

Synthesis and Characterizations of Nano Magnetic Particles (Co-Ni Fe₂O₄) Ferrite by Co-precipitation and Biomedical Application

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ABSTRACT

Characterization of Co_{x-1}Ni_x Fe₂O₄ nanoparticles (NPs) employing X-ray diffraction and field emission scanning electron microscopy (FESEM) was accomplished simply by chemical co-precipitation, FTIR and finally the Magnetic Resonance Spectrometer (VSM), the single-phase cubic spinel structure in X-ray diffraction. In FESEM, micrographs of Co ferrites nanoparticles that are virtually spherical can be seen with grain sizes of less than 20 nm. Two absorption bands are visible in the FTIR spectrum, with values ranging from 400-600 cm. These beams show that all of the samples have a ferrite spectral composition. Preparation of samples yielded M-H curves because of the tight turn, which means the paper samples are soft magnetic material in the VSM. Antibacterial activity of Co_{x-1}Ni_x Fe₂O₄ NPs in limiting the development of isolated pathogenic bacteria Staphylococcus aureus and E. coli was studied to compare their effects with the traditional antibiotics used before. Using Co_{x-1}Ni_x Fe₂O₄ nanoparticles, it has been found that the nanoparticles release ions into the environment, which interacts with the group (-SH) of proteins, resulting in the deflection of bacteria's cell membranes and the subsequent cell death.

Keywords: Pulsed laser deposition (PLD), Co-Ni ferrite, antibacterial of Co-Ni ferrite

1. INTRODUCTION

The topic of nanotechnology has advanced dramatically in recent decades, particularly in the physical sciences [1]. The ability to make ferrite nanoparticles has opened up a fascinating new field of research, with revolutionary possibilities not only in electrical technology but also in biotechnology [2]. Over the last decade, the use of metallic nanoparticles (NP) has increased dramatically, including in biomedical and other sectors. At this time, substantial studies have been carried out on the subject of production of metallic nanostructures and the study of their applications on a large scale [3-6]. For magnetic reasons, NP for iron, cobalt and nickel is regarded as among the many forms of nanostructures created [7]. Due to its unusual features, particularly magnetic and electromagnetism, NP magnetism has sparked a lot of attention and has been employed in a variety of applications [8-12]. In general, MFe₂O₄ is a formula for magnetic materials (M: divalent metal ion, such as Mn, Mg, Zn, Ni, Co, Cu and others) [13]. They offer a lot of potential for use because of their unique features in electronics [14], catalyst [15], battery [16], antimicrobial agents, magnetic storage devices and other medical disciplines [17], immunoassay [18], heat therapy [19] and magnetic resonance photography [20]. Cobalt ferrite is a well-known substance with a strong magnetic field, magnetization saturation and a material with a high coercive strength. Despite its low coactivity and saturation magnetization, and being a soft material, ferrite nickel has a high coercive strength and saturation magnetization when compared to other materials. They are great candidates for a wide range of biological, electrical and recording applications to several of these characteristics (hard and soft magnetic) [21-24]. From the standpoint of magnetic applications, nanoparticles' nature is mostly determined by their size

and form. For these nanoparticles, magnetic purity and stability (such as super magnetic blocking at a given temperature, etc.) are important [25].

2. EXPERIMENTAL WORK

2.1 Materials

Ferrite powders were prepared, while cobalt nitrate, iron nitrate and nickel nitrate were used as starting materials. Table 1 shows the raw materials and their density.

