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Integrating ZnO with fibrous silica zirconia p-n heterojunction for effective photoredox of hexavalent chromium and congo red

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ABSTRACT

The co-occurrence of congo red (CR) and hexavalent chromium (Cr (VI)) has presented a significant challenge to the remediation process. Particularly, the efficient elimination of those toxic dyes and Cr (VI) from wastewater by photocatalysis is still a challenge due to the unsatisfactory photocatalytic efficiency and difficult separation of the photocatalyst. Herein, the current study focused on the simultaneous photocatalytic oxidation of CR and reduced Cr (VI) using zinc oxide supported on the fibrous silica zirconia (ZnO/FSZr) catalysts. The synergistic effect of ZnO and FSZr results in faster charge migration and more efficient separation of photogenerated charge carriers. Remarkably, simultaneous remediation of Cr (VI) and CR over 0.5 g/L of 10ZnO/FSZr showed 78% and 100% photocatalytic efficiency, respectively, under visible light irradiation within 3 hours at pH 3 compared to the individual system. The ZnO impedes the recombination of charge carriers through forming p-n heterojunctions, as confirmed by photoluminescence and Mott-Schottky analysis. Scavenger tests proved that photogenerated electrons were the main species that reduced Cr (VI) into Cr (III). Holes and hydroxyl radicals also played a part in the photooxidation of CR. The p-n heterojunction demonstrated exceptional cyclic stability even after four continuous cycles, a critical attribute for real-world implementations. Additionally, the visible light (VIS)-ZnO/FSZr system's estimated electrical energy per order consumption was calculated to be 215 kWh m^{-3}, and its operational cost utilization of 10.9 USD demonstrated that this process is exceptionally practical and cost-effective in comparison to alternative photocatalytic processes (VIS-FSZr and VIS).

1. Introduction

Dyes in wastewater released from numerous industries, including paper, leather, cosmetics, and textiles, endanger aquatic bodies [1,2]. The release of dyeing effluent into aquatic environments can result in detrimental environmental outcomes, including the potential for mutagenic or carcinogenic effects that could affect ecosystems [3,4]. Notably, congo red (CR) is one of the azo dyes, which widely used in the textile industry [5,6]. CR is challenging to eliminate due to its resistance to biological degradation and the presence of recalcitrant organic molecules like benzidine [7]. In addition to dyes, textile effluents can contain trace levels of heavy metals such as hexavalent chromium (Cr (VI)), a common morden in color-fixing chemicals [8–10]. Cr (VI) is a mutagen, carcinogen, and teratogen due to its strong oxidising capabilities [11]. The provisional guideline for permissible levels of Cr (VI) is about 0.05 mg L^{-1} [12,13]. Given these environmental concerns, it is imperative to develop remediation approaches that simultaneously address the removal of dyes and Cr (VI) from the wastewater generated by the leather and textile industry.

Various water remediation techniques, including adsorption, ion exchange, precipitation and coagulation, filtration, biological treatment, and membrane separation, have been employed in the textile

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