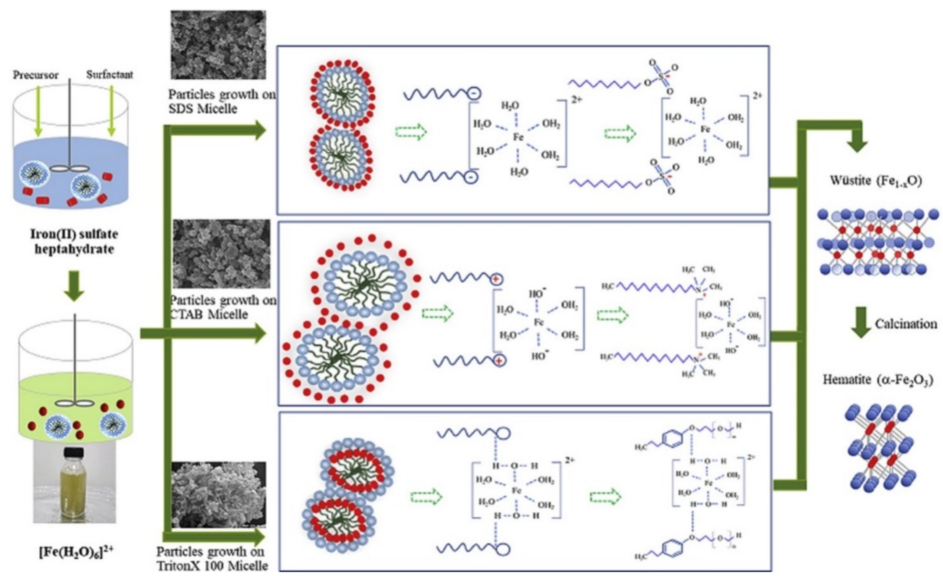

Figure 4. The process of synthesis of hydrothermal methods with various precursors(Kongsat et al., 2021)

Good crystals can be obtained by adding a mineralizer. Mineralizer serves to increase the polarity of water to increase the solubility of a dissolved substance. Compounds used as mineralizers should not be seen in reactions, and commonly used compounds are alkaline bases, NaOH, and KOH (Noviyanti et al., 2018).

Table 5. Comparison of research results using hydrothermal methods

Hydrothermal Variations	Particle Size and Shape	Physical, Mechanical, and Chemical Characteristics	Influence of Process Parameters	Ref.
Anionic, cationic, and nonionic surfactants. Temperature 180$^{oC.}$	Spherical particle shapes with a diameter ranging from 15-205 nm.	Single-domain magnetic behavior, coercivity of 225 Oe, high stability, and thermal conductivity of 0.4787 W/mK.	The type and concentration of surfactants can affect the colloidal stability and thermal stability of nanoparticle suspensions.	(Kongsat et al., 2021)
PVP surfactants and NaAc precipitants.	The average particle size is 40	The highest capacitance is 340.5 F/g at a current	The concentration of the precursor affects the	(M. Zhu et al., 2012)

Temperature 200oC.	nm with a spherical shape.	density of 1 A/g, remanent magnetization is 0.02 emu/g, coercivity is 66.8 Oe, and a long cycle life.	quality of the size and dispersion of the resulting hematite	
Fe sulfate heptahydrate solution Fe2 (SO4)3.7H2O Temperature 160oC.	Spherical in shape, and the average size is 8 nm.	It is superparamagnetic with blocking temperature T B = 52 K and irreversibility temperature T irr = 103 K. Magnetization Ms = 3.98 emu/g and magnetic moment mp = 657 B.	The magnetization properties of hematite nanoparticles are influenced by the crystallinity and surface of the nanoparticles.	(Tadic et al., 2014)
Fe (III) nitrate solution. Temperature 100oC.	The average particle size is 20-60 nm.	A low pH produces a positive potential value, while a pH of 7 produces a negative valueζ	The size of the synthesized particles increases with the reaction time. Particle size affects colloidal behavior to absorption and aggregation processes.	(Colombo et al., 2015)
Hierarchical nanostructures with various glycine-free and glycine-assisted morphologies.	The diameter of the particles is on average 20-80 nm, spherical in shape.	Ferromagnetic, coercivity H_c = 3725 Oe.	Glycine in hydrothermal reactions can increase the coercivity value up to 3 times.	(Trpkov et al., 2018)
Precursors of iron and sodium acetate. Temperature 180oC.	The size of 50 nm irregular nanoparticles, such as plates with a thickness of 10 nm and a diameter of 50-80 nm, a 3D ellipsoid with a length of 3.5 nm and a diameter of 1.5 mμ	Coerciveness of irregular nanoparticles Hc = 73 Oe, nanoplates Hc = 689 Oe, and 3D ellipsoid Hc = 2688 Oe. Indicates a low level of cytotoxicity.	The anisotropic form influences the increase in coercivity in hematite nanoplates, their structure and morphology.	(Tadic, Trpkov, et al., 2019)

Sonication

The sonication method is the easiest and most effective method for large-scale production with precise size control, high morphology, and crystallinity. In research using ultrasonic sonochemical methods obtained polyhedron monodispersa hematite nanoparticles with uniform shape, particle size of about 14nm at a temperature of 500^{o}C (Khalil et al., 2017). Shock waves in the sonification method can separate the agglomeration of a particle (agglomeration) and due to the influence of sonification (ultrasonic) can produce nanoscale crystal sizes. This method uses ultrasonic bath with high frequencies such as 20 kHz - 10 MHz to break down metal ions in molecules so that it is expected that the crystal growth process can take place quickly and can avoid oxidation of metal ions resulting in the formation of amorphous particles (Candani et al., 2018; Firnando & Astuti, 2015).

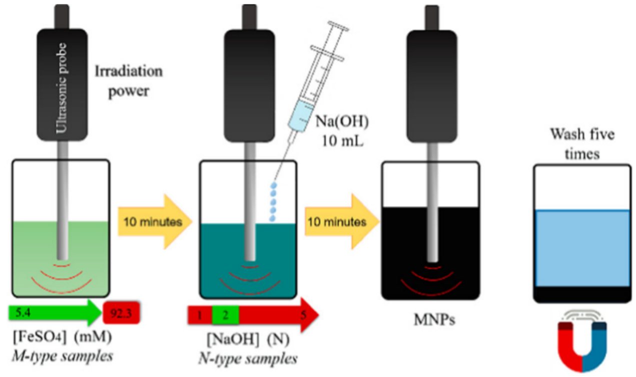

Figure 5. Synthesis process sonication method(Fuentes-García et al., 2020)

Applications of Hematite (α-Fe2O3) Nanoparticles

Hematite nanoparticles (α-Fe2O3) have potential applications in various fields of advanced nanotechnology, such as electronics, optical devices, photonics, and microwave absorbers. Much research has focused on hematite nanoparticles (α-Fe2O3) both undoped and doped as solar photoelectrochemical cell (PEC) materials (Bai et al., 2022; Dhiman et al., 2020; Kamil et al., 2022; Y. Li et al., 2021; Silva et al., 2020).

