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Physical, spectroscopic and antibacterial investigation of $Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ via temperature dependent hydrothermal approach

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Highlights

- Polycrystalline magnetic nanoparticles (MNPs) of $Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ Spinel ferrite were synthesized using a hydrothermal technique (pH-12) at sealing temperatures of 160°C, 180°C and 200°C for 18h.

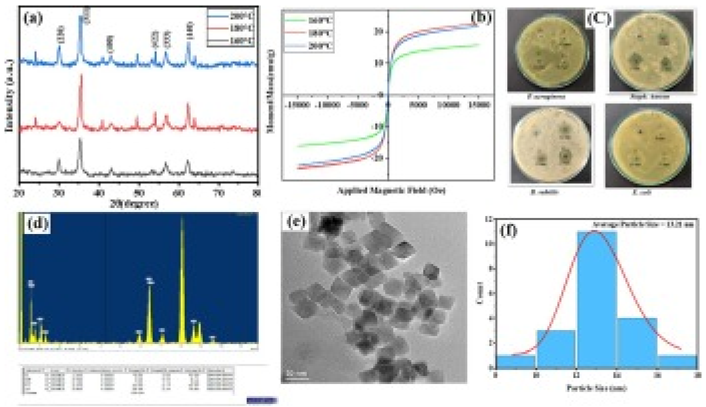
- The detailed investigation of synthesized spinel ferrite was committed by XRD, TEM, EDS and FTIR.
- Magnetic Study indicates superparamagnetic nature of synthesized MNPs.
- The dielectric properties of synthesized MNPs were studied which was found to be influenced by sealing temperature of hydrothermal approach.
- Antimicrobial Activity of synthesized MNPs have been studied on different pathogens.
- The superparamagnetic, antimicrobial efficacy and dielectric character of the produced MNPs strongly suggests that these materials could be used in therapeutic, biomedical and electronic applications.

Abstract

$Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ spinel ferrite magnetic nanoparticles (MNPs) were synthesized with sealing temperatures of 160°C, 180°C, and 200°C by hydrothermal route. The physicochemical parameters of synthesized MNPs were investigated by XRD, FTIR and VSM. The X-ray diffraction reveals the more crystallinity with temperature hence crystallite size (12nm-18nm). The functional group analysis by two strong absorptions within 400–600 cm^{-1} of FTIR and elemental analysis (EDS) confirms spinel ferrite MNPs. The M-H loop with minimal saturation Magnetization M_S (15.90, 22.96, 21.96 emu/g), Coercivity H_C (21.04, 22.69, and 20.63 O_e) and remnant magnetization M_r (0.64, 0.81, and 0.78 emu/g) as recorded by VSM. Particle size obtained by TEM signifies superparamagnetic nature of MNPs. The dielectric properties of MNPs with frequency were recorded using Impedance spectroscopy which were found to be influenced by crystallization. The dielectric constant of all samples decreases with rise in frequency, indicating dielectric dispersion at lower frequencies, possibly due to interfacial polarization. The antibacterial efficacy of MNPs against different gram positive and gram-negative bacteria was demonstrated by Zones of inhibition.

Graphical abstract

Figure:- Structural (Fig a), Magnetic (Fig b), antibacterial (Fig c) and morphological study (Fig d,e & f) of synthesized MNPs at different sealing temperature.



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Introduction

The nanostructured magnetic materials are in the recent trend of nano science and nano technology field due to their application potential in the wide range from industrial to biomedical field [1]. Ferrites are the magnetic material with Iron Oxide as a Key Component and show outstanding properties due to their good chemical stability, high resistivity, low dielectric losses, and tuneable magnetic properties. Out of various types of ferrites, spinel ferrite is soft magnetic material with chemical composition AB_2O_4, where A and B refer to divalent and trivalent metal ions respectively. The spinel ferrite displays exceptional properties with multifunctional nature applicable in drug delivery, bio-separation, absorbent materials, data processing devices, magnetic refrigeration systems, gas sensing, ultrahigh density(UHD) recording, magnetic resonance imaging (MRI), multilayer chip inductor(MLCI), microwave - radio frequency devices and electromagnetic interference (EMI) suppression [2]. The wide application area of spinel ferrite MNPs mainly depends on various structural, spectroscopic and magnetic parameters [3]. The spinel ferrite MNPs is synthesized by various effective bottom-up chemical routes. Some of them are hydrothermal/solvothermal, sol–gel auto-combustion, Co-precipitation and many others [4]. The physical and chemical properties of synthesized MNPs will decide the application area greatly affected by synthesis method, cation distribution and processing temperature [5].

The spinel ferrite MNPs, especially Mg-Zn ferrites have attained substantial recognition because of their adequate significance for applications in technology that includes biomedical diagnosis, MLCI, magneto calorific refrigeration, and information storage system due to their superior qualities like high electrical resistivity, low power losses, moderate saturation magnetization, high initial permeability [6].

