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Visible light photocatalytic degradation of thiophene using Ag–TiO₂/multi-walled carbon nanotubes nanocomposite

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Abstract

Ag–TiO₂ nanocatalyst, supported on multi-walled carbon nanotubes, was synthesized successfully via a modified sol–gel method, and the prepared photocatalyst was used to remediate aqueous thiophene environmentally by photocatalytic oxidation under visible light. The prepared Ag–TiO₂/multi-walled carbon nanotubes nanocomposite photocatalyst was characterized through X-ray diffraction, Brunauer–Emmett–Teller (BET), transmission electron microscopy, and UV–vis spectra (UV–vis). The results showed that both Ag and TiO₂ nanoparticles were well-dispersed over the MWCNTs and formed a uniform nanocomposite. Ag doping can eliminate the recombination of electron–hole pairs in the catalyst, and the presence of MWCNTs in the TiO₂ composite can change surface properties to achieve sensitivity to visible light. The optimum mass ratio of MWCNT:TiO₂:Ag was 0.02:1.0:0.05, which resulted in the photocatalyst's experimental performance in oxidizing about 100% of the thiophene in a 600 mg/L solution within 30 min and with 1.4 g L⁻¹ amount of catalyst used.

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1. Introduction

Photocatalytic degradation of harmful organic compounds is of great interest and importance for environmental protection [1–5]. It has been demonstrated that many organic pollutants present in water or air streams can be removed by means of photocatalytic oxidation. Sulfur-containing organic compounds are a class of pollutants in fuel oils, and these pollutants are difficult to remove [6]. Thiophene, one of the main sulfur-containing compounds in gasoline, is the most difficult to oxidize by conventional oxidative desulfurization processes. The inertness of thiophene in the oxidative desulfurization is mainly due to the aromaticity and the low electron density on the sulfur atom, which makes it harder for the thiophene molecule to oxidize. It is ideal, then, to develop an effective photocatalyst to remove sulfur-containing compounds in gasoline by photocatalytic oxidation. The material's photocatalytic efficiency is determined by particle size, band gap, surface area, life-time of the electron–hole pair, stability, and

other physical and chemical properties [7]. Researchers have explored various pathways to enhance the properties of catalysts toward a desired function. Such pathways include altering the preparation method, oxide-mixing, and doping [8–12]. An important issue in the choice of a photocatalyst is its band gap width. For example, the band gap of TiO₂, the most popular photocatalyst, lies within the range 3.0–3.2 eV. TiO₂ has been subjected to numerous experiments—such as mixing with semiconductors, doping with various metals, and various preparation methods—in an effort to increase its catalytic activity, fine-tune its band gap and surface area, and decrease the possibility of charge carriers recombining [13–15]. Therefore, it is essential to promote the TiO₂ visible-light activities by extending its absorption threshold from the UV-light region to the visible-light region and reducing the recombination of the photo-generated electron/hole. Recently, different routes have been used to enhance the photocatalytic activity of TiO₂. One of the routes is to modify the surface of TiO₂ by doping it with another metal. In this case, the doping metal acts as a sink to collect photogenerated electrons from the conduction band of the TiO₂ semiconductor, and hence it hinders the recombination of photogenerated electrons and

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