Hematite nanoparticles (α-Fe_2O_3) are also suitable for photocatalytic applications because they are environmentally friendly, cost-effective, and have chemical stability over a wide pH range. The size of the diameter and porosity of the hematite nanorod (ALP, 2023; S. A. Putri et al., 2021; Suchi Ramadhani Putri et al., 2022). α-Fe2O3 also affect the magnetization properties. Furthermore, hematite nanorods (α-Fe2O3) (Rifai et al., 2021; S., 2019; Simbolon et al., 2021; Sinuhaji et al., 2021) are also applied to gas sensors and Lithium-ion batteries, where it has been proven that the working principle of electrochemical and gas sensors is highly dependent on the size of the diameter and surface area of the Branauer Emmet-Teller (BET) (A. Ahmad et al., 2019; Hung et al., 2016; Indra & Noerochim, 2016; Liu et al., 2020; Ma et al., 2020; Qin et al., 2022).

Hematite nanoparticles (α-Fe2O3) can also be applied as microwave absorbers on aircraft walls. By utilizing the potential of natural sand in East Java, a prototype of a microwave absorbing coating based on Mhexaferite BaFe12-xZnxO19 has been successfully made, by making it a coating for paint composite materials on the interior walls of the aircraft. The use of hematite nanoparticles as microwave absorbers is also supported by the results of research conducted by Rianna et al using natural iron sand (Efhana et al., 2013; Rianna et al., 2023).

Barium hex ferrite is an ideal material to dampen electromagnetic interference (EMI) caused by malfunctions in electronic equipment. One of the ingredients for making Barium hexaferrite is hematite (α-Fe2O3) (Susanto et al., 2014). Barium hexaferrite has been widely studied because it has many advantages, including its relatively cheap price, high curie temperature, resistance to corrosion, good physical properties, and its manufacture is relatively easy (Dermayu Siregar & Humaidi, n.d.; Hayati et al., 2016; Widanarto et al., 2015).

Hematite nanoparticles as water and sewage treatment have been reported in research by Kefeni et al. Based on the research that has been done, hematite nanoparticles have succeeded in removing Al, Mg, Mn, Zn, Ni, Ca, and Na metals. The adsorption and precipitation properties possessed by hematite can help in the process of cleaning water from heavy metals and other solutes. This is also reinforced by the findings of Aal et al which show that hematite nanoparticles can absorb Cu, Ni, Co, Cd, and Pb ions (Abd El Aal et al., 2019; Kefeni et al., 2018).

In the medical field, hematite nanoparticles also show no less unique abilities, one of which is their use as a delivery drug. Hematite nanoparticles can be coated with drug compounds to be then directed to specific locations in the body using external magnetic fields. External magnetic fields can also generate heat through magnetic hysteresis in magnetic hyperthermia therapy to damage cancer cells. In addition, the unique magnetic properties that hematite nanoparticles possess can help in medical imaging techniques such as magnetic resonance (MRI) by increasing image contrast (Beato-López et al., 2020; Mabrouk et al., 2020; Pham et al., 2016; Surowiec et al., 2017).

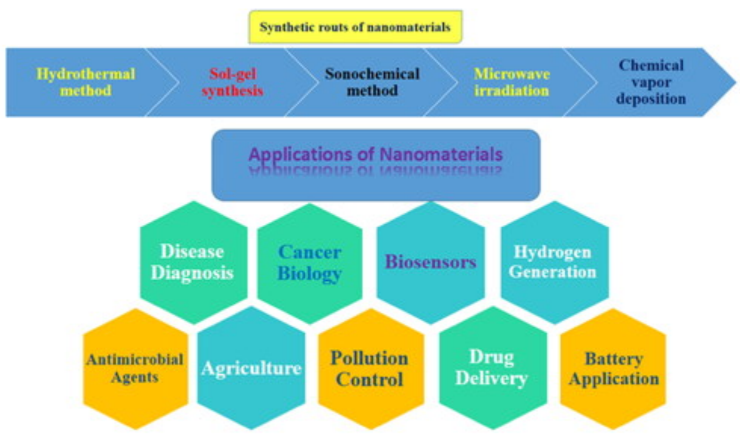

Figure 6. Applications and methods of synthesis of hematite nanoparticles(Kokila et al., 2022)

CONCLUSION

Based on the literature that has been described, it can be concluded that iron sand can be further utilized in producing a variety of minerals, especially hematite. The characteristics of iron sand used can be influenced by the location where iron sand is found. In addition, the synthesis method plays an important role in determining the physical, mechanical, and chemical properties of hematite nanoparticles from iron sand. The structure of hematite nanoparticles, especially at the level of crystallinity and surface morphology has an impact on the performance and application of hematite nanoparticles. Hematite nanoparticles have demonstrated their capabilities in a wide range of applications, including water and environmental treatment, catalysts, and energy storage.

