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Synthesis of Zinc Oxide nanoparticles and its photocatalytic application

Abstract

Zinc Oxide nanoparticles as photocatalyst were synthesized by a simple synthetic route involving hydrothermal method at 150°C, and it is effectively characterized by various techniques, such as XRD, FESEM, and UV-vis DRS. UV-vis DRS and showed a reflection edge with corresponding energy at 3.5 eV. The photocatalytic degradation activity of the Zinc Oxide nanoparticles was investigated against the degradation of methylene blue under natural sunlight irradiation. About 75% degradation of methylene blue is observed in 150 min.

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Introduction

The widespread use of natural dyes in industries that produce textiles and fabrics contributes to water pollution. Water bodies are often contaminated with leftover dyes that enter directly into the environment from dye and textile factories (Homem and Santos 2011; Rivera-Utrilla et al. 2013; Qin et al. 2021). Methylene blue, a cationic dye commonly used for coloring fabrics, is one such dye that is prevalent in this contamination. Methylene blue, being soluble in water, is extremely stable in water environments. It does not easily break down naturally, is not biodegradable, and is known to be carcinogenic, posing a threat to both humans and aquatic life (Michael et al. 2013; Dinh et al. 2017). Because of their persistent nature in water, these leftover dyes are not easily broken down, leading to contamination of groundwater and surface water. This contamination can result in the spread of diseases that are harmful to both animals and humans. While various methods have been employed to treat wastewater, some of these approaches have drawbacks such as producing excessive sludge and generating other harmful byproducts (Kumar and Dutta 2022a; Kumar and Kumar 2022; Kumar et al. 2022a; Mukherjee and Vellenki 2022).

Semiconductor-based photocatalysts, like zinc oxide and titanium dioxide nanoparticles, are frequently used to remove water pollutants through photocatalysis (Bisht et al. 2022; Kumar and Dutta 2022b; Kumar et al. 2022b). These materials are effective at degrading organic dyes, but they rely on ultraviolet light for activation due to their large band gap methods (Durán-Álvarez et al. 2016; Calvete et al. 2019; Akbari et al. 2021).

In recent decades, tin-based photocatalysts have emerged as a promising new class for wastewater treatment. They're used in various applications like producing ammonia from nitrogen, splitting water, reducing CO2, and breaking down water pollutants through photocatalysis (Nenavathu et al. 2013; Schneider et al. 2014). These photocatalysts have a band structure that makes them responsive to visible light, with a well-distributed valence band that reduces charge recombination. This makes them effective for treating wastewater compared to metal oxides. Another type of photocatalyst is metal sulfides, which mainly utilize visible light and even near-infrared light for catalytic reactions (Zhang et al. 2011).

The ability to harvest light makes these photocatalysts suitable for use with visible light. Zinc oxide has a band gap ranging between 3.1-3.3 eV, making it suitable for both visible and UV light activation. Additionally, it's non-toxic, cost-effective, and chemically stable in neutral and acidic conditions. These properties make zinc oxide an efficient photocatalyst for visible and UV light. For effective photocatalysis with visible light, a semiconductor must have a wide band gap, low charge recombination rate, and conduction band at a more negative potential than the valence band (Wang et al. 2014).

Experimental Section

Methodology

Synthesis of Zinc Oxide nanoparticles

Zinc Acetate dihydrate (0.4M) was mixed in 30 mL 0.5 M sodium hydroxide of deionized water. After stirring both the solutions for 30 min separately, with continuous magnetic stirring. After 1 hr constant stirring, the mixture was poured into a Teflon-lined stainless-steel autoclave and heated under a controlled temperature of 150 °C for 12 h. The finally prepared precipitates were washed with DI water and C_2H_5OH and was dried in an oven at 50 °C. The synthesized is photocatalyst is further used for the degradation of dyes. The synthesis route is shown in Figure 1.

