Prepared Magnesium Oxide Nanoparticles as Potential Antibacterial Agents

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ABSTRACT

This study explores the synthesis of magnesium oxide nanoparticles (MgO NPs) using the sol-gel method and investigates their potential as antibacterial agents. The X-ray diffraction analysis confirmed the formation of crystalline MgO NPs with an average crystallite size of approximately 18.5 nm. Fourier Transform Infrared Spectroscopy (FTIR) revealed the presence of characteristic functional groups of MgO, along with some impurities. Scanning Electron Microscopy (SEM) demonstrated the spherical shape and uniform aggregation rate of the MgO NPs, with average particle size 23.1 nm. To assess their antibacterial properties, the MgO NPs were evaluated against Staphylococcus aureus and Escherichia coli using the Agar Diffusion Assay. The results revealed significant antibacterial activity against Escherichia coli, with an inhibition zone diameter of 16 mm at a concentration of 1000 µg/ml. This strong activity against Escherichia coli may be attributed to the small particle size of the MgO NPs. The findings suggest that the synthesized MgO nanoparticles possess promising antibacterial properties, particularly against Escherichia coli. Further research and optimization are needed to explore their potential applications as effective antibacterial agents, offering a safe and efficient alternative to traditional antibiotics to combat bacterial infections and antimicrobial resistance challenges in various fields.

Keywords: NPs, sol-gel method, Staphylococcus aureus and Escherichia col

1. Introduction

Magnesium oxide (MgO) is an inorganic compound that has been used for centuries in a variety of applications, including medicine, food, and construction. In recent years, MgO nanoparticles have been investigated as potential antibacterial agents.[1] MgO nanoparticles have several properties that make them attractive for antibacterial applications. They are non-toxic, relatively easy to synthesize, and have a high surface area-to-volume ratio. This high surface area allows MgO nanoparticles to interact with bacterial cells in several ways, including [2]: Cell membrane disruption: The small size of MgO nanoparticles allows them to penetrate the bacterial cell membrane, disrupting the membrane's integrity and causing the cell to leak. Oxidative stress: MgO nanoparticles can generate reactive oxygen species (ROS), which can damage bacterial DNA and proteins.[3] Entry into the cell: MgO nanoparticles can be internalized by bacterial cells, where they can disrupt

cellular processes and cause cell death. Studies have shown that MgO nanoparticles have antibacterial activity against a wide range of bacteria, including both Gram-positive and Gram-negative bacteria. They have also been shown to be effective against antibiotic-resistant bacteria[3]. The use of MgO nanoparticles as antibacterial agents is still in its early stages, but the research results so far are promising. MgO nanoparticles can potentially be a safe and effective alternative to traditional antibiotics[4].

Magnesium oxide (MgO) has been studied for its antibacterial properties and has shown promising effects against various bacterial strains Bactericidal Effects: Magnesium oxide nanoparticles have been reported to exhibit bactericidal effects against a wide range of bacterial species, including both Gram-positive and Gram-negative bacteria. The nanoparticles have been found to inhibit bacterial growth and induce cell death, making them potential candidates for antimicrobial applications[5]. Mechanisms of Action: The antibacterial activity of magnesium oxide nanoparticles is attributed to several mechanisms. One of the main mechanisms involves the release of magnesium ions (Mg^{2+}) from the nanoparticles, which disrupts the bacterial cell membrane and interferes with essential cellular processes, leading to bacterial death [6, 7]. Antibiofilm Activity: Magnesium oxide nanoparticles have also demonstrated antibiofilm activity, inhibiting the formation and dispersal of bacterial biofilms. This is particularly relevant in medical settings, as bacterial biofilms on medical devices can lead to persistent infections and treatment complications.[8] Broad Spectrum Activity: Studies have shown that magnesium oxide nanoparticles exhibit broad-spectrum antibacterial activity, making them effective against various pathogenic bacteria, including drug-resistant strains.

2. Materials and Methods

The experimental setup for the synthesis of magnesium oxide nanoparticles by the sol-gel method typically involves the following components and steps:

2.1 Materials and Chemicals:

1. Magnesium precursor: Magnesium nitrate
2. Solvent: Water, ethanol, organic solvents.
3. Stabilizing agent (optional): A stabilizing agent or surfactant may be used to control the size and morphology of the nanoparticles.
4. pH adjuster: An acid or base may be used to adjust the pH of the solution during the sol-gel process.
5. Heating source: An oven or muffle furnace for drying and calcination steps.