REFERENCES

Abd El Aal, S. A., Abdelhady, A. M., Mansour, N. A., Hassan, N. M., Elbaz, F., & Elmaghraby, E. K. (2019). Physical and chemical characteristics of hematite nanoparticles prepared using microwave-assisted synthesis and its application as adsorbent for Cu, Ni, Co, Cd and Pb from aqueous solution. *Materials Chemistry and Physics*, *235*(April), 121771. https://doi.org/10.1016/j.matchemphys.2019.121771

Abdel-Karim, A. A. M., & Barakat, M. G. (2017). Separation, upgrading, and mineralogy of placer magnetite in the black sands, northern coast of Egypt. *Arabian Journal of Geosciences*, *10*(14), 1–17. https://doi.org/10.1007/s12517-017-3075-0

Afdal, & Niarti, L. (2013). Karakterisasi Sifat Magnet Dan Kandungan Mineral Pasir Besi Sungai Batang Kuranji Padang Sumatera Barat. *Jurnal Ilmu Fisika | Universitas Andalas*, *5*(1), 24–30. https://doi.org/10.25077/jif.5.1.24-30.2013

Ahmad, A., Undu, M. A. A., Ahmanas, S. R., Erniwati, & Fayanto, S. (2019). Utilization of iron sand and activated carbon of cashew nut shell as a material basic of lithium battery. *AIP Conference Proceedings*, *2169*. https://doi.org/10.1063/1.5132679

Ahmad, W. R. W., Mamat, M. H., Zoolfakar, A. S., Khusaimi, Z., Ismail, A. S., Saidi, S. A., Kadir, R. A., & Rusop, M. (2017). The effect of different ratio (stabilizer-precursor) in sonicated immersion method of hematite nanorods. *IEEE Student Conference on Research and Development: Inspiring Technology for Humanity, SCOReD 2017 - Proceedings*, *2018-Janua*(November 2018), 142–147. https://doi.org/10.1109/SCORED.2017.8305405

Ahmad, W. R. W., Mamat, M. H., Zoolfakar, A. S., Khusaimi, Z., Ismail, A. S., Yaakub, T. N. T., & Rusop, M. (2019). Effect of substrate placement in schott vial to hematite properties. *Bulletin of Electrical Engineering and Informatics*, *8*(1), 58–64. https://doi.org/10.11591/eei.v8i1.1391

ALP, E. (2023). Comparative Study of Improvement of Hematite as Visible Light-Driven Photocatalyst by Doping with Zinc and Copper. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, *11*(1), 502–512. https://doi.org/10.29130/dubited.1051644

Atabaev, T. S. (2015). Facile hydrothermal synthesis of flower-like hematite microstructure with high photocatalytic properties. *Journal of Advanced Ceramics*, *4*(1), 61–64. https://doi.org/10.1007/s40145-015-0133-5

Aziz, A. N. (2021). Optimasi desalinator tenaga matahari menggunakan bahan beton campuran pasir besi. *Jurnal Teras Fisika*, *4*(2), 237. https://doi.org/10.20884/1.jtf.2021.4.2.5102

Bahfie, F. (2022). PENGOLAHAN PASIR BESI UNTUK MENINGKATKAN KADAR TITANIUM (Ti) DENGAN METODE PEMISAHAN MAGNETIK SECARA BASAH. *Inovasi Pembangunan : Jurnal Kelitbangan*, *10*(03), 237. https://doi.org/10.35450/jip.v10i03.323

Bai, H., He, P., Hao, L., Liu, N., Fan, Z., Chen, B., Niu, R., & Gong, J. (2022). Engineering self-floating Fe2O3/N,O-doped carbon foam as a bifunctional interfacial solar evaporator for synergetic freshwater production and advanced oxidation process. *Journal of Environmental Chemical Engineering*, *10*(5), 108338. https://doi.org/10.1016/j.jece.2022.108338

Basavegowda, N., Mishra, K., & Lee, Y. R. (2017). Synthesis, characterization, and catalytic applications of hematite (α-Fe2O3) nanoparticles as reusable nanocatalyst. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, *8*(2). https://doi.org/10.1088/2043-6254/aa6885

Beato-López, J. J., Domínguez, M., Ramírez-del-Solar, M., & Litrán, R. (2020). Glutathione-magnetite nanoparticles: synthesis and physical characterization for application as MRI contrast agent. *SN Applied Sciences*, *2*(7), 1–14. https://doi.org/10.1007/s42452-020-3010-y

Candani, D., Ulfah, M., Noviana, W., & Zainul, R. (2018). A Review Pemanfaatan Teknologi Sonikasi. *INA-Rxiv*, *26*, 1–9.

Colombo, C., Palumbo, G., Di Iorio, E., Song, X., Jiang, Z., Liu, Q., & Angelico, R. (2015). Influence of hydrothermal synthesis conditions on size, morphology and colloidal properties of Hematite nanoparticles. *Nano-Structures and Nano-Objects*, *2*, 19–27. https://doi.org/10.1016/j.nanoso.2015.07.004

Dermayu Siregar, S., & Humaidi, S. (n.d.). *PEMBUATAN MAGNETIK BARIUM M-HEKSAFERIT YANG DIDOPING ION Cu*.

Dewi, S. H., & Adi, W. A. (2018). Synthesis and characterization of high purity Fe3O4 and α - Fe2O3 from local iron sand. *Journal of Physics: Conference Series*, *1091*(1). https://doi.org/10.1088/1742-6596/1091/1/012021

Dhiman, P., Sharma, S., Kumar, A., Shekh, M., Sharma, G., & Naushad, M. (2020). Rapid visible and solar photocatalytic Cr(VI) reduction and electrochemical sensing of dopamine using solution combustion synthesized ZnO–Fe2O3 nano heterojunctions: Mechanism Elucidation. *Ceramics International*, *46*(8), 12255–12268. https://doi.org/10.1016/j.ceramint.2020.01.275

Didik, L. A., Aini, H., & Zohdi, A. (2020). Analisis Perbandingan Kandungan Fe dan Karakteristik Sifat Listrik Pasir Besi Sungai dan Pantai. *Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat*, *17*(2), 138. https://doi.org/10.20527/flux.v1i1.7689

Edianta, J., Fauzi, N., Naibaho, M., Arsyad, F. S., & Royani, I. (2021). Review of the effectiveness of plant media extracts in barium hexaferrite magnets (Bafe12o19). *Science and Technology Indonesia*, *6*(2), 39–52. https://doi.org/10.26554/STI.2021.6.2.39-52

Efhana, D. P., Arifin, D. E. S., Dita, V., Fitriana, Abdillah, S., & Zainuri, Moch. (2013). Pembuatan Pelapis Penyerap Gelombang Mikro Berbasis M Hexaferrite BaFe12-2xZnxO19 dari Pasir Alam pada Kabin Pesawat. *Pekan Ilmiah Mahasiswa Nasional Program Kreativitas Mahasiswa-Penelitian 2013*, 3–6.

