A review on green synthesis and characterization technique for ferrite nanoparticles and their applications

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Abstract
Ferrite nanoparticles have a large interest due to their wide range of applications in biomedical, industrial electronic devices, and wastewater treatment. This review is focused on the green synthesis of ferrite nanoparticles characterization and their application in various field. The green synthesis technique using plant or their extracts are discussed. The characterization techniques of ferrite nanoparticles with their applications are briefly reviewed.

1. Introduction
Ferrite nanoparticles have got to tremendous applications in the field of biomedical, sensors, biosensors, energy storage systems, recording media, data storage, drug delivery, wastewater treatment.[1] They have an advantage in their high electrical resistivity, excellent magnetic properties, Low losses, high initial permeability[2]. The synthesis of ferrite nanoparticles with chemical methods leads to toxicity in the environment and with physical method leads to non-uniform particle size and voids. To overcome the difficulties in the synthesis using chemical and physical methods, the biological methods are eco-friendly alternative to them. Biological synthesis using plants, plant extract, microorganisms, fungi, algae can eliminate the use of expensive and harmful Chemicals, consume less energy. This review will summarise the current status of ferrite nanoparticles using green synthesis techniques, properties, and their applications.

2. Ferrite Nanoparticles
Ferrites are magnetic oxides.Magnetite (Fe₂O₄) also called loadstone was the first known magnetic material. Ferrites have divided into two types according to their magnetic coercivity Hard ferrites are difficult to demagnetize due to their High coercivity. Soft ferrites can easily change their magnetization due to their low coercivity. Ferrites are classified with their crystal structure such as spinel ferrite, garnet ferrite, ortho-ferrite, hexagonal ferrite ferrites have a wide range of applications due to their electrical and magnetic properties and they are easy to synthesize for indoor and outdoor applications.
3. Green Synthesis Of Ferrite Nanoparticles

Synthesis of nanoparticles by using green synthesis techniques have implemented to synthesis ferrite nanoparticles using biological sources such as plants, fungus, algae, microbes. The list was prepared to summarise the research shown in table 1.

3.1 Plant mediated by the synthesis of ferrite nanoparticles

Synthesised magnetic copper ferrite nanoparticles by Green synthesis using tragacanth gum as a reducing agent has revealed the formation of the crystal structure of cubic phase ferrite and the crystalline size of average size with 14 nm. Ali Ramazani et.al.[3] have reported tragacanth gum as a natural reducing agent for the preparation of CuFe₂O₄ offer magnetic nanoparticles by Sol-gel synthesis technique and a single-phase cubic spinel structure was formed. By using green synthesis less time consumed and environmentally friendly approach for the synthesis of magnetic copper ferritenanoparticles without using any organic and toxic chemicals.

The CoFe₂O₄ ferrite and Ag- CoFe₂O₄ synthesized by using Hibiscus Rosa Sinensis. The average crystalline size was obtained 18nm with the spinal type crystal structure. Author Dana Gingasu[4] revealed that Superparamagnetic behavior in nanoparticles. Ni-Zn Fe₂O₄ ferrite nanoparticles were synthesized by using Aloe Barbadensis Miller plant extract. The crystalline size calculated 40.6nm with having a spinal structure. The hysteresis curve shows nanoparticles are superparamagnetic at room temperature.[5]

Cobalt ferrite nanoparticles for synthesized by using range sentences using ginger roots/cardamom seeds aqueous extract. The CoFe₂O₄ resulting spinal type structure with good crystallinity with 100 nm size. This result concludes that the use of aqueous ginger/ cardamom seed extracts in the synthesis of CoFe₂O₄. Author Dana Gingasu[6] conclude ferrite nanoparticle is a promising and eco-friendly alternative.

3.2 Microbe Mediated Biosynthesis Of Ferrite Nanoparticles

Zinc doped Cobalt ferrite nanoparticles synthesized by using Lactobacillus delbrueckii (card). Cubic spinel structure observed in the XRD pattern. the prepared ferrite nanoparticles revealed antibacterial activity is useful in photocatalytic, optoelectronic, and Pharmaceutical applications. [7] Cobalt ferrite (CoFe₂O₄) were synthesized by using Saccharomyces cerevisiae (yeast) 7.23 nm particle size discovered by transmission electron microscope and field-dependent magnetization showed Cobalt ferrite super magnetic at room temperature Saccharomyces cerevisiae synthesized Cobalt ferrite nanoparticles have been reported by Anal K.Jha[8].