2.2 Experimental Steps:

1. Preparation of Sol:

A. Dissolve the 1 molar of the magnesium precursor in distilled Water to create a clear and homogeneous solution. The concentration of the precursor will influence the final nanoparticle size and concentration.

B. Add a stabilizing agent to control the particle growth and prevent agglomeration.

2. Hydrolysis and Gel Formation:

A. Adjust the pH of the sol using an acid or base to promote the hydrolysis reaction at 8 PH.

B. b. Allow the sol to undergo hydrolysis at a controlled temperature of 50 C for a specific duration. This step leads to the formation of metal hydroxide clusters, which act as precursors for the nanoparticles.

3. Aging:

A. After hydrolysis, allow the sol to age for a specific period at a controlled temperature of 50 C. Aging

B. promotes the growth of metal hydroxide clusters and results in the formation of a gel-like structure.

4. Drying:

A. Transfer the aged gel into a suitable container .

B. Dry the gel in an oven or at a controlled temperature to remove the solvent and excess water, leaving behind a dry gel.

5. Calcination:

A. Transfer the dry gel to a muffle furnace or oven for calcination.

B. b. Heat the gel at a specific temperature and duration to convert the metal hydroxides into magnesium oxide nanoparticles. The

calcination temperature may typically range from 300°C to 600°C, depending on the desired nanoparticle characteristics.

6. Cooling and Collection:

A. Allow the calcined nanoparticles to cool to room temperature.

B. Collect the synthesized magnesium oxide nanoparticles for further characterization and application.

After that Characterization techniques (XRD, SEM) of the prepared nanoparticles

Antibacterial evaluation methods used to assess the effectiveness of magnesium oxide (MgO) as an antibacterial agent use Agar Diffusion Assay (Kirby-Bauer Disc Diffusion Method):

This method involves impregnating paper discs or wells with a known concentration of MgO nanoparticles. These discs are then placed on an agar plate previously inoculated with the target bacterial strain. The antibacterial activity is evaluated by measuring the diameter of the zone of inhibition around the discs, which indicates the extent of bacterial growth inhibition. D. Controls and experimental setup

3 Results and Discussion

3.1 X-ray Diffraction Analysis:

X-ray diffractometer was used to analyse and study the structural properties of ceramics oxides (MgO) and used the Scherer equation to calculate the crystalline size. Miller Indices (hkl) calculated by Bragg's equation with matching using a COD standard card using match-3 software.

The X-ray diffraction pattern determined the structural phase of the MgO ceramic oxide. Figure (1) shows the XRD pattern of the observed peaks at

2θ, 40.909,62.278, and 78.571 are associated with the [200], [202], and [222] planes, respectively, which are in good accordance with the reported literature [9] Furthermore, no characteristic peaks of other impurities were observed, which indicated that the product had a high purity at heat treatment of 600°C for 2hr. In addition, the sharp and robust diffraction peaks indicate that they are well crystallized. The grain sizes correspond to the [200], [202], and [222] lattice planes of the MgO. The XRD pattern data of MgO are listed in Table 3.2, with the average Crystallite size (18 nm) .

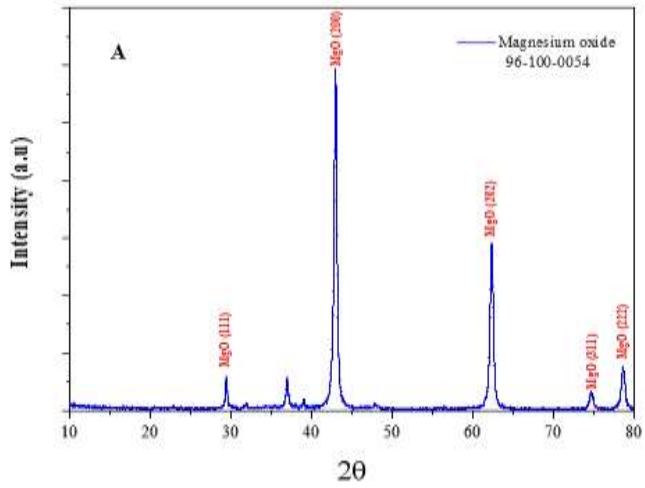


FIGURE 1.XRD Pattern of MgO NPs

TABLE 1. The structural parameters of MgO NPs

Sample	**MgO NPs at 600** ℃		
Two θ° (Deg.)	Strongest 3 Peaks		
	40.90	62.27	78.57

hkl	200	202	222
d_{hkl} Exp. (A°)	2.106	1.489	1.216
d_{hkl} Std. (A°)	2.108	1.4909	1.2173
Crystallite size (nm)	18.53	18.07	19.11
he average Crystallite size (nm)	18.56		
Card No.	96-100-0054 cubic		

