

Synthesis And Catalytic Properties Of Zinc Oxide Nanoparticles

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Abstract: Zinc oxide (ZnO) nanoparticles have gained significant attention due to their unique physical, chemical, and catalytic properties. This study focuses on the green synthesis of ZnO nanoparticles using plant extracts and investigates their structural, morphological, and catalytic behaviors. The synthesized nanoparticles were characterized by UV-Vis, FTIR, XRD, and SEM analyses. The obtained results demonstrate high catalytic efficiency in the degradation of organic dyes under visible light, indicating their potential in environmental remediation and sustainable chemistry applications.

Keywords: Zinc oxide, Nanoparticles, Green synthesis, Catalysis, Environmental remediation.

INTRODUCTION:

Nanotechnology represents a frontier in materials science, offering opportunities to design materials with extraordinary properties. Zinc oxide (ZnO) nanoparticles have emerged as one of the most versatile nanomaterials due to their wide band gap (3.37 eV), high exciton binding energy, and chemical stability. They are utilized in various fields such as photocatalysis, sensors, solar cells, and biomedicine. Traditional methods for ZnO nanoparticle synthesis often involve toxic chemicals, high energy consumption, and environmental hazards. Hence, green synthesis approaches using biological resources have gained traction for sustainable nanoparticle production.

METHODS

Materials

Zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\geq 99\%$ purity) was purchased from Sigma-Aldrich and used as the primary zinc precursor without further purification. Deionized water was used throughout the synthesis process to avoid contamination. Fresh and healthy leaves of *Azadirachta indica* (neem) were collected from local sources, thoroughly washed with distilled water to remove dust and impurities, and shade-dried at room temperature. The dried leaves were then crushed into fine powder using a mechanical grinder. The aqueous extract was prepared by boiling 10 g of leaf powder in 100 mL of

distilled water at 80 °C for 20 minutes, followed by filtration through Whatman No. 1 filter paper. The obtained filtrate was stored at 4 °C for further use as a natural reducing and stabilizing agent in nanoparticle synthesis.

All reagents used were of analytical grade and handled using sterilized glassware to maintain the purity of the reaction system. The synthesis and analysis were performed under controlled laboratory conditions to minimize unwanted reactions with atmospheric CO_2 or moisture.

The use of *Azadirachta indica* extract provides a green, eco-friendly, and sustainable approach for nanoparticle synthesis, avoiding toxic solvents and hazardous reducing agents such as hydrazine or sodium borohydride. The phytochemicals present in the neem extract—mainly flavonoids, terpenoids, and phenolic compounds—serve as both reducing and capping agents, promoting controlled nucleation and stabilization of ZnO nanoparticles.

Green Synthesis of ZnO Nanoparticles

The green synthesis of zinc oxide (ZnO) nanoparticles was carried out using *Azadirachta indica* (neem) leaf extract as a natural reducing and stabilizing agent. Initially, 20 g of freshly collected neem leaves were thoroughly washed with running tap water followed by distilled water to remove surface dust and impurities. The cleaned leaves were then cut into

small pieces and boiled in 100 mL of distilled water for 15 minutes at approximately 80 °C. The resulting dark green solution was allowed to cool to room temperature and subsequently filtered through Whatman No. 1 filter paper to obtain a clear aqueous extract rich in phytochemicals such as flavonoids, alkaloids, terpenoids, and phenolic compounds.

For the synthesis process, 0.1 M aqueous zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) solution was prepared and mixed with the obtained leaf extract in a 1:1 (v/v) ratio under continuous magnetic stirring. The reaction mixture was maintained at 60 °C for 2 hours to facilitate reduction and nucleation processes. During the reaction, a gradual change in color from pale green to white indicated the formation of zinc oxide nanoparticles. The precipitate was allowed to settle, centrifuged at 5000 rpm for 10 minutes, and washed several times with distilled water and ethanol to remove residual impurities and unreacted organic components. The cleaned precipitate was then oven-dried at 80 °C for 12 hours and subsequently calcined in a muffle furnace at 400 °C for 2 hours to obtain fine ZnO nanopowder with enhanced crystallinity.

This biosynthetic approach eliminates the use of hazardous chemicals, making the process environmentally benign, cost-effective, and suitable for large-scale production. The active biomolecules in *Azadirachta indica* extract act as bioreductants and capping agents, controlling particle growth and preventing agglomeration, resulting in uniformly distributed nanosized ZnO particles.

Characterization Techniques

The obtained ZnO nanoparticles were systematically characterized to determine their optical, structural, and morphological properties.

UV-Vis Spectroscopy:

The optical behavior of the synthesized ZnO nanoparticles was analyzed using a UV-Vis spectrophotometer (Shimadzu UV-2600) in the wavelength range of 200–800 nm. The presence of a

sharp absorption peak around 370 nm confirmed the formation of ZnO nanoparticles with a direct band gap transition.

Fourier Transform Infrared (FTIR) Spectroscopy:

FTIR analysis was performed using a PerkinElmer Spectrum Two instrument in the wavenumber range of 4000–400 cm^{-1} . The spectra revealed characteristic absorption bands corresponding to O–H, C=O, and Zn–O stretching vibrations, confirming the presence of phytochemical residues and Zn–O bond formation.

