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# A Thorough Study of Zinc Ferrite Nanoparticles with Reference to Green Synthesis

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## Abstract

The preparation of zinc ferrite nanoparticles is a strenuous area of scholastic and, more significantly, “application research” in nanoscience. This review epitomises, in an inclusive introduction, synthesis methods, Influence of rare-earth ions doping and applications of zinc ferrite nanoparticles. A number of chemical and physical techniques could be utilized for the synthesis of these nanoparticles. Notwithstanding, these techniques are loaded with many difficulties containing high energy requirement, use of hazardous solvents and precarious by-products. Consequently, there is an indispensable necessity to disclose nontoxic routes for preparation of zinc ferrite nanoparticles. To utilize the abundance of green resources, available in nature is a covenant way to accomplish this objective. Undeniably, various green resources such as plants, bacteria, algae, and viruses have been employed from several years, for synthesis of economic and environmentally benign nanoparticles. However, circumscribed research has been done in the field of green synthesis of magnetic nanoparticles. This review not only opens avenues for the future scopes in this area, but also highlights the study of new methods for green synthesis of zinc ferrite nanoparticles by plant resources.

**Keywords:** Nanoparticles; Zinc ferrites; Green synthesis; Rare earth ions; Plants

## Introduction

During the last decade, the world has seen huge interest in developing and understanding the matter of nanometric scale. It has allowed the scientists to develop and characterize materials with prominent properties and nanometric sizes. Due to the note-worthy properties, exhibited by nonmaterial, they have become centre of attention in the scientific community. In the last few years renovate interest has been opened up in magnetic particles with the probabilities of applications in the field of nano structured materials technology. Because of the massive specific area, surface effects might be able to include in the magnetism of extra ordinary small particles [1]. The ferrites have been subscribed as classes of magnetic oxide compounds that contain iron oxide as a principal component consist of lanthanides and fast transition metals unusual, iron, chromium, and manganese. The general formula of ferrite is $MM_2O_4$, where M is a rare-earth element (divalent metal ions such as $Fe^{2+}$, $Mg^{2+}$, $Ni^{2+}$, $Co^{2+}$, $Zn^{2+}$, $Cu^{2+}$) and M is iron, chromium, manganese, etc.(trivalent metal ions); that is, $Fe^{3+}$, $Cr^{3+}$, $Al^{3+}$, $Mn^{3+}$ [2]. Ferrofluids are magnetic colloid [3] and can be prepared by mixing of ferrite nanoparticles in water or oil at high concentrations [4]. The coercivity, saturation magnetization and low melting point are the efficient properties of ferrites. These applications of Ferrites can be profitable in many fields. In the structure of spinel ferrite, at tetrahedral (A) and/or octahedral (B) lattice sites oxygen forms a face centered cubic lattice with divalent metal ions. The lattice occupancy of these ions relies on normal, inverse, and mixed spinel structures. The tenancy of these metal ions on this lattice affects the quality of ferrite nanoparticles [5]. The high resistivity magnetic properties of ferrites make them suitable for high frequency applications [6].

In recent years, because of the fabrication of the nanoparticles, innumerable studies have been concentrated to research and enhanced its properties [7]. Zinc Ferrite exposes super paramagnetic behaviour among other ferrites [8]. Zinc ferrite has been extensively employed in different commercial applications such as absorbent materials, photocatalysts, gas sensors, catalysts [9], magnetic resonance imaging (MRI), and Li-ion batteries [8] due to its significant magnetic and electrical properties. Recently, Nano ferrites have been widely examined because they exhibit magnificent physical and chemical properties compete with bulk counterparts [8]. Between structure, composition, and properties of nanoparticle, zinc ferrite set a marvellous example of direct relation. When prepared as a bulk material, the zinc-iron oxide has a spinel structure $AB_2O_4$ with a tetrahedral a site occupied by $Zn^{2+}$ ions and an octahedral B site by $Fe^{3+}$ ions. Based on the distribution of cations, spinels can be either normal like zinc spinel or inverse with half of the trivalent ions in the tetrahedral position and the other half together with the divalent ions in the octahedral sites [10]. To prepare high electromagnetic zinc ferrites, various synthesizing methods have been reported, including *in situ* precipitation method [11], high-energy ball milling [12,13], Facile polyol process [14], reduction roasting [15], hydrothermal technique, advanced combustion route [16], co-precipitation [17-19], solvothermal method [20], Ferroceny precursor method, ultrasonic cavitation, microwave-assisted synthesis [21], thermal plasma [9], micro-emulsion process, combustion front quenching method (CFQM) [22], sol-gel auto combustion method [23,24], chemical precipitation method [25], self-propagating low-temperature combustion method [26], auto combustion technique [27] and conventional method [28] etc. However, some of the above methods faced problems such as non-uniform particle size and contain impurities, which impose further advancement in the achievement of the products [7].