EmiL-Kaya, E., Evren, B., Erdöl, Z., Ekinci, D., İPekoğlu, M., & Özenler, S. (2022). Morphological, microstructural and photocatalytic characterization of undoped and Ni, Co doped Fe2O3 particles synthesized by sonochemical method. *Turkish Journal of Chemistry*, *46*(6), 1897–1908. https://doi.org/10.55730/1300-0527.3489

Fahlepy, M. R., Wahyuni, Y., Andhika, M., Tiwow, V. A., & Subaer. (2019). Synthesis and characterization of nanopraticle hematite (A-fe2o3) minerals from natural iron sand using co-precipitation method and its potential applications as extrinsic semiconductor materials type-n. *Materials Science Forum*, *967 MSF*, 259–266. https://doi.org/10.4028/www.scientific.net/MSF.967.259

Farahmandjou, M., & Soflaee, F. (2015). Synthesis and characterization of α-Fe2O3 nanoparticles by simple co-precipitation method. *Physical Chemistry Research*, *3*(3), 191–196. https://doi.org/10.22036/pcr.2015.9193

Fatih, M. A. R., Dharma, R. H., & Zanuar, A. R. (2021). Kajian Pengembangan Industri Pengolahan Pasir Besi Di Kabupaten Trenggalek Dengan Pemanfaatan Bendungan Bagong Dan Tugu Sebagai Pembangkit Listrik Tenaga Mikrohidro (Pltmh) Guna Mendukung Pembangunan Yang Berkelanjutan. *Jurnal Ilmiah Penalaran Dan Penelitian Mahasiswa*, *5*(2), 198–217.

Fatni Mufit, Fadhillah, Harman Amir, & Satria, B. (2006). Kajian tentang Sifat Magnetik Pa sir Besi dari Pantai Sunur, Pariaman, Sumatera Barat. *Jurnal Geofisika 2006/1*, *1*, 2–5.

Firnando, H. G., & Astuti. (2015). Pengaruh Suhu Pada Proses Sonikasi Terhadap Morfologi Partikel dan Kristalinitas Nanopartikel Fe3O4. *Fisika Unand*, *4*(1), 1–5.

Fithriyani, A., Khair, H., Susilawati, Doyan, A., Taufik, M., Wahyudi, Gunawan, E., & Kosim. (2018). Identifikasi Kandungan Fe Pada Pasir Besi Alam Di Kota Mataram. *Jurnal Pendidikan Fisika Dan Teknologi*, *4*(1).

Fouad, D. E., Zhang, C., El-Didamony, H., Yingnan, L., Mekuria, T. D., & Shah, A. H. (2019). Improved size, morphology and crystallinity of hematite (α-Fe2O3) nanoparticles synthesized via the precipitation route using ferric sulfate precursor. *Results in Physics*, *12*(January), 1253–1261. https://doi.org/10.1016/j.rinp.2019.01.005

Fuentes-García, J. A., Carvalho Alavarse, A., Moreno Maldonado, A. C., Toro-Córdova, A., Ibarra, M. R., & Goya, G. F. (2020). Simple Sonochemical Method to Optimize the Heating Efficiency of Magnetic Nanoparticles for Magnetic Fluid Hyperthermia. *ACS Omega*, *5*(41), 26357–26364. https://doi.org/10.1021/acsomega.0c02212

Fulle, K., Sanjeewa, L. D., McMillen, C. D., & Kolis, J. W. (2018). High temperature hydrothermal synthesis of rare-earth titanates: Synthesis and structure of RE5Ti4O15(OH) (RE = La, Er), Sm3TiO5(OH)3, RE5Ti2O11(OH) (RE = Tm-Lu) and Ce2Ti4O11. *Dalton Transactions*, *47*(19), 6754–6762. https://doi.org/10.1039/c7dt04810f

Gandha, K., Mohapatra, J., Hossain, M. K., Elkins, K., Poudyal, N., Rajeshwar, K., & Liu, J. P. (2016). Mesoporous iron oxide nanowires: Synthesis, magnetic and photocatalytic properties. *RSC Advances*, *6*(93), 90537–90546. https://doi.org/10.1039/c6ra18530d

Gandha, K., Mohapatra, J., Poudyal, N., Elkins, K., & Liu, J. P. (2017). Enhanced coercivity in Co-doped α-Fe2O3 cubic nanocrystal assemblies prepared via a magnetic field-assisted hydrothermal synthesis. *AIP Advances*, *7*(5). https://doi.org/10.1063/1.4978317

Gobinath, R., Singh, R. D., Datta, S. C., Datta, S. P., & Kumar, S. (2015). Characterization of iron nano particles (Fe2O3) synthesized through coprecipitation and sol-gel methods. *Clay Research*, *34*(2), 59–65.

Gurudayal, G., Chiam, S. Y., Kumar, M. H., Bassi, P. S., Seng, H. L., Barber, J., & Wong, L. H. (2014). Improving the efficiency of hematite nanorods for photoelectrochemical water splitting by doping with manganese. *ACS Applied Materials and Interfaces*, *6*(8), 5852–5859. https://doi.org/10.1021/am500643y

Hayati, R., Budiman, A., & Puryanti, D. (2016). Karakterisasi Suseptibilitas Magnet Barium Ferit yang Disintesis dari Pasir Besi dan Barium Karbonat Menggunakan Metode Metalurgi Serbuk. *Jurnal Fisika Unand*, *5*(2), 187–192. https://doi.org/10.25077/jfu.5.2.187-192.2016

Hung, C. M., Hoa, N. D., Van Duy, N., Van Toan, N., Le, D. T. T., & Van Hieu, N. (2016). Synthesis and gas-sensing characteristics of α-Fe2O3 hollow balls. *Journal of Science: Advanced Materials and Devices*, *1*(1), 45–50. https://doi.org/10.1016/j.jsamd.2016.03.003

Ibrahim, A. F. M., Seifelnassr, A. A. S., Al-Abady, A., El-Salmawy, M. S., & Abdelaal, A. M. (2022). Characterization and Iron Removal Enhancement of El-Zaafarana White Sand. *Mining, Metallurgy and Exploration*, *39*(5), 2187–2198. https://doi.org/10.1007/s42461-022-00667-0

Indra, M. A. T., & Noerochim, L. (2016). Pengaruh Konsentrasi Lisin Pada Pembentukan Fe2O3 Hasil Proses Sintesis Hidrotermal Sebagai Anoda Baterai Ion Lithium. *Jurnal Teknik ITS*, *5*(2). https://doi.org/10.12962/j23373539.v5i2.17325

Indrayana, I. P. T. (2019). REVIEW Fe3O4 DARI PASIR BESI : SINTESIS, KARAKTERISASI, DAN FUNGSIONALISASI HINGGA APLIKASINYA DALAM BIDANG NANOTEKNOLOGI MAJU. *Jurnal UNIERA*, *8*(2), 65–75.