Table 1 Chemicals used

Compounds	Chemical formula	Mol. Mass (g. mol ⁻¹)
Iron nitrate	Fe(NO ₃) _{2.9} H ₂ O	403.8
Cobalt nitrate	Co(NO ₃) _{2.6} H ₂ O	291.031
Nickle nitrate	Ni(NO ₃) _{2.6} H ₂ O	290.79
Sodium hydroxide	NaOH	39.9971

2.2 Sample Preparation

Ferrites nanomaterials with the formula of CO_{1-x}Ni_xFe₂O₄ where "x = 0.0, 0.2 and 0.4" are created using "chemical co-precipitation". To make ferrite samples, molar quantities that are stoichiometric and all three nickel and cobalt (II) nitrates with steady magnetic stirring, ferric nitrate, nickel nitrate and cobalt nitrate were dissolved in de-ionized water. As a precipitation agent, a (1.5M) NaOH solution is utilized. Once the PH of the combination hits 12, we heat it at 80°C for 30 minutes to precipitate the components. The precipitates are then rinsed with deionized water many times until the pH level of the solution returns to normal (pH = 7-8). At 125°C, the product precipitates are dried to remove the water, then ground into powder and asserted in an electric furnace at 300 °C for 3 hours to get the ferrite phase of spinel.

3. RESULTS AND DISCUSSION

3.1 XRD Diffraction

The crystal structure and purity of the material can be determined using XRD. Figure 1 illustrates a specimens' XRD spectra for Ni_{1-x}Co_xFe₂O₄ at "x = 0.0, 0.2, and 0.4". X-ray diffraction patterns at 300 °C for 3 h revealed a cubic spinel-structured pure phase (JCPDS card number 40-1191). There are numerous peaks in the poly-oriented polygonal structure that indicate unique crystallite planes in the single-phase cubic spinel structure Ni_{1-x}Co_x Fe₂O₄"220, 311, 222, 400, 422, 511 and 440".

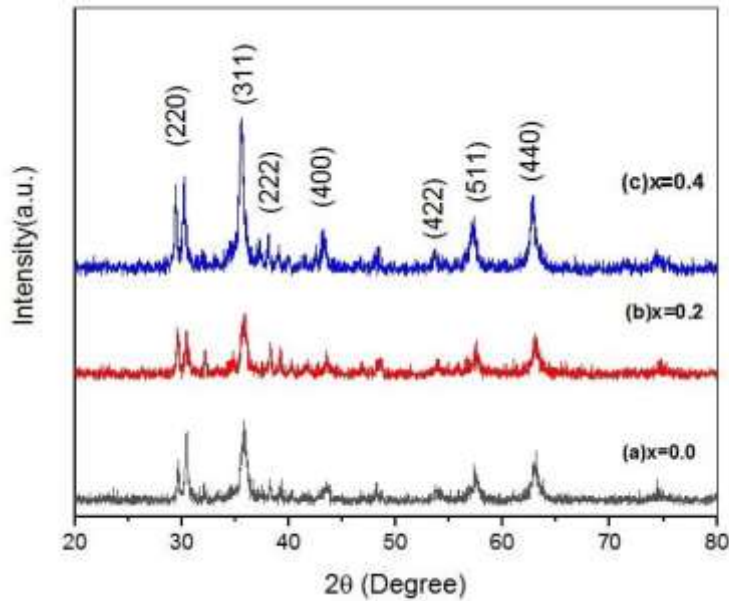


Figure 1. XRD patterns for $\text{Co}_{1-x}\text{Ni}_x\text{Fe}_2\text{O}_4$.

Table 2 XRD parameters of synthesized $\text{Ni}_x\text{Co}_{1-x}\text{Fe}_2\text{O}_4$

Material	Ratio	2θ (Deg.)	FWHM (Deg)	$d_{hkl}(\text{Å})$	D(nm)	(hkl)
CoFe_2O_4	0	35.69	0.6985	10.82	19.5	(113)
$\text{Ni}_{0.2}\text{Co}_{0.8}\text{Fe}_2\text{O}_4$	0.2	35.64	0.5675	13.32	28.3	(113)
$\text{Ni}_{0.4}\text{Co}_{0.6}\text{Fe}_2\text{O}_4$	0.4	35.69	0.6382	14.31	24.2	(113)