3.2 Results of Fourier Transform Infrared Spectroscopy (FTIR)

The Fourier Transform Infrared (FTIR) spectra within the wavenumber range of 400-4000 cm^{-1} were utilized to identify the chemical bonds and functional groups present in the MgO nanoparticles synthesized via the sol-gel method. The FTIR analysis revealed peaks at 1049.01, 1361.49, 2925.48, 3604.30, and 3721.94 cm^{-1}, indicating O–H stretching, C–O–H bending, and C–O stretching vibrational modes, respectively. These vibrations suggested the presence of alkanes, ketones, and alkenes in the sample. The peaks observed at 654.81 and 870.26 cm^{-1} were attributed to MgO vibrations, specifically associated with the periclase phase of MgO. Additionally, peaks at 2430.3, 2320.3, and 1841.5 cm^{-1} were classified as impure peaks, potentially originating from the polycrystalline nature of the sample, as supported by XRD analysis. The literature indicates that increasing the calcination time could diminish these impurity peaks..[10]

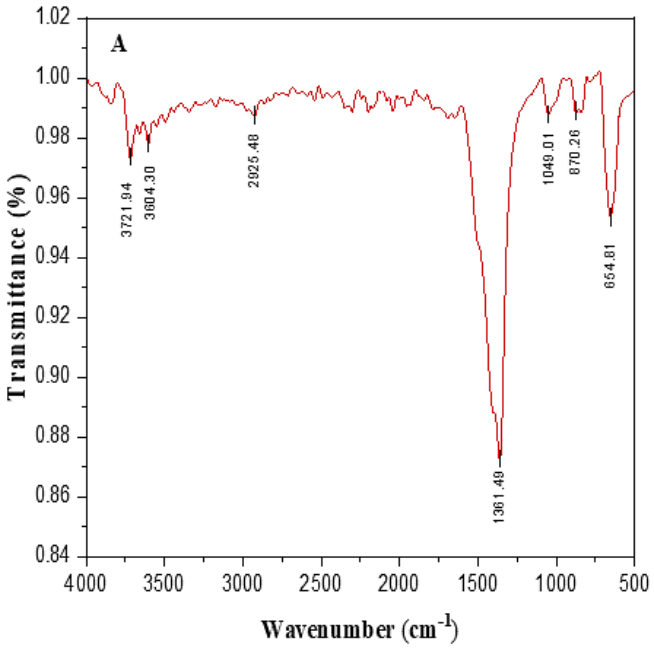
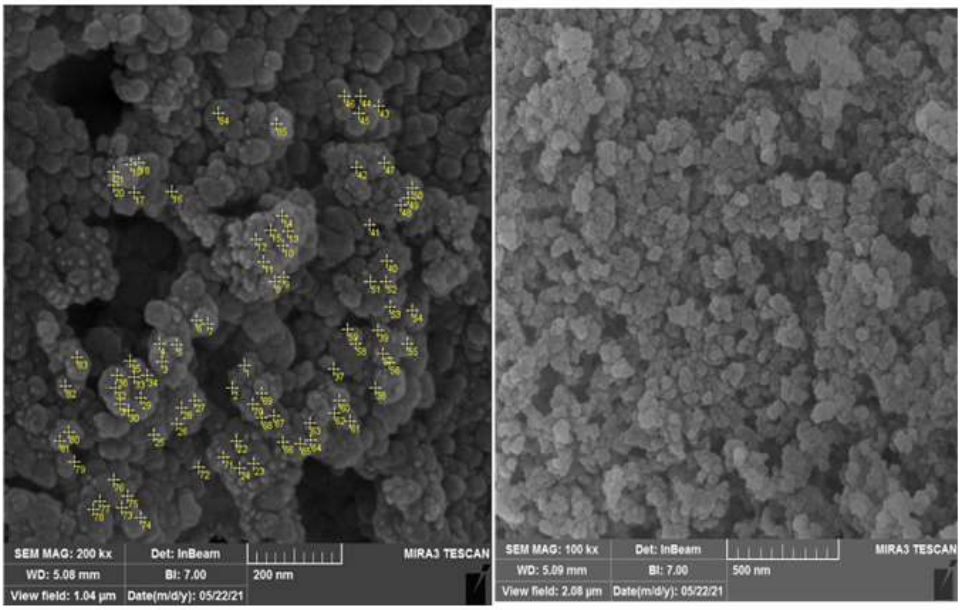