To surmount the problems, revealed with the above-described methods, is indispensable to coat magnetic nanoparticles with a surfactant and different capping agents to stabilize nanoparticles during fabrication

[29]. By manipulating the size of ferrite nanoparticles their properties can be changed, which is beneficial in constructing new composite materials with proficient properties in different field of applications [30].

The properties of a spinel material can be change to meet the needs of a particular application. Ferrites are generally synthesized by a ceramic process. The particles obtained through this process are indifferent in size. As result, these indifferent particles indicate various problems. Recent studies revealed that inorganic materials are the key of future developments in industrial and technological fields. During the yestyears, the most examined materials were the ones with magnetic behaviour due to their assuring applications. Presently, various types of magnetic NPs are utilized for magnetic separation, drug delivery, hyperthermic treatment of tumors [31], as MRI-contrast [32], magnetic data storage, gas sensors, tunnelling magneto-resistance (TMR), ferrofluid, magnetic field assisted radionuclide therapy as well as magnetically separable absorbents. Right now the utilization of magnetic nanoparticles for magnetic bioassays are most common, as their physical properties grant faster assay and in some cases enhance sensitivity over currently available commercial methods [33]. Zinc oxide nanoparticles are most applicable in the field of biomedical applications amongst materials with magnetic properties because of their established biocompatibility [1].

To fabricate various types of nanoparticles, a large number of methods are used such as physical, chemical, biological, and hybrid methods. The nanoparticles synthesized using each method exhibit particular properties. To prepare nanoferrites with simple routes by using cheap, non-toxic and eco-friendly precursors are still the core issue, among other proven synthesis methods [34]. Furthermore, the interconnection between inorganic molecules and biological structures is one of the most electrifying fields of investigation in modern nanoscience and technology [35]. However, green synthesis of metal nanoparticle by plants is still under process. Green nanotechnology has pulled a lot of attention and involves a vast range of processes that remove adverse substances to restore the environment [36]. There are huge green resources available in nature including fungi, algae, yeast, bacteria, viruses, plants and plant products which can be used for fabrication of nanoparticles. Of note, it is well known that intracellular or extracellular inorganic materials could be prepared by both unicellular and multicellular organisms [37]. Other than this, vitamins such as B1, B2, C, and tea could be successfully employed as reducing and capping agents to produce nanoparticles. They also eliminate the need of toxic reducing agents under sustainable strategy [38].

## Synthesis methods of Zinc Ferrite Nanoparticles with Inclusion of Different Elements

The densification and electromagnetic properties of ferrite can be efficiently improved by using $Zn^{2+}$. To enhance magnetization, $Zn^{2+}$ is included in spinel ferrite [39]. Now a day's different synthesis methods of zinc ferrite nanoparticles with versatile applications have attracted research interest. During the preparation of zinc ferrite nanoparticles several factors such as nucleation, growth, aggregation and adsorption of impurities affect the morphology of prepared particles. Though, in several cases it is not possible to obtain perfect sized and shaped nanoparticles. In recent years, various preparation methods have emerged to fabricate controlled, stable, biocompatible, and mono-dispersed zinc ferrite nanoparticles. The most familiar methods for the synthesis of high quality zinc ferrite nanoparticles are co-precipitation method [40-42], Sol-gel method [43,44], hydrothermal synthesis, Thermal Treatment Method, Conventional ceramic method and Microwave combustion method. The following sections briefly review the typical and recent synthetic pathway with the corresponding formation mechanism.

### Co-precipitation method

For the synthesis of zinc ferrite nanoparticles the co-precipitation technique is probably the uncomplicated and most productive chemical route. This method also provides favourable production of nanoparticles [45-47]. However, only kinetic factors are commanding the growth of the crystal due to which the control of particle size distribution is restricted. To command magnetic behaviour, Size and surface properties during the fabrication of iron oxide nanoparticles a lot of factors can be arranged. By maintaining pH, temperature, ionic strength, nature of the salts, or the Fe(II)/Fe(III) concentration ratio the shape and size of the nanoparticles can be customized [48].