3.2 FTIR Spectroscopy

They are called ferrites because they are made up of atoms that are "connected to all their nearest neighbors by the equivalent strength of ionic, covalent, or van der Waals interactions." From a wave number range (350 to 4000 cm^{-1}), the FTIR spectra of $\text{Ni}_{1-x}\text{Co}_x\text{Fe}_2\text{O}_4$ that have been obtained are shown in Figure 2. The metal ions in ferrites occupy two distinct sub-lattices in reference to the geometrical arrangement of oxygen's nearest neighbors, identified as tetrahedral "A-site" and octahedral "B-site." Wave numbers are greater in ν_1 , that can be seen in the range of 580 – 600 cm^{-1} , this is the vibration of the metal at the tetrahedral site "Mtetra \leftrightarrow O". There was a lower wave number one than there was "usually observed around 375 – 450 cm^{-1} " is attributed to octahedral stretching "MoctaO" [18, 19], in addition to vibrations in the NO_3 ion, the carboxyl group COO^- , and the stretching of the C–H bands and hydrogen bound O–H groups, it is possible to see " 1100 – 1300 cm^{-1} ", " 1400 – 1700 cm^{-1} ", " 2850 – 3000 cm^{-1} ", and 3400 cm^{-1} weaker absorbance bands at the margins respectively [20, 21]. The octahedral and tetrahedral complexes' change in Fe^{3+} –O $^{2-}$ ion distance is responsible for the notable shift in band locations. Interestingly, as the Co substitution content increases, the characteristic band 1 shifts towards lower and higher frequency regions. Table 3 shows the limits of the absorption bands of the compound.

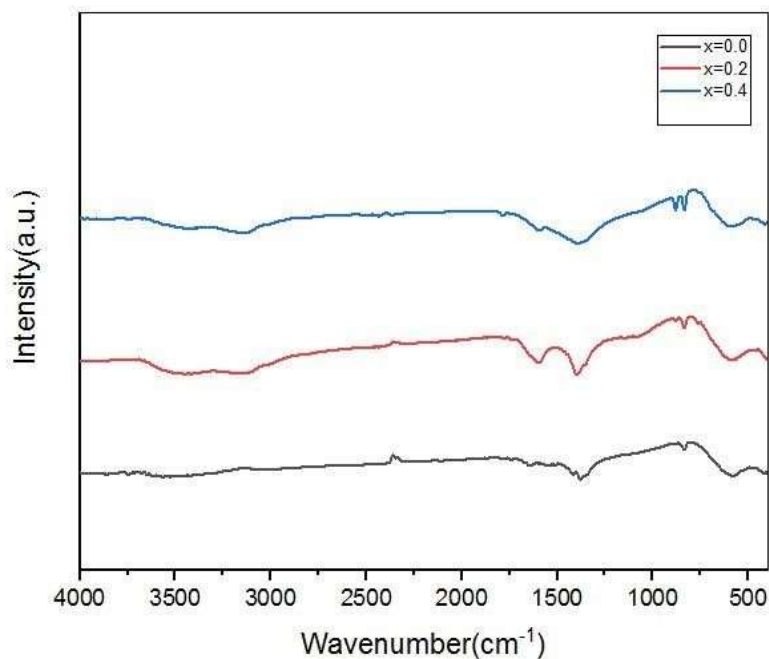


Figure 2. FTIR spectra of Ni_{1-x}Co_xFe₂O₄.

Table 3 IR absorption bands and force constants of the Co_{1-x}Ni_xFe₂O₄ samples

X	$\nu_T \text{ cm}^{-1}$	$\nu_B \text{ cm}^{-1}$
0.0	596.602	378.009
0.2	595.269	375.341
0.4	591.267	375.341

3.3 Magnetic Measurements

A magnetometer (VSM) is being used to investigate magnetic properties at room temperature of the produced samples. Figure 3 shows the M-H curves of the samples that have been prepared. The loop is narrow, which means the paper samples are soft magnetic material. In the applied field, as nano samples reach saturation magnetization as shown in the insert of figures, coercivity (HC) and saturation magnetization (Ms) values were extracted directly from these curves. All prepared samples of Co-Ni ferrite ($x = 0, 0.2$ and 0.4) at room temperature exhibit ferrimagnetic coupling. At room temperature, Ni concentration lowers both saturation magnetization and coercivity. The process of superexchange contact causes magnetic order in cubic spinels between the metal ions in their A-sites and B-sites, which makes them more magnetic than other spinels.