FIGURE 2. FTIR Spectra of MgO NPs

3.3 Scanning Electron Microscopy (SEM) Results

Figures 3 images (A and B) show the surface morphology investigations by the FE-SEM of the MgO NPs. It is found that the average particle size is (23.14) nm, with a spherical shape and uniform aggregation rate, the surface morphology of MgO ceramic oxide has a high specific surface area, as shown in Figures 4 and Table 2. The images show a homogenous

distribution of the spherical form with other different forms with low ratios. The high homogenous gains distribution on the surface is due to the regularity when preparing the sample; this gives the sample a surface homogeneity. It was noticed accumulation for some particles though the surface was homogeneous. The reason may be related to the slight difference in some circumstances of preparation.



A B

FIGURE 3 .The SEM images of, (A, B) MgO NPs

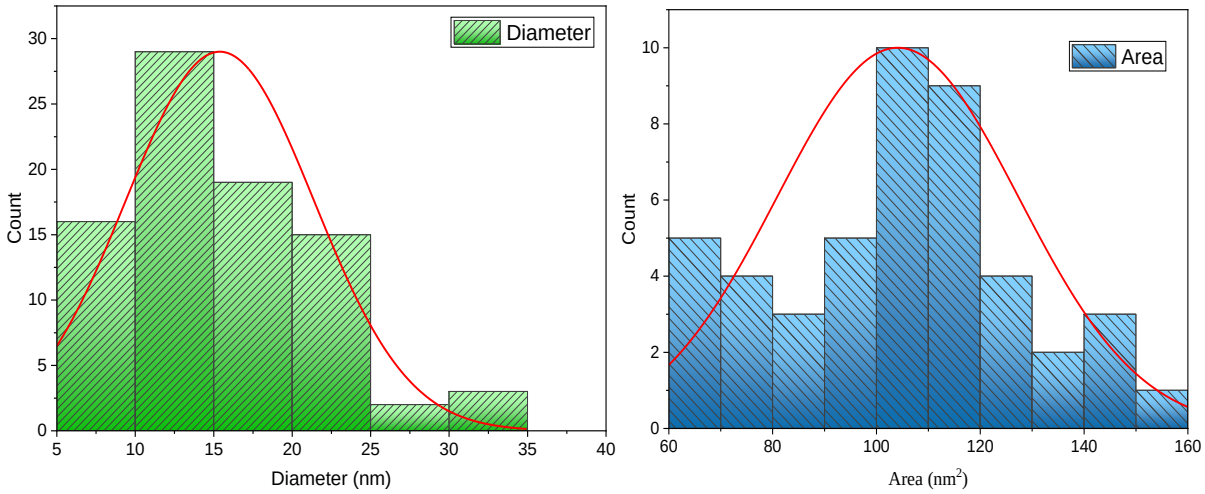


FIGURE 4. Histogram charts with Gauss distribution for MgO.

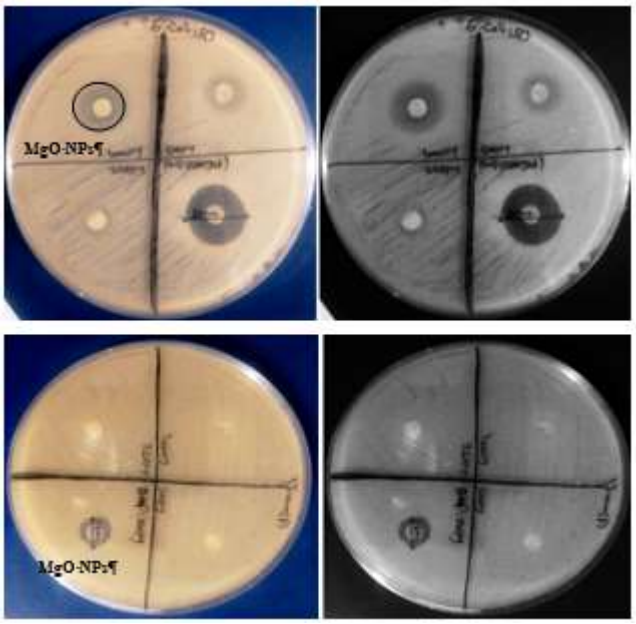
TABLE 2. The particles size and specific surface area MgO

	otal	n					
neter (nm)		4	3	7.70	2	7	2
(nm²)		107	10	3.92	99	674	523

3.4 Antibacterial test result

Based on the region of inhibition analysis, shows the results of the antibacterial activity test

