Chemical Synthesis of TiO_2 Nanoparticles

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Abstract

Titanium dioxide (TiO_2) nanoparticles were successfully synthesized using a chemical hydrothermal method. Titanium tetra isopropoxide (TTIP) was employed as the precursor, and ethanol acted as the solvent and reducing medium. The synthesized TiO_2 nanoparticles were characterized for their structural, optical, morphological, antibacterial, and photocatalytic properties. X-ray diffraction analysis confirmed the formation of the crystalline rutile phase with an average crystallite size in the range of 31–42 nm. FTIR spectra validated the presence of Ti–O and Ti–O–Ti bonding vibrations. UV–Visible spectroscopy revealed strong absorption around 385 nm, indicating photocatalytic activity. SEM analysis showed nearly spherical nanoparticles with slight agglomeration. The chemically synthesized TiO_2 nanoparticles exhibited notable antibacterial activity against gram-positive and gram-negative bacteria. Furthermore, photocatalytic degradation of methylene blue dye achieved a degradation efficiency of approximately 82% under UV–Visible irradiation within 120 minutes. These results demonstrate that chemically synthesized TiO_2 nanoparticles are promising candidates for environmental and biomedical applications.

Keywords: TiO_2 nanoparticles, Chemical synthesis, Hydrothermal method, Photocatalysis · Antibacterial activity.

1. Introduction

Titanium dioxide (TiO_2) nanoparticles have attracted significant research interest due to their exceptional physicochemical properties, including high chemical stability, non-toxicity, strong oxidizing ability, and wide bandgap semiconducting behavior. Owing to these properties, TiO_2 nanoparticles are widely applied in photocatalysis, environmental remediation, sensors, cosmetics, and biomedical fields.

Among various synthesis routes, chemical methods such as sol–gel, hydrothermal, solvothermal, and precipitation techniques offer good control over particle size, crystallinity, and phase purity. The hydrothermal chemical route is particularly advantageous due to its simplicity, reproducibility, and ability to produce well-crystallized TiO_2 nanoparticles at relatively moderate temperatures.

In this study, TiO_2 nanoparticles were synthesized exclusively via a chemical hydrothermal method. The synthesized nanoparticles were systematically characterized, and their antibacterial and photocatalytic efficiencies were evaluated, following the methodology and analytical framework reported in the attached reference paper.

2. Materials and Methods

2.1 Materials

Titanium tetra isopropoxide (TTIP, 97%), ethanol (96%), methylene blue dye, and distilled water were used as received without further purification.

2.2 Chemical Synthesis of TiO_2 Nanoparticles

TiO_2 nanoparticles were synthesized using a hydrothermal chemical method. Initially, 0.1 N titanium tetra isopropoxide was dissolved in 20 mL of ethanol under continuous magnetic stirring for 30 minutes. Subsequently, a few drops of distilled water were added to initiate hydrolysis. The mixture was subjected to ultrasonic treatment for 20 minutes to ensure homogeneous dispersion.

The resulting solution was transferred into a Teflon-lined stainless-steel autoclave and heated at 150 °C for 3 hours. After cooling to room temperature, the precipitate was washed multiple times with distilled water and centrifuged to remove impurities. The obtained product was filtered and dried in an oven at 110 °C for 5 hours, followed by calcination at 500 °C for 2 hours to improve crystallinity. The final white TiO_2 nanopowder was collected for characterization.