Magnetic $CO_{(1-x)}ZnxFe_2O_4$ (x=0.25, 0.50, 0.75) ferrite nanoparticles were prepared in an alkaline medium by using aqueous salt solutions ($FeCl_3.6H_2O$, $COCl_2.6H_2O$, and $ZnSO_4.7H_2O$) by co-precipitation method. Oleic acid was used as a surfactant, to form the waterproofing shell around the magnetic nanoparticles and prevent the agglomeration of them. A single domain of magnetic nanoparticles forms colloidal systems which are ferrofluids with a mean diameter around 30 nm. Energy Dispersive X-ray Spectroscopy and X-ray diffraction characterized the structure and composition of the sample. The particle size of prepared nanoparticles was studied by TEM in the range of 10-50 nm. In this study, the authors proved that with the increase of the Zn at % the coercive field of prepared nanoparticles, the sizes and crystal, decrease and hence they are considered as soft magnetic material given that the hysteresis loop is small [49].

Authors have fabricated Co–Zn substituted ultrafine particles of $Co_{1-x}Zn_xFe_2O_4$ with x varying from 0.1 to 0.5. The synthesis of nanoparticles was carried out by coprecipitation method using Oleic acid as a surfactant. XRD, TEM, VSM and Mossbauer studies were used to characterize the prepared sample. The TEM technique determined the size of prepared nanoparticle up to 50 nm. As zinc substitution increase the magnetic parameters and particle size were found to decrease. In this study, authors have established that the prepared nanoparticles were used to form ferrofluid and these ferrofluids can be effectively used for the energy conversion application utilizing the magnetically induced convection for thermal dissipation [50].

Here researchers have focused on the preparation of pure and Gd-doped $Mn_xZn_{1-x}Fe_2O_4$ via a modified coprecipitation approach. The characterization of prepared nanoparticles was carried out by various techniques by which it was confirmed that under optimum conditions pure and Gd-doped nanoparticles were enlarged from 11nm up to 18nm. The prepared nanoparticles are suitable candidate materials for magneto caloric pumping applications [51].

### Sol-gel method

The sol-gel technique is a low-temperature technique that provides economic products with perfect chemical composition. The materials produced by this method exhibited different applications in electronics, optics, space, energy, etc. In this method, during the solid state calcinations the preparation of a gel cut downs the demand for atomic diffusion and offers a superior degree of homogeneity. Followed by conversion into a homogeneous oxide (gel) after hydrolysis and condensation, a solution of the appropriate precursors is obtained first. Generally for the production of multicomponent oxides, alkoxides are putted together in alcohol. In some cases salts, such as acetates are used in place if alkoxides. In sol gel method water, alcohol, pH, concentration of alkoxides and controlled temperature required for hydrolysis.

According to Azadmanjiri [52] for the synthesis of nano-sized Ni–Zn ferrites sol–gel combustion method is convenient. As raw materials author used $Zn(NO_3)_2$•$6H_2O$, $Fe(NO_3)_3$•$9H_2O$, $Ni(NO_3)_2$•$6H_2O$ and citric acid. By using ammonia the pH value of the solution was maintained at 7. In this method gel is allowed to ignite in air after this it exhibited a self-propagating behaviour. With the help of this method author investigated that how Zn influenced the electromagnetic properties such as dielectric constant (ε'), complex dielectric constant (ε") and dielectric loss tangent (tanδ) of prepared nanoparticles. As zinc increase these values decrease. For identification and characterization of prepared sample XRD and EDX with Cu Kα radiation were used. VSM and impedance analyzer were used to determine the Magnetic and electromagnetic properties of prepared sample. The X-ray peak broadening of the (311) peak using Scherrer's formula calculated the crystal size of the prepared powder in the range of 73–80 nm. Researcher has claimed that the prepared nanoparticles could be used for several applications such as economical electronic materials with high performance because they possess good electromagnetic properties, as well as fine-grained microstructures.

Preparation of magnesium and copper doped Lithium zinc ferrites presented by Cao et al. [53] via sol–gel and subsequent calcination methods. Structural and crystalline nature of prepared particles characterized by SEM and XRD and the results showed that there is no difference between pure and doped sample. Investigators proved that microwave-absorbing properties were improved by doping with copper, while doping with magnesium had small improvement on microwave-absorbing properties of the sample. To enhance low-frequency microwave absorption the doping amount of copper in prepared sample should be investigated by authors in there further research.