Jung, K. W., Lee, S. Y., & Lee, Y. J. (2018). Hydrothermal synthesis of hierarchically structured birnessite-type MnO2/biochar composites for the adsorptive removal of Cu(II) from aqueous media. *Bioresource Technology*, *260*(Ii), 204–212. https://doi.org/10.1016/j.biortech.2018.03.125

Kamil, A. F., Abdullah, H. I., Rheima, A. M., & Mohammed, S. H. (2022). UV-Irradiation synthesized α-Fe2O3 nanoparticles based dye-sensitized solar cells. *Materials Today: Proceedings*, *61*, 820–825. https://doi.org/10.1016/j.matpr.2021.09.079

Kamiludin, U., Darlan, Y., & Setiady, D. (2016). Kaitan Tipologi Pantai Dengan Keberadaan Pasir Besi Di Pantai Mukomuko, Bengkulu. *Jurnal Geologi Kelautan*, *10*(2), 59. https://doi.org/10.32693/jgk.10.2.2012.216

Karbeka, M., Koly, F. V. L., & Tellu, N. M. (2020). Karakterisasi Sifat Magnetik Kemagnetan Pasir Besi Pantai Aru Kabupaten Alor-NTT. *Lantanida Journal*, *8*(2), 96–188.

Kefeni, K. K., Msagati, T. A. M., Nkambule, T. T. I., & Mamba, B. B. (2018). Synthesis and application of hematite nanoparticles for acid mine drainage treatment. *Journal of Environmental Chemical Engineering*, *6*(2), 1865–1874. https://doi.org/10.1016/j.jece.2018.02.037

Khalil, M., Liu, N., & Lee, R. L. (2017). Synthesis and characterization of hematite nanoparticles using ultrasonic sonochemistry method. *International Journal of Technology*, *8*(4), 582–590. https://doi.org/10.14716/ijtech.v8i4.9474

Kiswanto, H., Nurhidayati, I., Hendarto, A., & Harsono, P. (2023). Jawa Tengah 2 Program Studi Nautika, Politeknik Ilmu Pelayaran Semarang Jl. Singosari Raya No 2A, Wonodri, Kec. Semarang Selatan, Semarang 50242 Jawa Tengah 5 Program Studi Nautika, Politeknik Maritim Negeri Indonesia Jl. *Pawiyatan Luhur I No 1 Bendan Duwur, Kec. Gajah Mungkur*, *07*(02), 164–173.

Kokila, G. N., Mallikarjunaswamy, C., & Ranganatha, L. (2022). A review on synthesis and applications of versatile nanomaterials. *Inorganic and Nano-Metal Chemistry*, *30*(1), 2470–1556. https://doi.org/https://doi.org/10.1080/24701556.2022.2081189

Kongsat, P., Kudkaew, K., Tangjai, J., O'Rear, E. A., & Pongprayoon, T. (2021). Synthesis of structure-controlled hematite nanoparticles by a surfactant-assisted hydrothermal method and property analysis. *Journal of Physics and Chemistry of Solids*, *148*(July 2020), 109685. https://doi.org/10.1016/j.jpcs.2020.109685

Koo, K. N., Ismail, A. F., Othman, M. H. D., Rahman, M. A., & Sheng, T. Z. (2019). Preparation and characterization of superparamagnetic magnetite (Fe3O4) nanoparticles: A short review. *Malaysian Journal of Fundamental and Applied Sciences*, *15*(1), 23–31. https://doi.org/10.11113/mjfas.v15n2019.1224

Kotarumalos, S. H., Limehuwey, R., & Multi, W. (2023). Genesis and Characteristics of Iron Sand. *Tanah Goyang*, *1*(1).

Kushwaha, P., & Chauhan, P. (2021). Synthesis of spherical and Rod-Like EDTA assisted a-Fe2O3nanoparticles via Co-precipitation method. *Materials Today: Proceedings*, *44*, 3086–3090. https://doi.org/10.1016/j.matpr.2021.02.450

Lassoued, A., Dkhil, B., Gadri, A., & Ammar, S. (2017). Control of the shape and size of iron oxide (α-Fe2O3) nanoparticles synthesized through the chemical precipitation method. *Results in Physics*, *7*, 3007–3015. https://doi.org/10.1016/j.rinp.2017.07.066

Li, X., Wang, Z., Zhang, Z., Chen, L., Cheng, J., Ni, W., Wang, B., & Xie, E. (2015). Light Illuminated α-Fe2O3/Pt Nanoparticles as Water Activation Agent for. *Scientific Reports*, *5*, 1–7. https://doi.org/10.1038/srep09130

Li, Y., Zhang, N., Liu, C., Zhang, Y., Xu, X., Wang, W., Feng, J., Li, Z., & Zou, Z. (2021). Metastable-phase β-Fe2O3 photoanodes for solar water splitting with durability exceeding 100 h. *Chinese Journal of Catalysis*, *42*(11), 1992–1998. https://doi.org/10.1016/S1872-2067(21)63822-6

Liu, L., Fu, S., Lv, X., Yue, L., Fan, L., Yu, H., Gao, X., Zhu, W., Zhang, W., Li, X., & Zhu, W. (2020). A Gas Sensor With Fe2O3 Nanospheres Based on Trimethylamine Detection for the Rapid Assessment of Spoilage Degree in Fish. *Frontiers in Bioengineering and Biotechnology*, *8*(September), 1–9. https://doi.org/10.3389/fbioe.2020.567584

Ma, J., Kong, Y., Liu, S., Li, Y., Jiang, J., Zhou, Q., Huang, Y., & Han, S. (2020). Flexible Phosphorus-Doped Graphene/Metal-Organic Framework-Derived Porous Fe2O3Anode for Lithium-Ion Battery. *ACS Applied Energy Materials*, *3*(12), 11900–11906. https://doi.org/10.1021/acsaem.0c02030

Mabrouk, M., Abd El-Wahab, R. M., Beherei, H. H., Selim, M. M., & Das, D. B. (2020). Multifunctional magnetite nanoparticles for drug delivery: Preparation, characterisation, antibacterial properties and drug release kinetics. *International Journal of Pharmaceutics*, *587*(July), 119658. https://doi.org/10.1016/j.ijpharm.2020.119658

Malik, U., & Putra, S. U. (2018). *KOMPOSISI MATERIAL PASIR BESI PANTAI KATA PARIAMAN*. *3*(2), 11–14.