for MgO NPs. Figure 5 shows images of the antibacterial activity of MgO against Staphylococcus aureus and E. coli. The diameter of the inhibition zone was measured in mm. It is noticed from Figure 4 that the MgO NPs showed activity against Escherichia coli bacteria. The MgO sample showed the best inhibition zone against Escherichia coli at the concentration of (1000 µg/ml) where at this concentration the diameter of the inhibition zone appeared (16 mm). The reason that the MgO sample shows greater activity against Escherichia coli bacteria than other samples is due to the small particle size, which is equal according to SEM results(23.14nm).



4. Conclusion

In conclusion, the study investigated the antibacterial properties of magnesium oxide nanoparticles (MgO NPs) synthesized through the sol-gel method. The X-ray confirmed the formation of crystalline MgO NPs with an average crystallite size of approximately 18.5 nm. Fourier Transform Infrared Spectroscopy (FTIR) revealed the presence of functional groups characteristic of MgO, along with some impurities. Scanning Electron Microscopy (SEM) provided images of the MgO NPs, showcasing their spherical shape and uniform aggregation rate, with average particle size 23.1 nm. The antibacterial evaluation of the MgO NPs was performed against Staphylococcus aureus and Escherichia coli using the Agar Diffusion Assay. The results demonstrated that MgO NPs exhibited significant antibacterial activity against Escherichia coli, with an inhibition zone diameter of 16 mm at a concentration of 1000 µg/ml. This strong activity against Escherichia coli may be attributed to the small particle size of the MgO NPs. These findings suggest that the synthesized MgO nanoparticles possess promising antibacterial properties, particularly against Escherichia coli. Further investigations and optimizations are warranted to explore their potential applications as effective antibacterial agents. The use of MgO nanoparticles as a safe and efficient alternative to traditional antibiotics holds potential for addressing bacterial infections and antimicrobial resistance challenges in various fields, including medicine and biotechnology.

References

1. S. Sharifian, A. Loghmani, S. Nayyerain, S. Javanbakht, and P. Daneii, "Application of Magnesium Oxide Nanoparticles in Dentistry: A Literature Review," *European Journal of General Dentistry,* vol. 12, no. 01, pp. 001-006, 2023.
2. A. Sirelkhatim *et al.*, "Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism," *Nano-micro letters,* vol. 7, pp. 219-242, 2015.
3. K. Gold, B. Slay, M. Knackstedt, and A. K. Gaharwar, "Antimicrobial activity of metal and metal-oxide based nanoparticles," *Advanced*

Therapeutics, vol. 1, no. 3, p. 1700033, 2018.

4. B. Mubeen *et al.*, "Nanotechnology as a novel approach in combating microbes providing an alternative to antibiotics," *Antibiotics,* vol. 10, no. 12, p. 1473, 2021.
5. B. Das *et al.*, "Biosynthesis of magnesium oxide (MgO) nanoflakes by using leaf extract of Bauhinia purpurea and evaluation of its antibacterial property against Staphylococcus aureus," *Materials Science and Engineering: C,* vol. 91, pp. 436-444, 2018.
6. P. Bhattacharya, A. Dey, and S. Neogi, "An insight into the mechanism of antibacterial activity by magnesium oxide nanoparticles," *Journal of Materials Chemistry B,* vol. 9, no. 26, pp. 5329-5339, 2021.
7. N.-Y. T. Nguyen, N. Grelling, C. L. Wetteland, R. Rosario, and H. Liu, "Antimicrobial activities and mechanisms of magnesium oxide nanoparticles (nMgO) against pathogenic bacteria, yeasts, and biofilms," *Scientific reports,* vol. 8, no. 1, p. 16260, 2018.
8. F. Martinez-Gutierrez *et al.*, "Anti-biofilm activity of silver nanoparticles against different microorganisms," *Biofouling,* vol. 29, no. 6, pp. 651-660, 2013.
9. P. Tamilselvi, A. Yelilarasi, M. Hema, and R. Anbarasan, "Synthesis of hierarchical structured MgO by sol-gel method," *Nano Bulletin,* vol. 2, no. 1, p. 130106, 2013.
10. R. V. Poonguzhali *et al.*, "Citrus limon assisted green synthesis of MgO nanoparticles: Evaluation of phase, functional groups, surface morphology, thermal stability and colloidal stability," *Ceramics International,* vol. 48, no. 19, pp. 27774-27778, 2022.