### Hydrothermal method

Due to strong correlation between magnetic properties and some parameters such as controlled size and shape zinc ferrite nanoparticles are now become technologically significant. Some traditional routs like micro emulsion and thermal decomposition not only intricate the process but also demand high temperatures. As an alternative, hydrothermal route crystallized the substance in a sealed container from the high temperature aqueous solution at high vapor pressure by incorporating several wet chemical technologies. The grains produced in hydrothermal technique exhibited good crystallinity compared with other techniques, and to grow dislocation-free single crystal particles hydrothermal route has also been utilized, therefore hydrothermal synthesis is the most efficient pathway to acquire the extremely crystalline nanoparticles [54]. Many authors have presented the preparation of zinc ferrite nanoparticles by hydrothermal method.

For example Yu et al. [55] have used hydrothermal reaction for the fabrication of zinc ferrite nanoparticles in this technique they choose metal Zn sheet and FeCl2 as reactants in ammonia solutions at 180°C. Here authors prepared 300nm sized particles with octahedral shape. With the help of this, researchers have found that the preparation of $ZnFe_2O_4$ nanoparticle affected by concentration of ammonia solution, reaction time and the reaction temperature and they also proved that for the synthesis of high quality zinc ferrite nanoparticle hydrothermal technique is an effective pathway.

Here researchers Rath et al. [56] have demonstrated preparation of $Mn_{0.65}Zn_{0.35}Fe_2O_4$ nanoparticles a via hydrothermal precipitation route using aqueous ammonia as a precipitant from a solution of metal chloride. The prepared sample was characterized by TEM, VSM and XRD techniques. XRD investigated the crystallite size of the nanoparticles. Morphology and particle size were measured by TEM and the size of prepared nanoparticles was obtained in the range of 9-12 nm. The magnetic measurements of prepared sample were observed by VSM. The magnetic parameters such as remanent magnetization, coercivity and saturation magnetization were enhanced by applied magnetic field of 5 kOe. Through measuring magnetization the transition from ferromagnetic to paramagnetic state was observed.

### Thermal Treatment Method

Naseri et al. [57] used thermal treatment method to prepare nano sized particles of zinc ferrite. According to researchers this method is easy, economic and environmentally benign. With the help of this method pure, crystalline nanoparticles can be prepared. In this method the nanoparticles were stabilized by Poly vinyl pyrrolidon (PVP) which is a capping agent and calcined at different temperatures from 723 to 873K. The prepared nanoparticles characterized by various techniques such as XRD, TEM, FT-IR and VSM. The formation of $ZnFe_2O_4$ nanoparticles confirmed by XRD patterns and TEM images determined the sizes of particle from 17–31 nm. The absence of organic bands and presence of metal oxide bands showed through FT-IR. Vibrating sample magnetometer confirmed that the calcined nanoparticles exhibited super paramagnetic behaviours. Authors substantiated that the values such as coercivity and saturation magnetization based on the synthesis methods of the sample. The existence of unpaired electrons revealed through EPR spectroscopy.

Via thermal treatment method Leng et al. [58] have prepared nano sized particles of Ni-$ZnFe_2O_4$ by using deionized water as a solvent, metal nitrates as precursors and polyvinyl pyrrolidone as a capping agent to stabilized the particles. XRD, TEM and VSM were used to confirm the structure and particle size and magnetic properties of prepared sample. With the help of this researchers have investigated as the calcination temperature increases from 723 to 873 K the size of the particle increases from 7 to 25 nm and magnetization saturation also increases from 11-26 emu/g. FTIR determined the removal of all organic matters and presence of metal oxide bands. According to researchers thermal treatment is an eco-friendly method for the preparation of nanoparticles.

### Microwave combustion method

According to Kooti and Naghdi Sedeh [59] for the synthesis of ferrite nanoparticles several methods are available, among these methods; microwave combustion synthesis route has pulled attention of researchers due to its various qualities. Therefore, authors have used microwave combustion technique for the preparation of three nanocrystalline ferrites incorporating $MnFe_2O_4$, $ZnFe_2O_4$ and Mn-Zn-$Fe_2O_4$. To support sustainable combustion reaction, glycine was taken as a fuel during the synthesis of nanoparticles. The characteristics of prepared nanoparticles were studied by several techniques where, the BET and BJH methods were used to confirm the specific surface area and pore size allocations of the prepared particles, TEM and FESEM determined the particles size in the range of 25 nm and magnetic properties were obtained by VSM, respectively. Here investigators have proved that, the microwave combustion method is most suitable technique for the synthesis of nanoparticles and it can be possibly employed for the preparation of other ferrites.