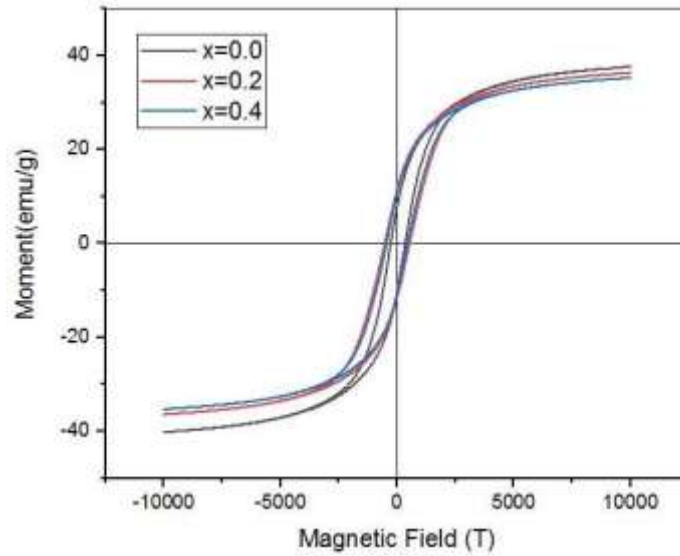


Figure 3. Room temperature M-H hysteresis loop for $\text{CO}_{1-x}\text{Ni}_x\text{Fe}_2\text{O}_4$ system.

Table 4 Saturation magnetization, residual magnetization and force field values of nickel cobalt ferrite

Molar ratio	Ms (emu/g)	Mr (emu/g)	Hc (kOe)
0.0	35.551	11.475	0.002
0.2	34.660	11.355	0.025
0.4	24.601	9.205	0.016

3.4 FESEM Analysis

Figure 4 shows the results of FESEM analysis. It shows FESEM micrographs of Co ferrites nanoparticles that are virtually spherical and have grain sizes of less than 20 nm. Furthermore, despite the fact that these tiny crystallites are equally distributed across the area, showing the development of fine granularity due to magnetic nanoparticle interactions, agglomeration can occasionally reveal a visible boundary between nearby crystallites.

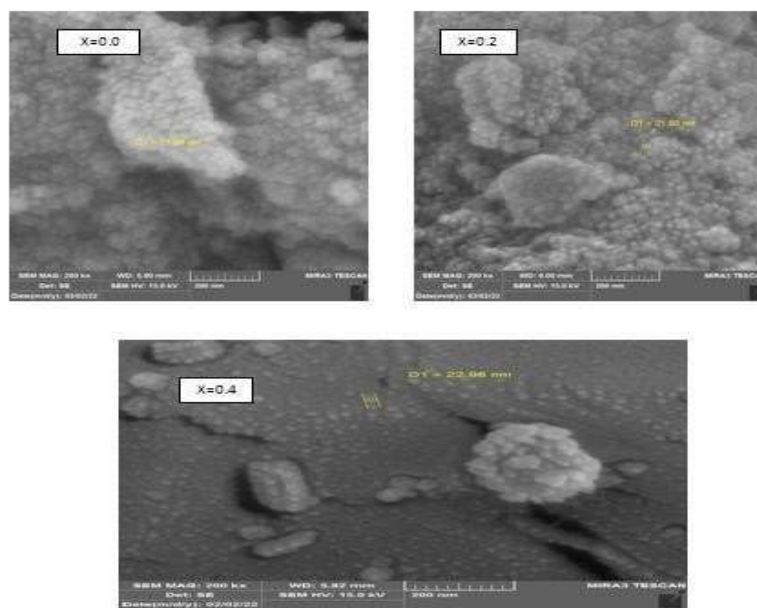


Figure 4. FESEM image of Co_{1-x}Ni_xFe₂O₄.

