Water Science and Engineering 2023, 16(1): 76–82

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Water Science and Engineering

journal homepage: wse.hhu.edu.cn

Waste fly ash–ZnO as a novel sunlight-responsive photocatalyst for dye discoloration

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Received 20 May 2022; accepted 24 October 2022
Available online 3 November 2022

Abstract

Treating waste with a waste material using freely available solar energy is the most effective way towards sustainable future. In this study, a novel photocatalyst, partly derived from waste material from the coal industry, was developed. Fly ash hybridized with ZnO (FA–Zn) was synthesized as a potential photocatalyst for dye discoloration. The synthesized photocatalyst was characterized by X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and ultraviolet–visible/near infra-red spectroscopy. The photocatalytic activity was examined with the discoloration of methylene blue used as synthetic dye wastewater. All the experiments were performed in direct sunlight. The photocatalytic performance of FA–Zn was found to be better than that of ZnO and the conventionally popular TiO_2. The Langmuir–Hinshelwood model rate constant values of ZnO, TiO_2, and FA–Zn were found to be 0.016 min^{-1}, 0.017 min^{-1}, and 0.020 min^{-1}, respectively. There were two reasons for this: (1) FA–Zn was able to utilize both ultraviolet and visible parts of the solar spectrum, and (2) its Brunauer–Emmett–Teller surface area and porosity were significantly enhanced. This led to increased photon absorption and dye adsorption, thus exhibiting an energy-efficient performance. Therefore, FA–Zn, partly derived from waste, can serve as a suitable material for environmental remediation and practical solar energy applications.

Keywords: Photocatalyst; ZnO; Fly ash; Geopolymer; Wastewater treatment; Methylene blue

1. Introduction

While stringent and government-enforced norms regarding the discharge of wastewater into natural water bodies are necessary to combat the issue of water pollution from chemical industries, advanced oxidation processes, such as photolytic processes, ozonation, Fenton reactions, piezocatalysis, ultrasonic/hydrodynamic cavitation, photochemical processes, and (photo)electrocatalysis (Zheng et al., 2023; Li et al., 2021a, 2022; Wang et al., 2021) have been found to be more effective and popular. As an advanced oxidation treatment process, solar photocatalysis can degrade organic pollutants into clean water and CO_2 (Fujishima, 2008; Herrmann, 1995, 2010a, 2010b).

TiO_2 and ZnO are conventionally popular photocatalysts (Tian et al., 2011; Chen et al., 2008, 2009). However, owing to their characteristic band gap (around 3.2 eV), they can only utilize ultraviolet (UV) light, which is around 4% of the solar spectrum. Several studies have been conducted to improve the efficacy of TiO_2 and ZnO by causing them to work in the visible region (around 47% of the solar spectrum). One method of increasing the effectiveness of a photocatalyst is to hybridize the photocatalyst with a material that has a relatively low band gap. As a result, the hybridized photocatalyst can utilize visible light as well (Yuan et al., 2021; Fouad et al., 2021; Li et al., 2021b; Ye et al., 2021; Murgolo et al., 2021). Another effective method is to load the photocatalyst onto a substance with a high porosity and large surface area.

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Peer review under responsibility of Hohai University.

https://doi.org/10.1016/j.wse.2022.11.001