### Conventional ceramic method

By the Substitution of Non-magnetic Al–Ion [60] improved of the Magnetic Properties of Mn-Ni-Zn Ferrite. With the help of this researchers substantiated that the initial permeability and saturation magnetization both improved by Al-ion substitution, porosity increases while the lattice parameter decreases and they also claimed that for all substituted samples the dc resistivity and Curie temperatures increased. In this study, authors have established that the prepared particles can be effectively used in high frequency applications.

### Green synthesis

Due to high coercivity and super paramagnetism like uncommon properties magnetic nanoparticles have come to light in the utmost few years. But the conventional synthesis routes of these nanoparticles are facing several restrictions.

Indeed, there are various green resources like micro-organisms and plants are available for the synthesis of nanoparticles. Recently, plant based green synthesis of nanoparticles have attracted the attention of researchers. The extract of plants not only reduces the metal ions in a shorter time but also provides high – yield nanosized particles. The preparation time of nanoparticles depends upon the variety of plants and the concentration of phyto-chemicals. Notwithstanding, plant based green synthesis of magnetic nanoparticles is still under research and a number of papers regarding this subject have published in recent four years [61].

Pattanayak and Nayak [62] have reported the green synthesis of iron nanoparticles by using the extracts of 10 different plant species that included Curry leaves, thymol seeds, origano leaves, Cumin seeds, Rose leaves, Coffee seeds, Green tea leaves, Black Tea, Clove buds, Mango leaves. With the help of this investigation authors have established that, the green synthesis route is not only environmentally benign but it is also cheap nontoxic and user friendly. In this research XRD, SEM, TEM and FTRI characterization techniques were used for the study of prepared nanoparticles.

Recently, Shah et al. [63] have fabricated 13-21 nm nano sized iron particles by using the extract of plant parts such as *Cymbopogon citrates, Calotropis procera, Datura innoxia, Tinospora cordifolia, Tridax procumbens* and *Euphorbia milii* with the reaction of ferric chloride. It is well known that, now-a-days plant parts are used for stabilizing and for the prevention of agglomeration of nanoparticles. The prepared nanoparticles were characterized by UV-vis absorption spectrophotometer, transmission electron microscopy (TEM) and dynamic light scattering (DLS), particle size analyzer.

Dhuper et al. [64] have adapted green route and presented the formation of nano sized zerovalent irons by using *mangifera indica* plant extract. Authors have claimed that 50-100 nm sized prepared nanoparticles are non toxic ecofriendly and biocompatible. Thus, green route is a substitute to chemical synthesis protocols and provides cheap and non toxic agents for the formation of nanoparticles.

Kumar et al. [65] and Dora et al. [66] have synthesized nanosized Ni-Zn-ferrite and Mg-Zn ferrite particles by adapting green route via modified sol-gel method in which aloe vera plant extract was used as a precursor. X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FT-IR), transmission electron microscopy (TEM) and Vibrating sample magnetometer (VSM) were used to determine the structural characteristics, Magnetization measurements and size of the particles. The investigators have established that the aloe vera plant extract as a precursor is not only inexpensive and user friendly but it also serves high production with perfect structure and particle size.

Palanisamy et al. [29] have presented the Synthesis, characterization and implication of iron oxide nanoparticles by using co-precipitation technique and the nanoparticles were stabilized with olive oil (bio surfactant). The Prepared nanoparticles were characterized by different techniques where size of the nanoparticles confirmed by TEM in the range of 20-50 nm. Investigators have also suggested that the prepared nanoparticles coated with bio surfactant can be used as antibacterial agent.

## Influence of Rare-Earth Ions Doping in Zn Ferrite Nanoparticles

Now-a-days the creation of advanced materials with improved properties and novel synthesis pathway withstands the enhanced technological need, have attracted the considerable attention of many researchers. Presently nano materials are the core of interest due to their note-worthy physical and chemical properties with wide technological applications. It is well known that ferrites nanoparticles are responsive to the preparation routes, therefore composition and micro structures can be easily affect the magnetic, structural and chemical properties of nanoparticles [67]. The physical and chemical properties of spinel ferrites also based upon the quality of do pant and the distribution of cations in tetrahedral and octahedral sites. The high-frequency applications of ferrites directly related with its high resistivity [68].

Many researchers have focused on the inclusion of rare earth metal ions into the zinc ferrite structure to significantly enhance the electrical and magnetic properties, But only circumscribed literature is present on the effect of rare earth metal ion inclusion on the properties of ferrite nanoparticles [69].