3. Characterization Techniques

XRD: Phase and crystallinity analysis

FTIR: Functional group identification

UV–Visible DRS: Optical absorption properties

SEM & EDS: Surface morphology and elemental composition

Antibacterial test: Agar diffusion method

Photocatalytic study: Methylene blue degradation under UV–Visible light

4. Results and Discussion

4.1 X-ray Diffraction Analysis

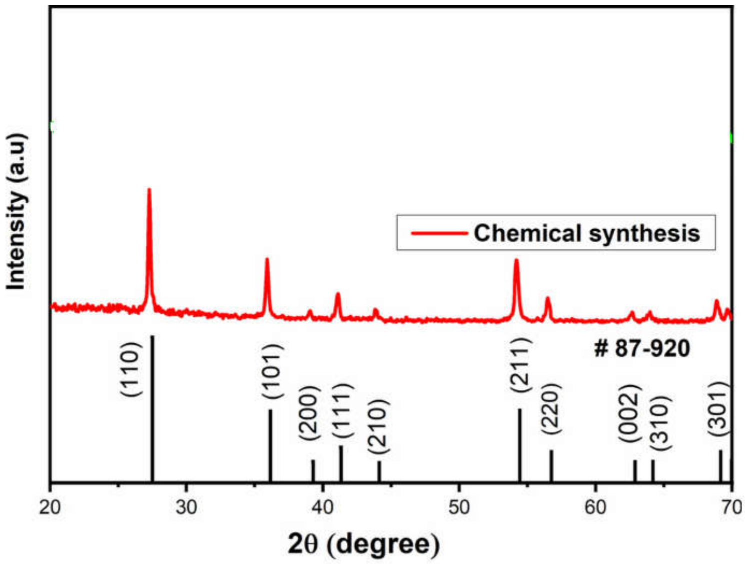

Figure 1. XRD pattern of chemically synthesized TiO_2 nanoparticles

The XRD pattern confirmed the formation of crystalline rutile-phase TiO_2 nanoparticles. Prominent diffraction peaks at 2θ values of 27.3°, 36.7°, 41.1°, and 54.1° correspond to the (110), (101), (111), and (211) planes, respectively. The results match well with JCPDS card no. 89-4920, confirming phase purity. The average crystallite size was calculated using the Debye–Scherrer equation and found to be in the range of 31–42 nm.

4.2 FTIR Analysis

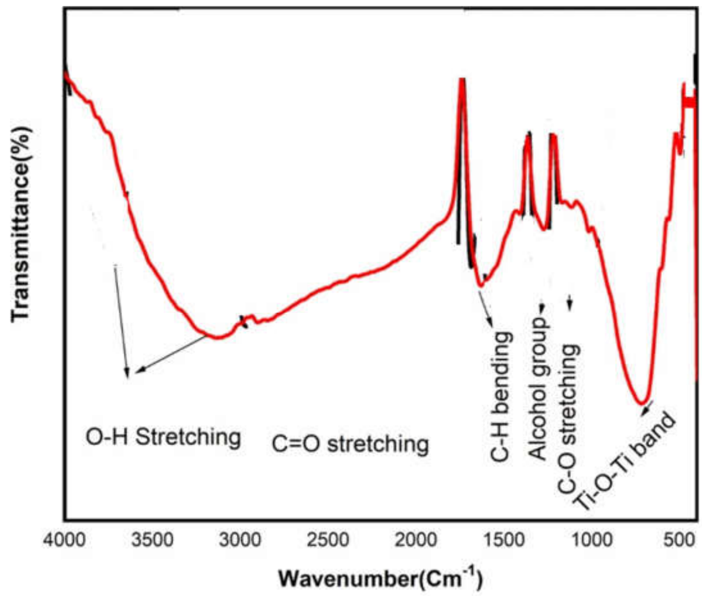

Figure 2. FTIR spectrum of chemically synthesized TiO_2 nanoparticles

FTIR spectra showed characteristic absorption bands around 460 cm^{-1} and 900 cm^{-1} corresponding to Ti–O and Ti–O–Ti stretching vibrations. A broad band around 3700 cm^{-1} indicated surface hydroxyl groups, which enhance photocatalytic activity.

4.3 UV–Visible Spectroscopy

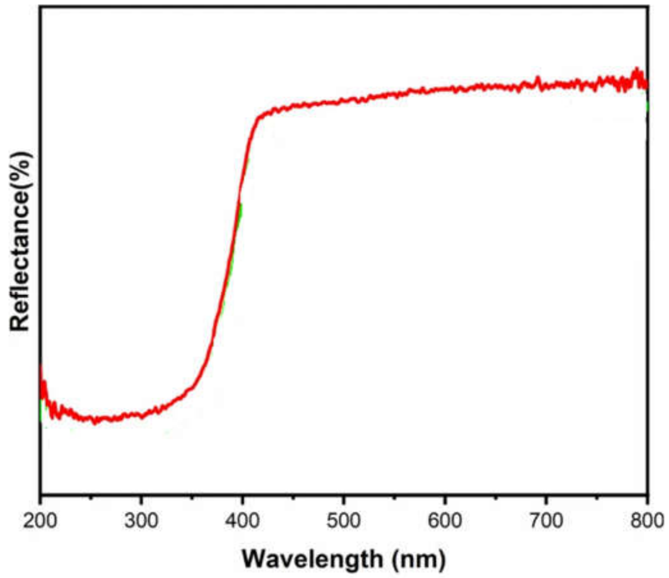

Figure 3. UV–Visible reflectance spectrum of TiO_2 nanoparticles

The UV–Visible DRS spectrum exhibited strong absorption at ~385 nm, indicating charge transfer from O 2p to Ti 3d orbitals. This optical behavior confirms the photocatalytic suitability of the synthesized TiO_2 nanoparticles.