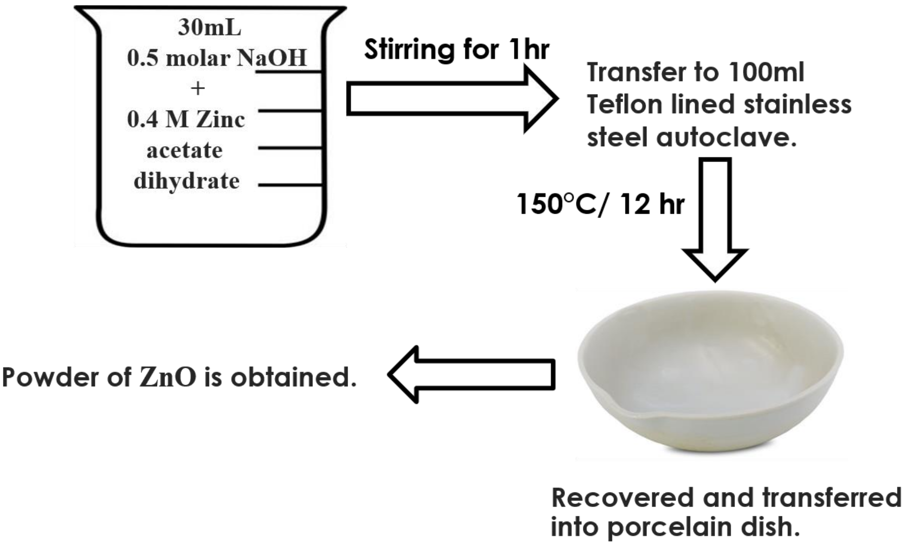

Figure 1. Synthesis route of Zinc Oxide nanoparticles

Results and discussions

XRD analysis

The XRD plot of Zinc Oxide was recorded on X-ray diffractometer. The XRD peaks for Zinc Oxide were detected at 2θ = 2θ=15.5°, 23.4°, 25.2°, 30.6°, 36.3°, 37.7° and 39.7° which are matched to (1 0 1), (1 1 0), (1 0 2), (1 0 1), (1 0 3), (1 1 0) and (1 1 1) monoclinic planes of zinc Oxide (Card No.- 79-1868) (Figure.2).

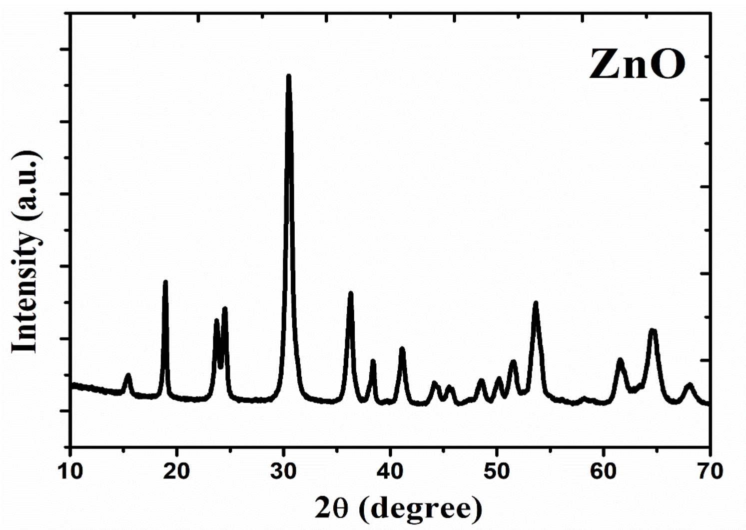

Figure 2. XRD Zinc Oxide nanoparticles

FE-SEM analysis of Zinc Oxide

The FE-SEM image of Zinc Oxide nanoparticles was recorded by scanning electron microscope, shows nanoplate-like structures with a diameter in the range of 80-90 nm (Figure. 3). The FESEM indicates the presence of agglomerated nanoparticles of zinc oxide, which confirm the high adsorption of dye molecules which result in the good removal of dye molecule from the waste water.

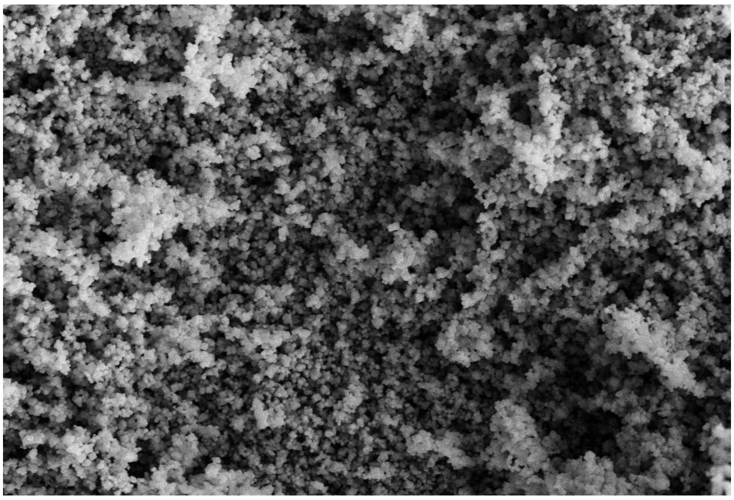

Figure 3. FE-SEM image of Zinc Oxide nanoparticles

Optical analysis

The pure zinc oxide nanoparticles absorb in the UV-visible light region (Figure.4). The UV-vis DRS spectra were changed into absorption spectra by using (K-M function) Kubelka-Munk (Kortüm 1969), and the band gap was calculated from the Taucs plots [22], Figure. shows Tauc's plots of ZnO photocatalyst. The optical band gap of ZnO was determined to be 3.5 eV.