Naidu et al. [70] have prepared $ZnFe_2O_4$ nanoparticles via sol-gel method with Ni, and Sm. The size of Sm doped Zn-ferrite nano particles determined by SEM monographs. XRD analyzed the structure and composition of particles and the magnetic behaviour of prepared particles confirmed by VSM studies. According to investigators if the ionic size is small during the synthesis it consequent easier growth of particles and they also proved that as the Sm increased the coercive force and Saturation magnetization also increased which caused nano size of the ferrite particles. Authors established that the prepared particles can be effectively used in antenna construction and miniaturization process of several microwave components.

Through the substitution of rare earth $Nd^{3+}$ ion Eltabey et al. [71] improved the magnetic properties for Mn–Ni–Zn ferrites. Researchers investigated the composition dependence of the physical and magnetic properties by preparing $Mn_{0.5}Ni_{0.1}Zn_{0.4}Nd_xFe_{2x}O_4$ ferrite with the help of ceramic method. SEM and EDX confirmed that the average grain size is not affected by substitution of $Nd^{3+}$ ion. Where as its concentration in the grain is lower than that in the grains boundaries. Saturation magnetization increased and reached a maximum value with the $Nd^{3+}$ ion concentration.

Through sol–gel technique Jacob et al. [69] have been fabricated Ni–Zn ferrite with the doping of Terbium. The characterization of prepared sample by using XRD showed the formation of single phase FCC spinel structure. Investigators demonstrated that the properties, structure, size and AC conductivity of prepared sample influenced by the doping of $Tb^{3+}$.

Papa et al. [72] investigated the catalytic activity of simple and neodymium substituted zinc ferrites for coupling oxidative of methane (OCM) reaction. In this experiment Pure and neodymium substituted zinc ferrites synthesized via combustion method. With the help of this experiment authors proved that for OCM reaction the completely substituted ferrite ($ZnNd_2O_4$) and the pure ferrite ($ZnFe_2O_4$) were the most active catalysts.

## Applications

### Biomedical applications of zinc ferrite nanoparticles

Noteworthy attention has arisen in the investigation of nanoparticles during the utmost few years, specifically in biomedical fields. The merging of nanotechnology into the area of medical science has unlocked new probabilities. Recently, Molecular biology is comprehended by further research of nanoparticles. As a result, there are various techniques have emerged for the remedying of diseases which were inconceivable before now. At present the fabrication of bio functional nanoparticles is the core of interest of various researchers for making this field advanced for biomedical applications.

Blanco-Andujar et al. [73] have presented Carboxyl dextran coated of Mn/Zn ferrite NPs which make them steady under physiological states. They also investigated the betterment of nanoparticle's colloidal stability and the involvements of bio molecules, based on the working of nanoparticles. According to them during the synthesis of ferrite nanoparticles, employment of an alcohol-based ligand upgrades ligand exchange.

During the last decades, the most investigated nanoparticles were the ones with magnetic properties because of their potential applications in fields such as magnetically separable absorbents, magnetic field assisted radionuclide therapy, Sensors, Catalysts in Biotechnology, hyperthermia, contrast agents in MRI, targeted drug delivery, ferrofluid, tunnelling magneto-resistance (TMR), gas sensors as well as magnetic data storage. Among these applications zinc ferrites are most efficient in biomedical field because it's substantiated biocompatibility [1].

According to Raj Kumar et al. [1] Mn-Zn ferrite losses low power and shows high magnetic permeability. Therefore they prepared $MnZnFe_2O_4$ via Solution Combustion Method in the range of 10-40 nm. These prepared particles can be effectively used in several biomedical applications such as Drug delivery Application, anti-bacterial, antifungal and conducting properties for electronic applications.

For biomedical applications Joseyphus et al. [74] have fabricated ferrite nanoparticles with the help of aqueous process. In this paper investigators substantiated that due to high magnetization-temperature gradient and low Curie temperature Mangenese zinc ferrites can be utilise for various biomedical applications such as drug delivery systems and medical diagnostics and ferrofluids.

**$ZnFe_2O_4$ as novel T1 MRI contrast agents:** Zinc ferrites have been actively sought because of its intriguing magnetic properties. Zinc ferrite nanoparticles also exhibit low toxicity in place of other metallic cations. Hence it can be easily substantiated that zinc ion incorporation should be a better option to improve novel non-lanthanide-based MRI contrast agents.