3.5 Antibacterial Activity of Co_{x-1}Ni_xFe₂O₄ Ferrite

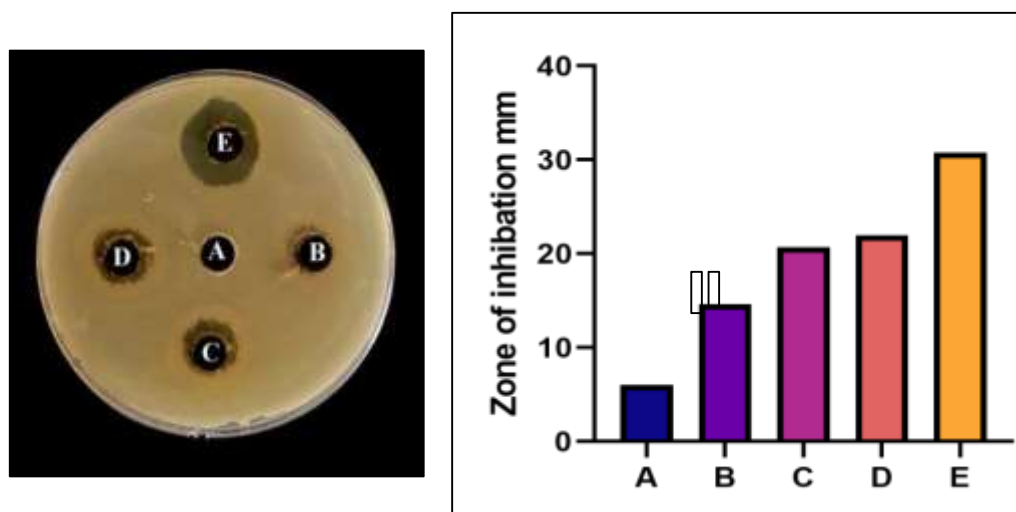


Figure 5. Antibacterial activity of sample 1 against *E. Coli*, for A (control), B (25%), C (50%) D (75%), E (100%).

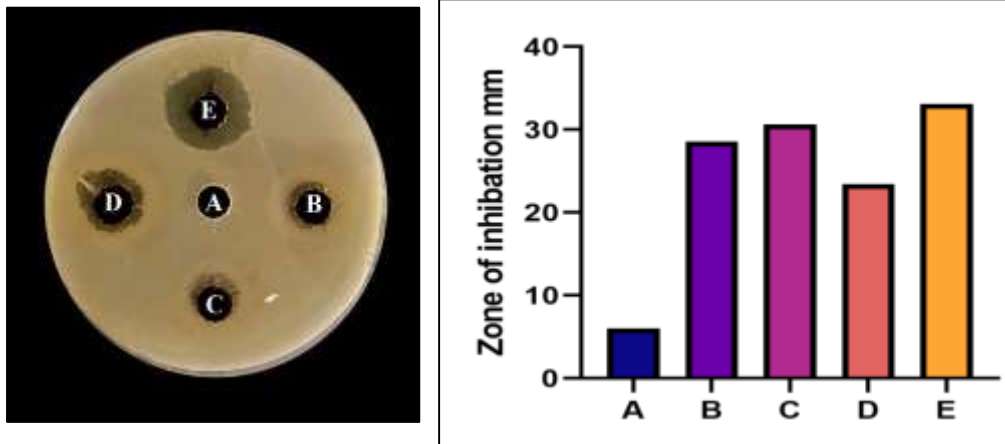


Figure 6. Antibacterial activity of sample 2 against *E. Coli*, for A (control), B (25%), C (50%) D (75%), E (100%).