4.4 SEM and EDS Analysis

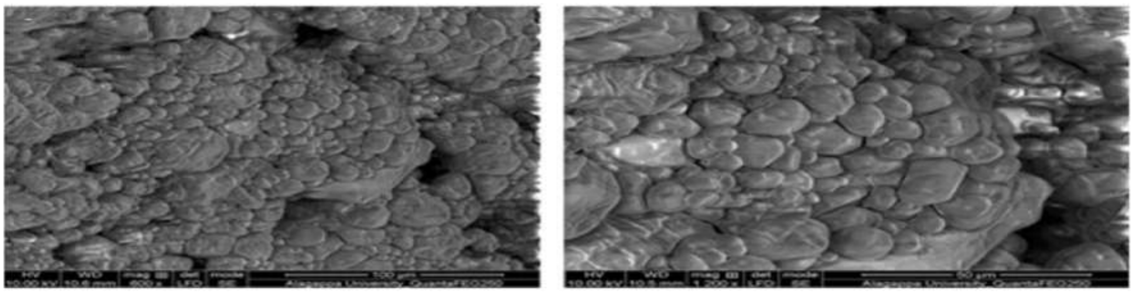

Figure 4. SEM images of chemically synthesized TiO_2 nanoparticles

SEM images revealed nearly spherical TiO_2 nanoparticles with mild agglomeration. The particle size observed from SEM correlated well with XRD results. EDS confirmed the presence of titanium and oxygen elements without impurities.

5. Results

The chemical hydrothermal synthesis route successfully yielded crystalline TiO_2 nanoparticles with controlled morphology and significant functional performance. XRD analysis confirmed the formation of phase-pure rutile TiO_2 with an average crystallite size ranging from 31 to 42 nm. FTIR spectra verified the presence of Ti–O and Ti–O–Ti bonding along with surface hydroxyl groups, which play a critical role in photocatalytic reactions. UV–Visible spectroscopy demonstrated strong absorption in the near-UV region (~385 nm), indicating efficient photoexcitation capability. SEM analysis showed nearly spherical nanoparticles with slight agglomeration, which is typical for chemically synthesized oxide nanoparticles. The synthesized TiO_2 nanoparticles exhibited effective antibacterial activity against both Gram-positive and Gram-negative bacteria and achieved approximately 82% degradation of methylene blue dye within 120 minutes under UV–Visible irradiation. These results collectively highlight the multifunctional potential of chemically synthesized TiO_2 nanoparticles for environmental and biomedical applications.

6. Photocatalytic and Antibacterial Performance

6.1 Photocatalytic Degradation of Methylene Blue

The photocatalytic efficiency of TiO_2 nanoparticles was evaluated using methylene blue as a model organic pollutant. Upon UV–Visible light irradiation, electron–hole pairs were generated, leading to the formation of highly reactive hydroxyl and superoxide radicals. These reactive species effectively oxidized and decomposed the dye molecules. The observed degradation efficiency (~82% in 120 minutes) confirms the strong oxidative capability of rutile-phase TiO_2 nanoparticles synthesized via the chemical hydrothermal method.

6.2 Antibacterial Activity

The antibacterial activity of TiO_2 nanoparticles was assessed using the agar diffusion method. The nanoparticles showed clear zones of inhibition against both Gram-positive and Gram-negative bacterial strains. The antibacterial mechanism is attributed to the generation of reactive oxygen species, disruption of bacterial cell membranes, and oxidative damage to intracellular components. The results indicate that chemically synthesized TiO_2 nanoparticles possess broad-spectrum antibacterial properties.

7. Conclusion

In the present study, TiO_2 nanoparticles were successfully synthesized using a purely chemical hydrothermal method employing titanium tetra isopropoxide as a precursor. Structural characterization confirmed the formation of crystalline rutile-phase TiO_2 nanoparticles with nanoscale dimensions. The presence of surface hydroxyl groups and strong UV absorption enhanced the photocatalytic efficiency of the nanoparticles. Morphological studies revealed nearly spherical particles with slight agglomeration. The synthesized TiO_2 nanoparticles demonstrated excellent photocatalytic degradation efficiency toward methylene blue dye and notable antibacterial activity against different bacterial strains. These findings confirm that chemical hydrothermal synthesis is a reliable and scalable method for producing high-performance TiO_2 nanoparticles suitable for environmental remediation, wastewater treatment, and biomedical applications.

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