Wan et al. [15] successfully prepared 6nm nanosized $ZnFe_2O_4$ particles through polyol process. For colloidal stability researchers stabilized the nanoparticles by using a layer of hydrophilic polyol and the Preliminary cytotoxicity tests confirmed that the prepared particles are not toxic in nature. With the help of this investigators have established that as novel T1 MRI contrast agents the zinc ferrite nanoparticles can be efficiently used in place of conventional iron oxide particles and gadolinium chelates.

**Cytotoxicity effect of $ZnFe_2O_4$ on cancer cells:** For the first time Gahrouei et al. [75] have investigated the influence of cytotoxicity of Cobalt-Zinc Ferrite Magnetic Nanoparticles on human prostate cancer cell lines. According to researchers the cytotoxicity of nanoparticles is highly being attracted for various biomedical applications. In this research they also prepared DMSA coated Cobalt-Zinc Ferrite Magnetic Nanoparticles for better results. With the help of this research authors have substantiated that at high concentrations DMSA coated Cobalt-Zinc Ferrite Magnetic Nanoparticles exhibited some cytotoxicity on human prostate cancer cell lines.

## Zinc ferrite as catalyst

Due to large surface area now-a-days nanopartticles are widely used in the field of catalysis [38]. The Catalytic applications of ferrites with lanthanides and commonly with cobalt, nickel, copper, zinc have reported by many researchers. Recently with maintaining magnetic properties silica and titania are successfully incorporated in Core–shell nanostructures. C–C coupling, alkylation, oxidation, reactions of dehydrogenation, decomposition etc are the main applications of ferrite nanoparticles. The most important advantage of ferrite nanoparticles is that it can be employed in various reactions without deprivation of its catalytic activity [76].

According to Kharisov et al. [76] the oxidative conversion of methane and oxidative coupling of methane by non-nano-sized pure and neodymium substituted zinc ferrite as catalyst was investigated. In this investigation it is proved that the neodymium substituted ferrites exhibited low activity in coupling reaction while pure zinc ferrite ($ZnFe_2O_4$) and $ZnNd_2O_4$ were highly active.

In further Kharisov et al. [76] have reported the synthesis of Zinc ferrite nanopowders in the range of 5–45 nm via co-precipitation method by using nitrate precursors. In this research the investigators have proved that the prepared zinc ferrite nanopowders are efficient catalysts as they successfully decomposed methanol to CO and hydrogen.

Semiconductors, magnetic resonance imaging, computer memory chips, pigments are such effective applications offered by ferrites due to their most efficient electrical, dielectric and magnetic behavior. Alkylation of hydrocarbons, photocatalytic ozonation of dyes, phenol hydroxylation (oxidation), and treatment of automobile-exhausted gases, decomposition of alcohols and hydrogen peroxide and oxidative dehydrogenation of hydrocarbons are such industrial processes in which the catalytic characteristics of ferrites have been employed. The study of Nanocrystalline zinc ferrites 6–45 nm sized with cubic structure prepared by co-precipitation method proved the catalytic activity in methanol decomposition to CO and hydrogen. With the help of this it is established that ferrite materials exhibited good catalytic activity and selectivity to CO in methanol decomposition [76].

**Zinc ferrites as heterogeneous photo-fenton catalysts:** Anchieta et al. [21] investigated the catalytic activity of zinc ferrite for the organic pollutant decomposition by heterogeneous photo-Fenton reaction. $ZnFe_2O_4$ nanoparticles were prepared by using ethylene glycol and 1,4 butanediol as solvent diols through solvothermal method. As a result higher catalytic activity for the pollutant degradation was found. $ZnFe_2O_4$ particles can be effectively used as a heterogeneous photo-Fenton catalyst for the degradation of Procion red dye in the presence of visible light.

**Zinc ferrite for dye degradation:** Now-a-days developing countries are facing a difficulty to treat wastewater due the presence of dye. These dyes are very hard to degrade as they are having complex aromatic structure. In water they undergo in many processes like hydrolysis and oxidation as a result they create carcinogenic by-products. Therefore, it becomes mandatory to degrade these dyes for public fitness and safety. Recently, Mahmoodi et al. [78] have established that the zinc ferrite nanoparticles are most efficient for the elimination of organic and inorganic pollutants present in water.

Mahmoodi et al. [78] studied the photocatalytic dye degradation and mineralization ability of zinc ferrite nanoparticle from colored wastewater in the presence of hydrogen peroxide by using Reactive Red 198 and Reactive Red 120 as model dyes. In which they evaluated the dye degradation from the effects of $ZnFe_2O_4$ dosage, salt and initial dye concentration. The results substantiated that to degrade dyes from colored wastewater $ZnFe_2O_4$ could be efficiently used as a magnetic photocatalyst.

