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Hydrothermal synthesis of zinc stannate nanoparticles for antibacterial applications

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Abstract

A facile and economical hydrothermal method was used to synthesise Zn_2SnO_4 nanoparticles with cubic spinel structure. The crystallography and optical properties of the as-synthesised nanoparticles were studied using X-ray diffraction (XRD) and UV–visible spectroscopy (UV–vis). The morphology of the nanoparticles was observed using field emission scanning electron microscopy (FESEM). The synergistic antibacterial effect of Zn_2SnO_4 nanoparticles against Gram-positive and Gram-negative pathogenic bacteria was investigated. These results indicate that the Zn_2SnO_4 nanoparticles have potent antibacterial activity against both Gram-positive and Gram-negative bacteria and can be used as a bactericidal agent to prevent and control the spread and persistence of infectious diseases.

Keywords: Zinc stannate; Hydrothermal method; Antibacterial property

1. Introduction

Microbes and humans have forged a unique and largely beneficial relationship, but emerging infectious diseases continue to be one of the daunting challenges worldwide, leading to the upsurge in the investigation of nanomaterials. Given that the bacteria have developed resistance against many common antibacterial agents, there is a need for concrete advances in developing effective antibacterial therapeutic agents. Significant efforts have been directed towards the development of metal oxide nanoparticles, which are demonstrated to be effective for treating infectious diseases to combat antibiotic-resistant bacteria [1,2]. Recently, zinc-based stannate materials have attracted considerable

Abbreviations: XRD, X-ray diffraction; UV–vis, UV–visible spectroscopy; FT-IR, Fourier transform infrared spectroscopy; FESEM, field emission scanning electron microscopy; NZ, no zone; NPs, nanoparticles.

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attention due to their versatile applications in diverse fields, including photoelectrochemical cells, transparent conductive electrodes, Li-ion batteries, photocatalysts, and sensors [3–10]. Researchers have developed different techniques to synthesise zinc stannate nanostructures, which include solvothermal [11], high-temperature calcination [12], solution combustion [13], precipitation method [14], sol–gel [15], and hydrothermal reaction [5,7,16–19]. The hydrothermal synthesis has been demonstrated beyond doubt to be the most efficient method for growing zinc stannate nanostructures with various morphologies, such as cubes, spheres, and rods, by varying the chemicophysical parameters. Although the antibacterial behaviour of many metal oxides has been investigated, the studies on the antibacterial potential of zinc stannate nanoparticles are still at a nascent stage. Considering the potential toxicity of metal oxide nanoparticles to pathogenic bacteria, we report the antibacterial efficacy of Zn_2SnO_4 nanoparticles prepared via hydrothermal method. In this study, we investigated their structural and optical properties and their antibacterial activity against Gram-positive (*Staphylococcus aureus*, *Bacillus subtilis*) and Gram-negative (*Klebsiella pneumonia*, *Escherichia coli*) bacteria. To that end, this report describes the first systematic study on the antibacterial properties of Zn_2SnO_4 nanoparticles.

2. Materials and methods

2.1. Materials

Zinc chloride, tin chloride pentahydrate and sodium hydroxide (NaOH) were purchased from Sigma Aldrich. Double distilled water is used throughout the experiment.

2.2. Preparation of Zn_2SnO_4 nanoparticles

Zn_2SnO_4 nanoparticles were synthesised via hydrothermal method using NaOH as a mineraliser. In a typical procedure, the ratio of Zn:Sn:NaOH is 2:1:8. Zinc chloride and tin chloride pentahydrate were completely dissolved in double-distilled water to form a transparent solution under magnetic stirring for 3 h. NaOH was subsequently added drop-wise into the mixture to form a white slurry. The precursor solutions were maintained at a pH of 8. After stirring for 30 min, the final mixture was transferred into a Teflon line stainless steel autoclave with a filling capacity of 80%. The autoclave was maintained at 200 °C for 24 h and cooled naturally to room temperature. The resulting nanoparticles were separated from the reaction solution by centrifugation and washed repeatedly with deionized water and ethanol. Finally, the washed particles were dried at 80 °C for 20 h to obtain the powdered sample.

2.3. Analysis of Zn_2SnO_4 nanoparticles

The optical absorption spectra of Zn_2SnO_4 nanoparticles were obtained using a Perkin Elmer Lambda 25 UV-Vis spectrometer in the wavelength range of 200–800 nm. The as-synthesised NPs were pressed into a pellet, and FT-IR spectrum of the pellet was recorded in the region 4000–400 cm^{-1}. The X-ray diffraction patterns was recorded using a Rich Seifert diffractometer with monochromatic CuK_α ($\lambda = 1.5406$ Å) radiation in the 2θ range of 10–80°. The morphology of the ZnO and Zn_2SnO_4 nanoparticles was observed using a FESEM (Field emission scanning electron microscopy).

2.4. Antibacterial assay

The antibacterial activities of the as-synthesised Zn_2SnO_4 nanoparticles were evaluated using the quantitative well diffusion assay. All glassware, media, and reagents used for this test were sterilised in an autoclave at 121 °C for 15 min. The Mueller Hinton agar was used as a test medium for antibacterial susceptibility testing. Gram-positive (*S. aureus*, *B. subtilis*) and Gram-negative (*K. pneumonia*, *E. coli*) bacteria were used as the model test strains. Microbes were streaked on the plate surface using a sterile cotton swab. A sterile cork borer (8 mm diameter) was used to make five wells. The four different concentrations (250, 500, 750, and 1000 μg) of Zn_2SnO_4 nanoparticle suspension were filled in the wells. The well plates were incubated at 37 °C for 24 h, and they were examined for the effectiveness of Zn_2SnO_4 nanoparticles by measuring the zone of inhibition.

3. Results and discussion

The powder XRD pattern of the as-synthesised sample is shown in Fig. 1. The diffraction pattern matches notably well with the standard JCPDS powder diffraction file no. 24-1470. The pattern reveals the formation of face-centered cubic spinel structure with the lattice constant $a = 8.657$ Å. In a hydrothermal process, the alkaline concentration is a key factor that influences the crystallinity, morphology, and size of the as-synthesised sample [19]. The XRD pattern indicates that the reaction is complete and the as-synthesised nanoparticles are close to the expected stoichiometric ratio. The mean