Meijer, J. M., & Rossi, L. (2021). Preparation, properties, and applications of magnetic hematite microparticles. *Soft Matter*, *17*(9), 2354–2368. https://doi.org/10.1039/d0sm01977a

Meiliyadi, L. A. D., Wahyudi, Muh., Damayanti, I., & Fudholi, A. (2022). Morphological characteristics and electrical properties analysis of silica based on river and coastal iron sand. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *11*(1), 129–140. https://doi.org/10.24042/jipfalbiruni.v11i1.12390

Mercier, C., Lossouarn, J., Nesbø, C. L., Haverkamp, T. H. A., Baudoux, A. C., Jebbar, M., Bienvenu, N., Thiroux, S., Dupont, S., & Geslin, C. (2018). Two viruses, MCV1 and MCV2, which infect Marinitoga bacteria isolated from deep-sea hydrothermal vents: functional and genomic analysis. *Environmental Microbiology*, *20*(2), 577–587. https://doi.org/10.1111/1462-2920.13967

Miftahul Khoiroh, L., Mardiana, D., Sabarudin, A., & Ismuyanto, B. (2013). Synthesis of Hematite Pigments (alpha-Fe2O3) by Thermal Transformations of FeOOH. *The Journal of Pure and Applied Chemistry Research*, *2*(1), 27–34. https://doi.org/10.21776/ub.jpacr.2013.002.01.120

Mulyani, L., Setiawan, F., & Sofyan, E. (2022). Analisis Karakteristik Keausan Material Dengan Matriks Resin Menggunakan Filler Serat Bambu Dan Pasir Besi Untuk Aplikasi Kampas Rem. *Teknika STTKD: Jurnal Teknik, Elektronik, Engine*, *8*(1), 103–111. https://doi.org/10.56521/teknika.v8i1.549

Nengsih, S., Abdulmadjid, S. N., Mursal, M., Idroes, R., & Jalil, Z. (2023). Magnetization Study of Iron Sand from Sabang, Indonesia: The Potential of Magnetic Materials in the Photocatalytic Field. *Bulletin of Chemical Reaction Engineering and Catalysis*, *18*(2), 344–352. https://doi.org/10.9767/bcrec.19041

Novita, N., Naibaho, M., Puspita, E., Ramlan, R., Ginting, M., & Humaidi, S. (2023). Analysis of Mineral Content and Magnetic Properties of Iron Sand of Bah Bolon Simalungun River, North Sumetera. *Asian Journal of Engineering, Social and Health*, *2*(12), 1633–1639. https://doi.org/10.46799/ajesh.v2i12.196

Noviyanti, A. R., Prijamboedi, B., Nyoman Marsih, I., & Ismunandar. (2012). Hydrothermal preparation of apatite-type phases La9.33Si6O26 and La9M1Si6O26.5 (M = Ca, Sr, Ba). *ITB Journal of Science*, *44 A*(2), 193–203. https://doi.org/10.5614/itbj.sci.2012.44.2.8

Noviyanti, A. R., Syarif, D. G., Amynurdin, R., Hastiawan, I., Rahayu, I., & Yuliyati, Y. B. (2018). Konduktivitas Apatit Lantanum Silikat La9.33Si6O26 Hasil Sintesis Hidrotermal dengan Mineraliser NaOH dan KOH. *ALCHEMY Jurnal Penelitian Kimia*, *14*(1), 1. https://doi.org/10.20961/alchemy.14.1.8468.1-15

Nugroho, S. H., & Basit, A. (2014). Sediment Distribution Based on Grain Size Analyses in Weda Bay, Northern Maluku. *Jurnal Ilmu Dan Teknologi Kelautan Tropis*, *6*(1), 229–240. https://doi.org/10.28930/jitkt.v6i1.8644

Ou, X., Lei, S., Zhang, X., Wan, K., Wang, Y., Zhou, W., Xiao, Y., & Cheng, B. (2018). Hydrothermal growth of ferrous hydroxide terephthalate as a new positive electrode material for supercapacitors. *Dalton Transactions*, *47*(35), 12056–12060. https://doi.org/10.1039/C8DT02377H

Parvathy Namboothiri, P. M., & Vasundhara, M. (2023). Synthesis and characterization of nano-hematite. *Materials Today: Proceedings*, *92*, 1459–1463. https://doi.org/10.1016/j.matpr.2023.05.652

Pham, X. N., Nguyen, T. P., Pham, T. N., Tran, T. T. N., & Tran, T. V. T. (2016). Synthesis and characterization of chitosan-coated magnetite nanoparticles and their application in curcumin drug delivery. *Advances in Natural Sciences: Nanoscience and Nanotechnology*, *7*(4). https://doi.org/10.1088/2043-6262/7/4/045010

Purnawan, S., Azizah, A., Jalil, Z., & Zaki, M. (2018). Karakteristik Sedimen dan Kandungan Mineral Pasir Besi di Labuhan Haji Timur, Kabupaten Aceh Selatan. *Jurnal Rekayasa Kimia & Lingkungan*, *13*(2), 110–119. https://doi.org/10.23955/rkl.v13i2.10532

Puspitaningrum, A., Taufiq, A., Hidayat, A., Sunaryono, Hidayat, N., & Samian. (2017). Optical Properties of Fe3O4 Magnetic Fluid from Iron Sand. *IOP Conference Series: Materials Science and Engineering*, *202*(1). https://doi.org/10.1088/1757-899X/202/1/012054

Puspitarum, D. L., Safitri, G., Ardiyanti, H., & Anrokhi, M. S. (2019). KARAKTERISASI DAN SIFAT KEMAGNETAN PASIR BESI di WILAYAH LAMPUNG TENGAH. *Jurnal Pendidikan Fisika*, *7*(2), 236. https://doi.org/10.24127/jpf.v7i2.2189

Putri, D. F., Maulina Ritonga, H., Murdiati, V., & Zainul, D. R. (2019). What Is Hydrothermal ? *Jurnal FMIPA*, 1–17.