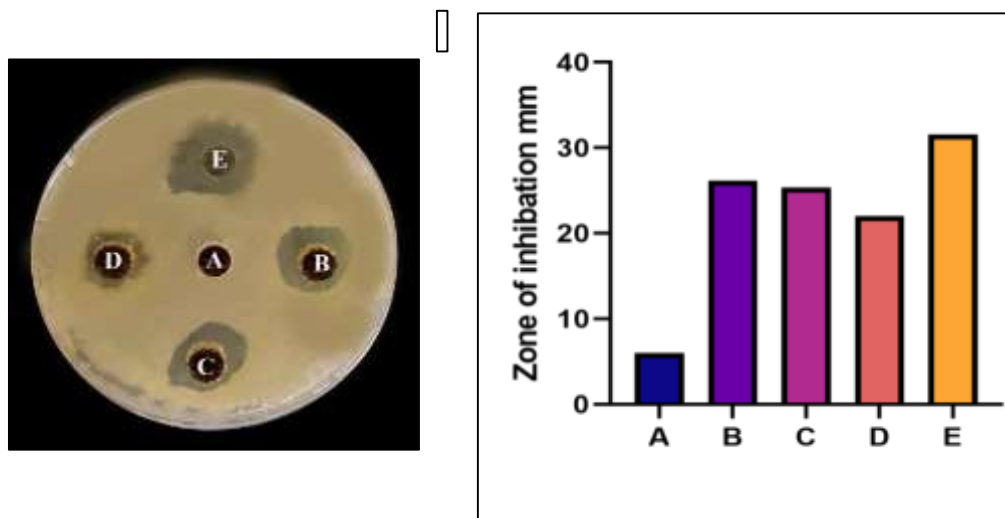


Figure 7. Antibacterial activity of sample 3 against *E. Coli*, for A (control), B (25%), C (50%) D (75%), E (100%).

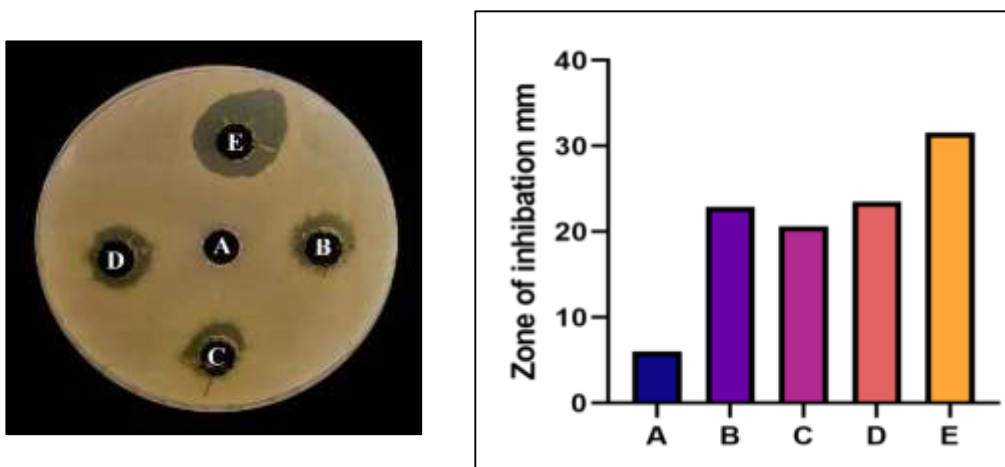


Figure 8. Antibacterial activity of sample 1 against *S. aureus*, for A (control), B (25%), C (50%) D (75%), E (100%).