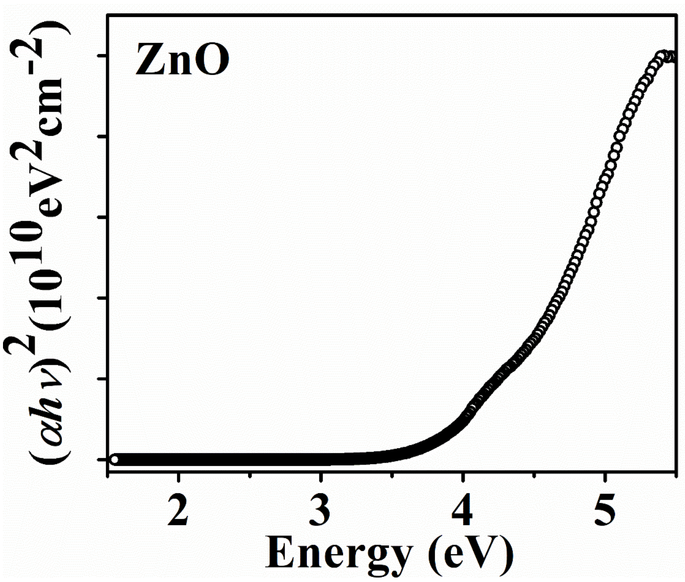

Figure 4. Tauc's plot of pure ZnO

Photocatalytic activity

The sunlight-mediated photocatalytic degradation of MB dye (10 mg/L) by the zinc oxide nanoparticles is shown in Figure. 5. The zinc oxide nanoparticles show the photocatalytic performance of about 75 % methylene blue dye degradation after 150 min of sunlight exposure. Figure.5 shows the UV-vis absorption spectra, which shows the change in concentration of methylene blue dye during the photocatalytic degradation. The decrease in the intensity of the absorption peak of methylene blue dye (664 nm) was observed over 150 min period of sunlight irradiation.

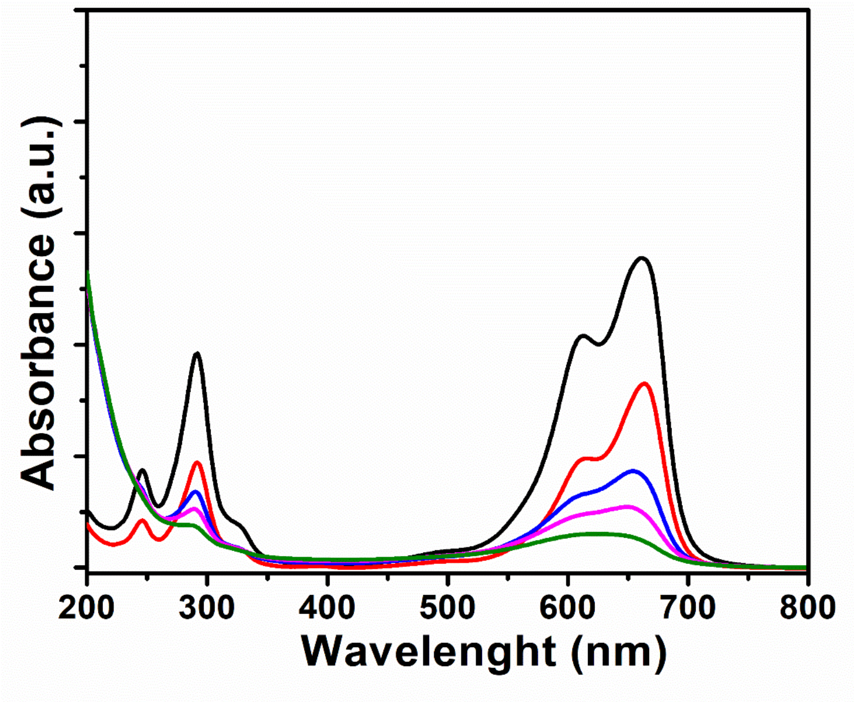

Figure 5. UV-is absorbance spectra of MB dye solution

Conclusions

A simple synthetic route of hydrothermal has been used for the synthesis of zinc oxide nanoparticles photocatalyst. The zinc oxide photocatalyst shows photocatalytic performance towards the degradation of 75 % of methylene (MB) under sunlight irradiation. zinc oxide is an effective UV-visible light photocatalyst option for removing various organic dyes in aqueous media due to its strong photocatalytic activity.

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