**Zinc ferrite as photocatalyst under visible light:** For the decomposition of toxic gases, photo electrochemical or solar cell devices and in water splitting for hydrogen energy production photocatalysts have attracted much interest because of its high-effciency.

Jang et al. [79] synthesized zinc ferrite with a spinel crystal structure via solid-state reaction method. Here researchers investigated the photocatalytic activity of $ZnFe_2O_4$ by using the photo-decomposition of isopropyl alcohol under visible light (420 nm) and it is found to be much a more active photocatalyst than the recently reported $TiO_{2x}N_x$ photocatalyst. Here Authors proved that for the decomposition of toxic gases $ZnFe_2O_4$ can be used as an active photocatalyst under visible light.

In further Jang et al. [80] have investigated the photoelectric and photocatalytic properties of Spinel-type zinc ferrite with high crystallinity, homogeneity and surface area which was successfully synthesized by polymerized complex method. It was found that the photo-degradation activity of zinc ferrite fabricated by PC method is greater than that fabricated by SSR method as well as to that of $TiO_{2-x}N_x$. Here Authors proved that for the decomposition of toxic gases $ZnFe_2O_4$ prepared by PC method can be used as an active and more efficient photocatalyst under visible light than the zinc ferrite prepared by SSR and $TiO_{2-x}N_x$.

### $ZnFe_2O_4$ as Sensors

There has been renewed interest in spinel ferrites with the probabilities of applications opening up now days. Consequently, these ferrites are now extensively utilizing as sensing elements. Ferrites could be employed as humidity/gas sensor materials because they are very sensitive with these parameters. The porosity of ferrites is a beneficial property which is very essential for sensor. The size of pores not only affects the sensor but they also serve adsorption sites for humidity/gases. Srivastava and Yadav [2] have reported the alteration in sensitivity for some sensing elements such as $CuFe_2O_4$, $CdFe_2O_4$, and $ZnFe_2O_4$ at various concentrations of gas with temperature. The ferrite sensors dependent on electrical resistivity exhibited wide applications with various properties.

### $ZnFe_2O_4$ as corrosion inhibitors

Now-a-days nanoparticles have been emerged as playing a vital role to inhibit the corrosion. There are some chemical substances which act as a corrosion inhibitors applied on corrosive surface. The satisfactory inhibitors have many properties such as effortless production, low toxicity, low price and high inhibition efficiency. Some nanoparticles are not only exposing such properties but they are also environmentally benign. Iron oxide nanoparticles showed high corrosion inhibition efficiency because they have superior stabilizing proficiency. Therefore, to obtain good corrosion protection, olive oils as natural stabilizing agents are taken with iron oxide nanoparticles and coated on mild steel after storage of six months at room temperature. For the formation of iron oxide nanoparticles as stabilizing agent green synthesis mechanism was employed by adding olive oil as natural agent. At the end the results indicated that the olive oil stabilized nanoparticles exhibited high inhibition proficiency with greater anticorrosion behaviour [81].

## Conclusions and Future Outlook

- Ferrite Nanoparticles have been a steadfast source of research. These nanoparticles have received much attention for their paramagnetic properties.
- Medicine, catalyst, Sensors, magnetic storage, Corrosion inhibitors and water purification etc. are such applications of ferrite nanoparticles.
- Among ferrites, zinc ferrite nanoparticles have multifunctional characteristics which prove to be most promising and active research area in advanced materials.
- Zinc ferrites, both doped and undoped, are attractive candidates in a wide range of application. They also have promising scope in the development of water treatment and water purification.
- In research field, till date, we are enlightened by the work on preparation of zinc ferrite nanoparticles prepared by several methods such as sol-gel, co-precipitation and hydrothermal. These are most commonly used methods for synthesis of zinc ferrite nanoparticles.
- But the preparation methods of ferrite nanoparticles have not been explored exhaustively. The methods used, by the time, are based on chemical route, resulting chemically prepared nanoparticles which are toxic in nature.
- Most of the chemical methods are not able to reduce particle size at nano level but green synthesis route has made it possible based on the usage of available plants. It is not only economic but can prepare non toxic nano size particles also.

Therefore, it becomes mandatory to go for advanced, detailed and systematic study on green synthesis of zinc ferrite nanoparticles.

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