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Effect of Deposition Temperature on the Growth of Tungsten Oxide Layer Deposited on Polyethylene Terephthalate Fibers

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Abstract

Photocatalytically active tungsten oxide (WO_x) layer were deposited on polyethylene terephthalate (PET) fibers using sol gel method in order to minimize the lost of WO_x into flowing water during photocatalysis process. This helped to reduce the deterioration of photocatalytic performance of WO_x over time as well as the formation of secondary pollutant by WO_x particles. In this work, the optimum deposition condition of WO_x layer was achieved using 90 ^oC deposition temperature. The photocatalytic activity of WO_x layer in removal of Rhodamine B (RhB) dye followed first order kinetics. As much as 60.04%, and 32.18% of RhB dyes were removed using WO_x layer grown on PET surface under UV light and visible light irradiation, respectively. Under UV light exposure and continuous circulation of RhB solution with a flow rate of 35 mL/min, the wastewater purifier loaded with WO_x layer based PET fibre showed 54.18% photodegradation efficiency. The repeated cycles of single WO_x layer on PET fibers upon photodegradation of RhB observed good stability and reusability. Scavenger tests indicated that the holes and hydroxyl radicals were the dominant reactive species in photocatalytic degradation of RhB dye. Based on these findings, the photodegradation mechanism of RhB dye by WO_x layer was proposed.

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Keywords: Tungsten oxide; PET fibers; Rhodamine B; Photocatalytic; Scavenger test.

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1. Introduction

Textile industries produce large volumes of colour dye effluents, which largely are toxic and non-biodegradable [1]. Various physical and chemical processes such as disinfection, precipitation, flocculation, reverse osmosis, adsorption, membrane separation and chemical oxidation are used for organic dyes removal from textile effluents. Advance oxidation processes (AOPs) using semiconductor photocatalysts have been found to be an alternative wastewater treatment method. In fact, intensive research have been carried out to explore the applications of semiconductor photocatalysts in the fields of air and water remediation [2], self-cleaning surfaces, self-sterilizing surfaces [3], and hydrogen generation using sunlight [4].

Particularly, titanium dioxide (TiO_2) is the most common study semiconductor photocatalyst. Nevertheless, it absorbs only a small portion of solar spectrum in the UV region attributed to its wide bandgap (3.27 eV) [5]. It is important to transform the semiconductor materials absorbs the visible light spectrum. Hence, research has been diverted to other alternatives instead of TiO_2. Tungsten oxide semiconductor has a bandgap between 2.4 to 2.8 eV (442.8 - 516.6 nm). Therefore, it could absorb ultraviolet and visible regions of the solar spectrum [6,7]. It is an inexpensive material. With its remarkable stability in acidic environments, it is a good candidate for treatment of wastewater that possibly contaminated by acids [3]. It was reported that WO_x displayed a better photocatalytic activity than Fe_2O_3, NiO and TiO_2 [8].

However, using of semiconductor photocatalysts in particle form has their own drawbacks. The particles are easily washed away by running water in the photocatalytic process. This results in deterioration of photocatalytic performance over time and generation of secondary pollutants. These secondary pollutants, in the form of sludge, will require additional separation process e.g. filtration or centrifugation, from liquid. These processes can be costly and time consuming. Besides, these particles may ultimately affect the ecosystem if failing of removing them from the water body.

In order to rectify the above issue, attempts have been made to grow semiconductor photocatalysts on solid support. For instance, ZnO nanorods were grown on stainless steel wire via chemical vapor deposition method [9]. The stainless steel wire could reduce the amount of ZnO nanorods that being washed away by the flowing water during water treatment process. On the other hand, semiconductor photocatalysts that grown on PET fibers substrate offers more flexibility in handling compared to the rigid substrate. Semiconductor photocatalysts that has been reported grew on PET fibers are ZnO nanorods [10] and β-MnO nanotubes [11] by using low temperature sol-gel technique. This work presents the effect of deposition temperature on the coverage of WO_x layer deposited on the PET fibers by sol-gel method, its photocatalytic performance in degrading of RhB organic dye under UV and visible light irradiation, as well as associated photodegradation mechanism of WO_x layer based on scavengers study.

2. Experiments

2.1. Synthesis of WO_x layer grown on PET fibers

A typical synthesis process of WO_x layer on PET fibers was conducted as followed. A layer of 1-dodecanethiol ($CH_3(CH_2)10CH_2SH$) (5 wt. %) was coated on the fibers by immersing the fibers into 1-dodecanethiol solution for 2 h. The purpose of 1-dodecanethiol layer was to improve the adhesion of WO_x layer in the subsequent step. Next, a sol solution was prepared for the deposition of WO_x seed layer onto the fibers. A 0.4 M sodium tungstate dehydrate ($Na_2WO_4.2H_2O$) was prepared in 15 ml deionized water. Then, 7 ml of 3 M hydrochloric acid (HCl) was added into the solution under continuous stirring condition at 90 °C. This solution was kept at 90 °C for 2 h. The solution was then centrifuged at 3000 rpm for 40 min. The fibers were dipped into the sol solution for 21 h at 90 °C for the deposition of WO_x layer. The remaining WO_x layer in the sol solution were filtered and dried in the oven at 100 °C. The effect of deposition temperature on the coverage of WO_x layer onto the PET fibers was studied by varying the temperature at 70, 80 and 90 °C.