Putri, S. A., Amanah, I. N., Susilawati, J., & Fabiani, A. (2021). Degradasi Zat Warna Rhodamin-B Menggunakan Green Fotokatalis Seng Ferit (ZnFe2O4)-Ekstrak Daun Pucuk Idat

(Cratoxylum Glaucum). *Fullerene Journ. Of Chem*, *6*(2), 135–142. https://doi.org/10.37033/fjc.v6i2.341

Qin, Q., Olimov, D., & Yin, L. (2022). Semiconductor-Type Gas Sensors Based on γ-Fe2O3 Nanoparticles and Its Derivatives in Conjunction with SnO2 and Graphene. *Chemosensors*, *10*(7). https://doi.org/10.3390/chemosensors10070267

Qiongyu Li. (2018). Authors : Ac ce d M us pt. *2D Materials*, 0–23.

Rianna, M., Sembiring, T., Situmorang, M., Kurniawan, C., Setiadi, E. A., Tetuko, A. P., Simbolon, S., Ginting, M., & Sebayang, P. (2018). Characterization of Natural Iron Sand From Kata Beach, West Sumatra With High Energy Milling (Hem). *Jurnal Natural*, *18*(2), 97–100. https://doi.org/10.24815/jn.v18i2.11163

Rianna, M., Setiadi, E. A., Susiani, S., Soehada Sebayang, A. M., Fauzi, M., Hussain, M. K., Yuliana, K., Asri, N. S., Nurdiyansah, L. F., Tetuko, A. P., & Sebayang, P. (2023). Enhanced calcination temperatures of SrFe12O19 synthesized by local iron sand from Lombok Island. *Case Studies in Chemical and Environmental Engineering*, *8*(October), 100530. https://doi.org/10.1016/j.cscee.2023.100530

Rifai, M., Yunasfi, Y., Sukirman, E., Sarwanto, Y., & Mujamilah, M. (2021). Structure and Magnetic Properties Of Fe/Si Nanoparticles Prepared by High Energy Milling Process. *Indonesian Journal of Applied Physics*, *11*(2), 239. https://doi.org/10.13057/ijap.v11i2.51029

Rostami, M., Jafarpour, M., & Majles Ara, M. H. (2021). An investigation on the microwave absorption properties of Co–Al–Ti substituted barium hexaferrite-MWCNT nanocomposites. *Journal of Alloys and Compounds*, *872*. https://doi.org/10.1016/j.jallcom.2021.159656

S., R. (2019). Journal of Pharmaceutical Science and Technology. *International Journal of Research and Development in Pharmacy and Life Sciences*, *3*, 1223–1235.

Setiady, D., Sudjono, E. H., Hans, D. Z., & Sutardi. (2020). Kandungan Mineral Pada Pasir Besi di Pantai Loji dan Ciletuh, Kabupaten Sukabumi, Jawa Barat Berdasarkan Data Bor dan Georadar. *Jurnal Teknologi Mineral Dan Batubara*, *16*(3), 125–138. https://doi.org/10.30556/jtmb.Vol16.No3.2020.1117

Setianto, Santosa, B., Hidayat, D., & Panatarani, C. (2017). Quantitative Analysis of Oxide Mixtures as A Basis for Identification of the Content of Natural Resources. Case Study: Mineral Content of Iron Sand on The South Coast, South West Java. *Eksakta*, *18*(2), 173–177.

Silva, E. D. N., Brasileiro, I. L. O., Madeira, V. S., De Farias, B. A., Ramalho, M. L. A., Rodríguez-Aguado, E., & Rodríguez-Castellón, E. (2020). Reusable CuFe2O4-Fe2O3catalyst synthesis and application for the heterogeneous photo-Fenton degradation of methylene blue in visible light. *Journal of Environmental Chemical Engineering*, *8*(5), 104132. https://doi.org/10.1016/j.jece.2020.104132

Simbolon, T. R., Sembiring, T., Hamid, M., Hutajulu, D. A., Rianna, M., Sebayang, A. M. S., Tetuko, A. P., Setiadi, E. A., Ginting, M., & Sebayang, P. (2021). Preparation and characterization of ZnFe2O4 on the microstructures and magnetic properties. *Journal of Aceh Physics Society*, *10*(2), 32–35. https://doi.org/10.24815/jacps.v10i2.18710

Sinuhaji, P., Ginting, M., Sebayang, P., Rianna, M., Hamid, M., Simbolon, T. R., Harahap, V., Tetuko, A. P., Setiadi, E. A., Asri, N. S., Nurdiyansah, L. F., & Sebayang, A. M. S. (2021). Microstructures, Magnetic and Electrical Properties of BaFe12O19/ZnO Composite Material. *International Journal of Electrochemical Science*, *16*, 1–8. https://doi.org/10.20964/2021.08.22

Sismanto, S., Sutanto, Y., Akbar, R., & Alaidin, S. F. (2019). Identifikasi Sebaran dan Kedalaman Pasir Besi Di Daerah Pantai Samas Dusun Ngepet Desa Srigading Kab.Bantul dengan Menggunakan Metode Geofisika Magnetik, Dan Geolistrik. *Jurnal Fisika Indonesia*, *21*(3), 25. https://doi.org/10.22146/jfi.42357

Song, S., & Pistorius, P. C. (2019). Formation of hematite whiskers during magnetite concentrate oxidation. *ISIJ International*, *59*(10), 1765–1769. https://doi.org/10.2355/isijinternational.ISIJINT-2018-755

Suchi Ramadhani Putri, Wulan, R., Ollia, E., Zaldi, D., & Khairul Kamal, F. (2022). Photocatalyst Coating of Mno-Fe2O3Ps From Natural Materials. *Spectrum*, *1*(01), 30–35. https://doi.org/10.54482/spectrum.v1i01.110

Suhendi, E., Amanda, Z. L., Ulhakim, M. T., Setiawan, A., & Syarif, D. G. (2021). The enhancement of ethanol gas sensors response based on calcium and zinc co-doped LaFeO3/Fe2O3 thick film ceramics utilizing yarosite minerals extraction as Fe2O3 precursor. *Journal of Metals, Materials and Minerals*, *31*(2), 71–77. https://doi.org/10.14456/jmmm.2021.21

Surowiec, Z., Miaskowski, A., & Budzyński, M. (2017). Investigation of magnetite Fe3O4 nanoparticles for magnetic hyperthermia. *Nukleonika*, *62*(2), 183–186. https://doi.org/10.1515/nuka-2017-0028

Susanto, E. A., Handoko, E., & Marpaung, M. A. (2014). Material Barium Heksaferrat Tipe-W sebagai Material Penyerap Gelombang Elektromagnetik. *Material Barium Heksaferrat Tipe-W Sebagai Material Penyerap Gelombang Elektromagnetik*, *April*, 78–80.