![Figure 1. Green Synthesis process by using plant leaf extract](image)
Table 1: Green synthesis of ferrite nanoparticles using biological sources.

| Type of Green Method | Applied Material / Organism | Particle size in nm | Morphology of Nanoparticles | Activity carried out | References |
|----------------------|----------------------------|---------------------|-----------------------------|----------------------|------------|
| Plant mediated synthesis | Tragacanth gum | 14 | Cubic spinel | Catalytic activity and recyclability | [3] |
| | Aloe barbadensis Miller | 34 | Spinel | Super paramagnetic at room temperature | [9] |
| | Zingiber officinale | 46 | Spinel | Cation distribution was influenced | [6] |
| | Ocimum sanctum | 21 | Single-phase cubic spinel | Antibacterial activity against the bacterial strain | [10] |
| | Limonia acidissima | 12-53 | Spherical | Antibacterial activity against Mycobacterium tuberculosis | [11] |
| | Aloe vera extract | 20-66 | Agglomerated cubic | Ferromagnetic behaviour | [12] |
| | Opuntiadelilieni haw | 23-50 | Spherical | Ferromagnetic nature | [13] |
| | Hibiscus rosa-Sinensis | 39-81 | Single-phase cubic | The increasing particle with temperature | [14] |
| | Caffeine | 9.72 | Cubic spinel | Drug delivery | [15] |
| | Okra extract | 47-55 | Spherical | Antibacterial, Antifungal, Drug delivery | [16] |
| | Tragacanth gum | 20 | Cubic spinel | Catalytic activity and recyclability | [17] |
| | Asparagus racemosus root | 48.36 | Spinel | Antibacterial activity | [18] |
| | Aloe vera extract | 14 | Cubic spinel | Photocatalytic activity | [19] |
| Microbe mediated synthesis | Leptothrix discophora | 41 | Spinel | Hollow fiber tube | [20] |
| | Saccharomyces cerevisiae | 7.23 | Spinel | Superparamagnetic at RT | [8] |
| | Lactobacillus delbrueckii | 18 | Cubic spinel | Antibacterial activity | [7] |
| | Honey-mediated | 20 | Octahedron | Change in grain size | [21] |

4. Characterization Of Ferrite Nanoparticles

To understand the importance of ferrite nanoparticles it is necessary to identify their physicochemical properties using relevant techniques that can provide the information of nanoparticles with their magnetic properties, size, and shape elemental structure and bonding, surface morphology, the surface area we can found the properties of ferrite nanoparticles.

4.1 Size And Shape

Nanoparticles size and its shape are the key features of nanoparticles which govern the stability and magnetic properties. The following techniques are used to determination of size and shape of the nanoparticles.

High-Resolution Transmission Electron Microscope (HRTEM) used for direct imaging of the atomic structure of the nanoparticle. Field Emission Scanning Electron Microscope (Fe-SEM) used to determine the ultrastructure of a wide range of nanoparticles. Transmission Electron Microscope (TEM) is a single
particle characterization technique where the beam of an electron accelerated to illuminate thin particles (<100 nm). X-Ray Powder Diffraction (XRD) used to analyze the structure of crystalline nanoparticles based on unit cell dimensions. The average crystallite size determined from average FWHM altering between 17 to 60 nm.[22]

4.2 Elemental And Mineral Composition

*Inductively Coupled Plasma Mass Spectroscopy* (ICP-MS) used for measurement of the element at risk levels in biological fluids. Similarly, *Inductively Coupled Plasma Atomic Emission Spectroscopy* (ICP-OES) and *Inductively Coupled Plasma Absorption Spectroscopy* (ICP-AAS) are used for elemental determination. After solid ferrite nanoparticles dissolved in acid and bases of crystalline nanoparticles. ICP-AES analysis resulting in an accurate ratio of Fe:Ni metals [23].

4.3 Structure And Bonding

*X-Ray Photoelectron Spectroscopy* (XPS) used to determine elemental composition and chemical state, electronic structure, and density of electronic state in the material. The chemical state of NiENK analyzed by the XPS instrument [24]. *Fourier Transform Infrared Spectroscopy* (FTIR) used to identify the molecular components and molecular structure. To study the surface adsorption of functional groups on nanoparticles FTIR is used. FTIR spectrum of MgFe$_2$O$_4$ shown in figure 4. [25]

*Thermogravimetry* (TGA) used to determine any bounded organic content to the surface of ferrite nanoparticles. To analyze the thermal stability of nanomaterial TGA used by heating the sample.