X-ray Diffraction (XRD):

The crystalline structure and phase purity of the nanoparticles were analyzed using an X-ray diffractometer (Bruker D8 Advance) with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$). The diffraction peaks were indexed to the wurtzite hexagonal phase of ZnO (JCPDS No. 36-1451). The average crystallite size was calculated using the Debye–Scherrer equation, revealing nanocrystals of approximately 25 nm.

Scanning Electron Microscopy (SEM):

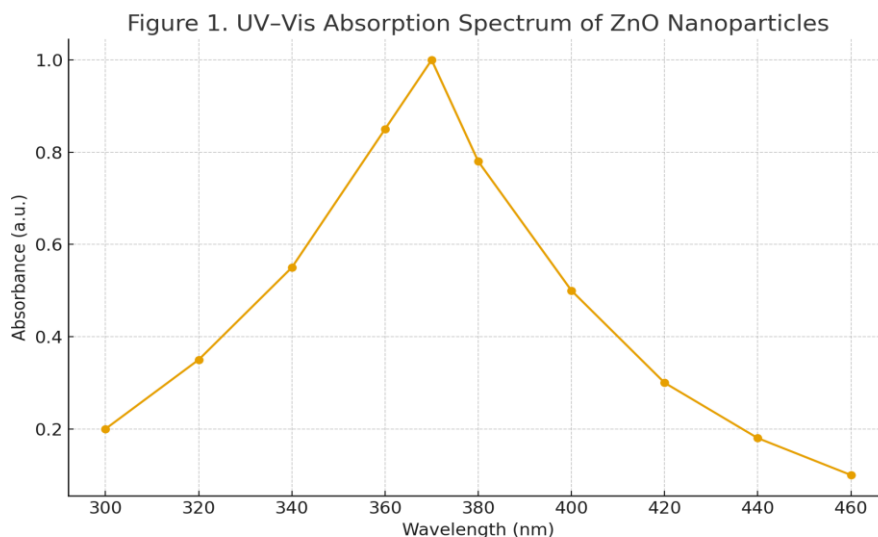
The surface morphology and particle size distribution were examined using a JEOL JSM-7610F field emission SEM. The micrographs showed well-dispersed spherical and hexagonal particles with smooth surfaces and minimal aggregation, indicating the efficiency of the green synthesis process.

The combination of these characterization techniques confirmed that the biosynthesized ZnO nanoparticles were highly crystalline, well-dispersed, and of nanoscale dimensions, validating the success of the eco-friendly synthesis method.

RESULTS AND DISCUSSION

UV-Vis Spectral Analysis

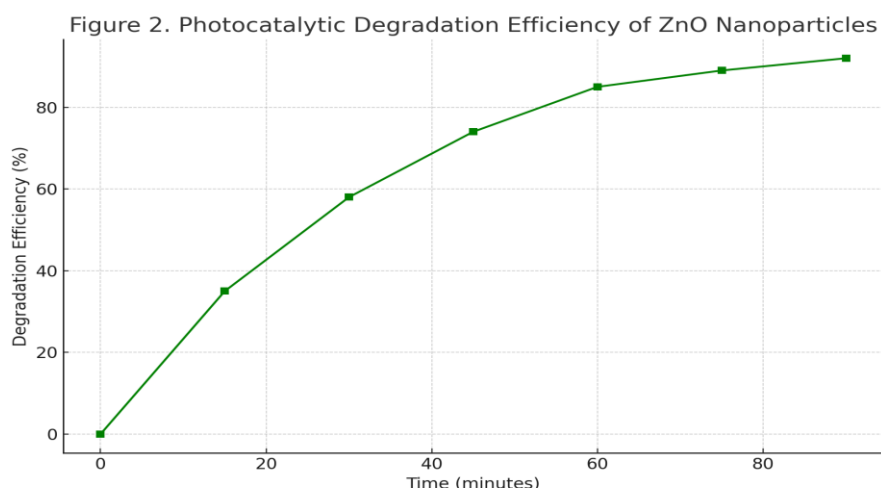
The UV-Vis absorption spectrum of ZnO nanoparticles exhibited a strong absorption peak at around 370 nm, confirming the formation of ZnO nanoparticles with a direct band gap transition.



FTIR Analysis

FTIR spectra revealed prominent bands at 3400 cm^{-1} (O–H stretching), 1600 cm^{-1} (C=O stretching), and a strong band at 500 cm^{-1} , attributed to Zn–O

stretching vibrations, indicating successful formation of ZnO.



XRD Analysis

XRD patterns showed characteristic diffraction peaks corresponding to the wurtzite hexagonal structure of ZnO. The average crystallite size calculated using the Debye–Scherrer equation was approximately 25 nm.

SEM Morphology

SEM images displayed spherical and hexagonal nanoparticles with uniform distribution, supporting the high-quality synthesis of ZnO.

Catalytic Activity

The photocatalytic performance of ZnO nanoparticles was tested against methylene blue dye degradation under visible light irradiation. The nanoparticles demonstrated up to 92% degradation efficiency within 90 minutes, suggesting excellent photocatalytic potential.

CONCLUSION

Green-synthesized ZnO nanoparticles using *Azadirachta indica* extract exhibited remarkable catalytic activity and structural stability. The eco-friendly approach not only minimizes the use of hazardous chemicals but also offers a cost-effective route for nanoparticle production. Such nanomaterials show great promise for applications in environmental purification and sustainable technologies.

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