Susilawati, S., Doyan, A., & Hadisaputra, S. (2022). Analysis Magnetic Mineral Content of Natural Iron Sand in Beach Island Lombok as Basic Materials of Micro Wave Absorbers. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2048–2052. https://doi.org/10.29303/jppipa.v8i4.2274

Susilawati, S., Doyan, A., Taufik, M., Wahyudi, W., Gunawan, E. R., Kosim, K., Fitriani, A., & Khair, H. (2018). Identifikasi Kandungan Fe Pada Pasir Besi Alam Di Kota Mataram. *Jurnal Pendidikan Fisika Dan Teknologi*, *4*(1), 105–110. https://doi.org/10.29303/jpft.v4i1.571

Tadic, M., Kopanja, L., Panjan, M., Lazovic, J., Tadic, B. V., Stanojevic, B., & Motte, L. (2021). Rhombohedron and plate-like hematite (α-Fe2O3) nanoparticles: synthesis, structure, morphology, magnetic properties and potential biomedical applications for MRI. *Materials Research Bulletin*, *133*(July 2020), 111055. https://doi.org/10.1016/j.materresbull.2020.111055

Tadic, M., Panjan, M., Damnjanovic, V., & Milosevic, I. (2014). Magnetic properties of hematite (α-Fe 2 O 3) nanoparticles prepared by hydrothermal synthesis method. *Applied Surface Science*, *320*, 183–187. https://doi.org/10.1016/j.apsusc.2014.08.193

Tadic, M., Panjan, M., Tadic, B. V., Lazovic, J., Damnjanovic, V., Kopani, M., & Kopanja, L. (2019). Magnetic properties of hematite (α - Fe2O3) nanoparticles synthesized by sol-gel synthesis method: The influence of particle size and particle size distribution. *Journal of Electrical Engineering*, *70*(7), 71–76. https://doi.org/10.2478/jee-2019-0044

Tadic, M., Trpkov, D., Kopanja, L., Vojnovic, S., & Panjan, M. (2019). Hydrothermal synthesis of hematite (α-Fe2O3) nanoparticle forms: Synthesis conditions, structure, particle shape analysis, cytotoxicity and magnetic properties. *Journal of Alloys and Compounds*, *792*, 599–609. https://doi.org/10.1016/j.jallcom.2019.03.414

Tan, D., Ma, Y., Li, Z., Jin, J., Liu, R., Zou, X., & Tao, T. (2024). Characteristics of quartz grains in the middle and lower reaches of the Hutubi River, NW China, and its paleo-environmental significance. *Sedimentary Geology*, *459*, 106551. https://doi.org/10.1016/j.sedgeo.2023.106551

Tiwow, V. A., Rampe, M. J., & Arsyad, M. (2018). Kajian Suseptibilitas Magnetik Bergantung Frekuensi terhadap Pasir Besi Kabupaten Takalar. *Sainsmat : Jurnal Ilmiah Ilmu Pengetahuan Alam*, *7*(2), 136. https://doi.org/10.35580/sainsmat7273662018

Togibasa, O., Bijaksana, S., & Novala, G. C. (2018). Magnetic properties of iron sand from the tor river estuary, sarmi, papua. *Geosciences (Switzerland)*, *8*(4), 1–7. https://doi.org/10.3390/geosciences8040113

Trpkov, D., Panjan, M., Kopanja, L., & Tadić, M. (2018). Hydrothermal synthesis, morphology, magnetic properties and self-assembly of hierarchical α-Fe 2 O 3 (hematite) mushroom-, cube- and sphere-like superstructures. *Applied Surface Science*, *457*(June), 427–438. https://doi.org/10.1016/j.apsusc.2018.06.224

Wang, C., Fan, H., Ren, X., Ma, J., Fang, J., & Wang, W. (2018). Hydrothermally Induced Oxygen Doping of Graphitic Carbon Nitride with a Highly Ordered Architecture and Enhanced Photocatalytic Activity. *ChemSusChem*, *11*(4), 700–708. https://doi.org/10.1002/cssc.201702278

Wang, W., Xu, Y., Wang, X., Zhang, B., Tian, W., & Zhang, J. (2018). Hydrothermal liquefaction of microalgae over transition metal supported TiO2 catalyst. *Bioresource Technology*, *250*(October 2017), 474–480. https://doi.org/10.1016/j.biortech.2017.11.051

Widanarto, W., Nurrahman Fauzi, F., Tri Cahyanto, wahyu, & Mukhtar, E. (2015). Peningkatan Sifat Magnetik Material Hematit Melalui Subtitusi Barium Dan Kontrol Temperatur Sintering. *Berkala Fisika*, *18*(4), 125–130.

Widodo, R. D., Priyono, Rusiyanto, Anis, S., Ichwani, A. A., Setiawan, B., Fitriyana, D. F., & Rochman, L. (2020). Synthesis and characterization of iron (III) oxide from natural iron sand of the south coastal area, Purworejo Central Java. *Journal of Physics: Conference Series*, *1444*(1). https://doi.org/10.1088/1742-6596/1444/1/012043

Yulianto, A., Bijaksana, S., & Loeksmanto, W. (2003). Comparative Study on Magnetic Characterization of Iron Sand from Several Locations in Central Java. *Indonesian Journal of Physics*, *14*(2), 63–66.

Zarringhadam, P., & Farhadi, S. (2018). Hydrothermal synthesis of novel magnetic plate-like Bi2O2CO3/CoFe2O4 hybrid nanostructures and their catalytic performance for the reduction of some aromatic nitrocompounds. *Acta Chimica Slovenica*, *65*(2), 448–461. https://doi.org/10.17344/acsi.2018.4224

Zhu, G. T., Hu, X. L., He, S., He, X. M., Zhu, S. K., & Feng, Y. Q. (2018). Hydrothermally tailor-made chitosan fiber for micro-solid phase extraction of petroleum acids in crude oils. *Journal of Chromatography A*, *1564*, 42–50. https://doi.org/10.1016/j.chroma.2018.06.006

Zhu, M., Wang, Y., Meng, D., Qin, X., & Diao, G. (2012). Hydrothermal synthesis of hematite nanoparticles and their electrochemical properties. *Journal of Physical Chemistry C*, *116*(30), 16276–16285. https://doi.org/10.1021/jp304041m