H. Mohseni et al. [7] highlighted magnetic and structural studies of the Mn substituted Mg–Zn ferrite nanoparticles synthesized by the glycine nitrate process. They summarized the increasing content of Mn^{2+} results in increasing crystallite size which also tends to reduce coercivity.

T.A. Nhlapo et al. [8] studies Magnetic properties of $Mn_{0.1}Mg_{0.2}TM_{0.7}Fe_2O_4$ (TM=Zn, Co, or Ni) synthesized by hydrothermal process. The study reveals in comparison to Ni- and Co-based compounds, the Zn-based compound with bigger Zn atoms has the lowest crystallite size. The magnetic characteristics are significantly influenced by chemical composition and crystallite size.

Maksoud et al. [9] reported Mn-Zn nanostructured ferrites substituted with Mg in order to provide a magnetic recyclable catalyst with remarkable photocatalytic and antibacterial properties. Prepared MnZnMg spinel ferrite NPs showed an excellent UV- assisted photocatalytic activity against Chloramine T and Rhodamine B as compared to pure MnZn spinel ferrite NPs. Furthermore, the $MnZnMgFe_2O_4$ NPs showed a high antibacterial activity towards pathogenic bacteria.

Sharma, Rohit et al. [10] reports nanoparticles of Mn^{2+} doped $Mg_{0.5}Zn_{0.5-x}$ $Mn_xFe_2O_4$ (x=0–0.50) ferrites produced via co-precipitation for use in applications involving high temperatures. They claim that Mn^{2+} doped material's soft ferri-magnetic behaviour points to their potential for use as memory storage and as a reliable heating source in hyperthermia applications.

Out of reported synthesis methods, the hydrothermal method is effectively used to obtain nanoparticles (MNPs) because of its economic and a high degree of compositional control. Additionally, it's not essential to have extremely high processing temperature or advanced processing in hydrothermal synthesis. For instance, ferrites can be formulated through the hydrothermal route at a temperature range of 150°C-200°C [11]. To the best of the author's knowledge, the ferrites having composition $Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ prepared by hydrothermal route have not been reported yet. In hydrothermal synthesis oxides, halides and nitrates of respective metals can be used as a precursor and then transferred to a High Pressure Teflon Coated Stainless Steel container termed as Autoclave.

In the present module, $Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ MNPs were synthesized at various processing temperature (sealing temperature) ranges of 160–200°C by hydrothermal route. Teflon Lined Stainless Steel autoclave has a maximum sustainable temperature of 220°C, according to the instructions. As a result, the upper higher temperature of 200°C is used here. We are attempting to optimise the temperature range and determine the best appropriate sealing temperature for the synthesis process in this study. The temperature affected various structural, spectroscopic, magnetic, and dielectric parameters obtained from X-ray diffraction, Fourier transforms infrared analysis, Vibrating sample magnetometer, Transmission electron microscopes, Energy-dispersive X-ray spectroscopy and Impedance analyser are discussed.

Furthermore, synthesized spinel ferrite MNPs nanoparticles were examined for their antibacterial efficacy against several harmful microorganisms. Gram-positive bacteria like Bacillus subtilis and Staphylococcus aureus, Gram-negative bacteria like E. coli and Pseudomonas aeruginosa are among the investigated microorganisms.

Section snippets

Materials and experimental details

The $Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ MNPs were synthesized using the hydrothermal method at 160 °C, 180 °C and 200 °C with pH-12 For the synthesis, 0.4 M of $FeCl_3$ taken in one beaker and 0.2 M of $MnCl_2·4H_2O$, 0.2 M of $MgCl_2·6H_2O$ and 0.2 M of $ZnCl_2$ were taken in other beaker containing 40 ml of double distilled water to create an aqueous homogeneous solution by constant stirring. After continuing the stirring process for 30 min, both solutions were mixed together and stirred continuously with the addition of …

Conclusion

$Mg_{0.3}Zn_{0.5}Mn_{0.2}Fe_2O_4$ spinel ferrite nanoparticles were successfully synthesized by hydrothermal technique at sealing temperatures of 160 °C, 180 °C, and 200 °C. XRD, TEM, EDS FTIR, VSM, and Impedance characterization methods have been used to investigate the structural, magnetic, and dielectric behaviour of hydrothermally produced MNPs. The temperature effect on various structural parameters of prepared MNPs such as crystallite size, lattice dimension in accordance with sealing temperature were …

CRediT authorship contribution statement

Sarang R. Daf: Conceptualization, Data curation, Formal analysis, Writing – original draft, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. **Dilip S. Badwaik:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. **Shrikant M. Suryawanshi:**…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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