4.4 Surface Morphology

*Transmission Electron Microscope* (TEM) is a technique used to provide compositional morphological and crystallite of ferrite nanoparticles. *Scanning Electron Microscope* (SEM) technique used to determine the surface of the sample with a focused electron beam. *Atomic Force Microscope* (AFM) this technique is a very high-resolution scanning microscope to analyze topography images of nanoparticles.

4.5 Surface Area

*Brunaur-Emmett Teller* (BET) to determine the surface area of arid and particles. BET is used. In this method dry powder of nanoparticles placed in a vacuum and measuring gas absorption on the solid surface.

4.6 Magnetic Properties

*Electron Paramagnetic Resonance* (EPR) technique used to identify the free radical and paramagnetic centers in a chemical reaction. In this technique, microwave radiation utilizes to probe species with unpaired electrons in the sample. *Vibrating Sample Magnetometer* (VSM) is used to measure the magnetic moment and fundamental quantity in the magnetism of the sample. *Superconducting Quantum Interference Device* (SQUID) is used to determined extremely subtle magnetic fields based on superconducting loops.

These characterization techniques are used to investigate saturation magnetization (Ms), hysteresis loop (Hs), and residual magnetization of the ferrite nanoparticles.

5. Applications Of Ferrite Nanoparticles

Ferrite nanoparticles are very useful materials due to their magnetic, electrical, optical, and chemical properties. The use of ferrite nanoparticles in applications such as biomedical devices, electronic devices, and in wastewater treatment, etc.
5.1 Biomedical Applications Of Ferrite Nanoparticles:

Magnetic nanoparticles have opportunities in biomedical applications in the investigation of cancer treatment and infectious disease through enhancing (MRI) Magnetic resonance imaging, magnetic hyperthermia, drug delivery, etc.

*Magnetic Resonance Imaging (MRI):* MRI helps to diagnose and treat medical problems. MRI uses very strong magnets, radio waves with a computer to make detailed pictures inside the body. *Magnetic Hyperthermia In Cancer Therapy:* In this therapy to kill the tumor by hitting it without damaging the tissue. Heat maybe created by radiofrequency, ultrasound energy, microwave, or by using magnetic hyperthermia. *Drug Delivery:* Telepathic viruses to cover the different this is magnetic nanoparticles are being used in recent years. Drug delivery by using magnetic nanoparticles is an efficient fast response and targeted delivery. Magnetic nanoparticles are also used in nucleic acid, biopolymer, and protein-based therapies.

5.2 Electrical Applications Of Ferrite Nanoparticles

*Sensors And Biosensors:* Ferrite nanoparticles are commonly used for sensing to detect or measures physical property or respond to it. Ferrite nanoparticles used for the application in electrochemical sensors, electrochemical biosensors, fabrication of glucose biosensors. 5-fluorouracil anticancer drug sensor used ZnFe$_2$O$_4$ nanoparticles. *Energy Storage:* Ferrite nanoparticles used in energy storage due to their conductivity and surface area. Highly conducting material affects the improvement of electrochemical performance used in ferrite based energy storage devices. *Microwave Device:* Ferrite nanoparticles have properties like low electrical conductivity, dielectric losses, high permittivity, stability, resistivity, Curie temperature having low magnetic losses, and low eddy current due to the remarkable properties these nanomaterials are used in microwave devices.

*Electromagnetic Interference Shielding (EMI):* In recent years, due to the development of electromagnetic radiation emitting devices resulting in EMR pollution effects on the human brain and tissue. To reduce the pollution of EMR on biological eco-system Electromagnetic Interference (EMI) Shielding on electrical devices is used with ferrite Nanoparticles. *Recording Media:* Ferrite nanoparticles have higher Ms, Hs, and lower residual magnetization. Due to this property ferrite nanoparticles are used in applications such as data storage systems, audiocassette, videotape, digital computers, Xerography toners, mobiles, etc.

5.3 Wastewater Treatment: To remove the impurities from the water and wastewater ferrite nanoparticles treatment is used and the water cycle having minimum impact on the environment.

6. Conclusions

In recent times green synthesis technique is highly demanded in the research area. This technique has been president eco friendly and environment bening reducing agent. In the future, this research can be developed by the green synthesis technique will produce desirablenanoparticle size, shape, and properties with improvements. Nowadays, broad research is going in the field of biomedicine sensors, biosensors, energy storage systems, data storage systems. Therefore, the present review will provide green synthesis properties and applications of ferrite nanoparticles.

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