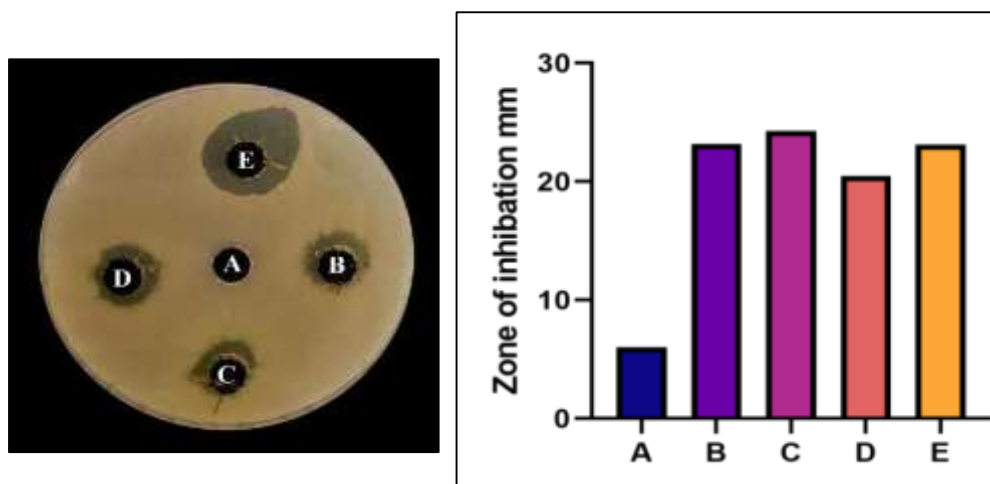


Figure 9. Antibacterial activity of sample 2 against *S. aureus*, for A (control), B (25%), C (50%) D (75%), E (100%).

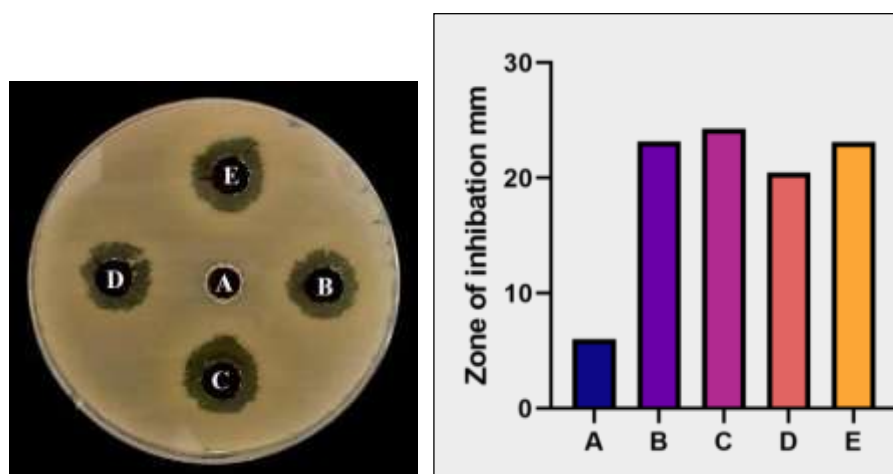


Figure 10. Antibacterial activity of sample 3 against *S. aureus*, for A (control), B (25%), C (50%) D (75%), E (100%).

Table 5 Results of the inhibition zone for Co-Ni-Fe₂O₄ ferrite by methods, co-precipitation, antibacterial activity of NPs against gram-negative (*E. coli*)

SAMPLES	A	B	C	D	E
1	6	14.635	20.686	21.965	30.798
2	6	28.565	30.639	23.457	33.131
3	6	26.145	25.375	22.053	31.571

Table 6 Results of the inhibition zone for Co-Ni -Fe₂O₄ ferrite by co-precipitation method

SAMPLES	A	B	C	D	E
1	6	22.917	20.634	23.512	31.553
2	6	23.18	24.274	20.453	23.137
3	6	21.145	24.653	24.885	23.562

4. CONCLUSION

At 300 °C for 3 hours, chemical co-precipitation was used to make cobalt replaced nickel spinel nanoparticles. The cubic spinel phase is seen in the ferrite samples' XRD patterns. As established by X-ray diffraction, the size of a single cubic spinel structure ranging from 19.5 to 24.2 nm is the typical crystalline size of ferrite nanoparticles. The nanocrystal lines in the produced products are confirmed by FESEM images. Infrared spectroscopy of the ferrite powders reveals two distinct bands in the 500-600 cm⁻¹ and 385-450 cm⁻¹ wavelength range. It is possible that the tetrahedral and octahedral complexes are responsible. High-quality ferrite nanopowder can be made using a simple and low-cost process called co-precipitation.

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