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Investigation of Dye Photodegradation of Commercial Titania Supported On TUD-1 Mesoporous Material

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Abstract
Methylene blue is a type of general dye that is highly toxic and can cause cancer. Titanium dioxide (TiO_2) has been extensively studied as a photocatalyst for decomposing organic pollutants. However, a major drawback of TiO_2 is its wide band gap, which limits its photocatalytic activity to the ultraviolet (UV) region and restricts its effectiveness under visible light. To address this limitation, TiO_2 was supported with TUD-1, a mesoporous material containing active metal ions. The characterization of all the synthesized TiO_2/TUD-1 photocatalysts was carried out. X-ray diffraction analysis (XRD) patterns showed a broad band that represents the amorphous structure of mesoporous TUD-1 silica and different crystal phases of TiO_2 such as anatase or rutile. Fourier transform infrared spectroscopy (FTIR) analysis depicted broad absorption in the range of 400–800 cm^{-1}, which corresponds to the stretching vibrations of the Ti-O-Ti bonds in the crystal lattice. The strong absorption bands around 1100–1200 cm^{-1}, correspond to the stretching vibrations of the Si-O-Si bonds. The photocatalytic activity of the synthesized samples was tested by photodegradation of methylene blue under visible light irradiation. The results indicated the anatase TiO_2 has been enhanced by 37% after being supported on TUD-1. The photocatalytic activity of the sample increased with the increasing amount of TiO_2 in TUD-1.
Keywords: TUD-1, Titanium dioxide (TiO_2), Methylene blue, dye photodegradation

1. Introduction

The use of synthetic colours in textile industry contributes significantly to water pollution. These colours are released into the water as wastewater since they do not adhere firmly to the fabric. This continuous discharge of untreated wastewater from numerous textile factories has harmful effects on the environment and human health (Jessica, B. et al., 2020). Textile dyes can pose a threat to aquatic organisms, potentially entering the food chain. They also degrade the visual quality of water bodies by increasing biochemical and chemical oxygen demand, hindering photosynthesis, and causing recalcitrance, and bioaccumulation, as well as potential toxicity, mutagenicity, and carcinogenicity.

To minimize the negative impacts on the environment, human health, and natural water resources, it is crucial to treat wastewater containing dyes using eco-friendly technologies (Al Tohamy, R. et al., 2022). Advanced oxidation processes (AOPs) have emerged as practical approaches for the destruction of dyes present in water systems. These processes operate by generating highly reactive hydroxyl radicals (OH•) that effectively decompose a wide range of pollutants in a non-selective and rapid manner (Fadoua, S. et al., 2020). AOPs offer a versatile method for the overall degradation of diverse organic pollutants (Lydia, C. et al., 2019). Photocatalytic degradation, using non-metals, semiconductors, nanoparticles, and polymers, is a popular area of scientific research to improve the effectiveness of these reactions (Al Tohamy, R. et al., 2022).

Titanium dioxide (TiO_2) has been utilised well as a photocatalyst in a number of chemical processes because TiO_2 is readily available, cost-effective, and non-toxic. However, the main limitations

of TiO_2 as a photocatalyst is its large band gap. For TiO_2, the band gap is relatively large, which means that only high-energy photons, such as those in the ultraviolet (UV) range, can provide enough energy to excite electrons from the valence band to the conduction band. the material's large band gap restricts its photocatalytic uses (Ling, C.M. et al., 2020). Additionally, TiO_2 has a low surface area, which restricts the available surface sites for catalytic reactions. Moreover, the fast recombination rate of positive holes and electrons reduces the overall efficiency of TiO_2 as a photocatalyst (Ling, C.M. et al., 2021).

Technische Universiteit Delft-1 (TUD-1) material is a type of mesoporous silica that has gained significant attention due to its structural advantages, including a high surface area, as well as high thermal and mechanical stability. The effectiveness of the adsorption process using mesoporous silica largely depends on enhancing the surface properties through functionalization methods with appropriate functional groups (Khai Ooi, Y. et al., 2019). A series of TiO_2/TUD-1 samples were utilized as photocatalysts for the photooxidation of propane. In comparison to commercially available anatase powder, TiO_2 nanoparticles incorporated in TUD-1 demonstrated a significantly higher level of photochemical selectivity (Fadoua, S. et al., 2020).

In this study, the photocatalysts of commercial TiO_2 loaded TUD-1 were synthesized and characterized. Furthermore, the catalytic efficacy of TiO_2/TUD-1 photocatalysts for dye photodegradation was investigated. The percentage degradation rate for TiO_2 and TiO_2/TUD-1 was compared.

2. Methodology

The process of creating TUD-1 involved several steps. Initially, a mixture containing water, triethanolamine (TEA), tetraethylammonium hydroxide (TEAOH), and tetraethyl orthosilicate (TEOS) in a molar ratio of 1:0.5:0.1:11 was stirred for two hours. Subsequently, the solution was allowed to evaporate at room temperature for 24 hours. The resulting solution underwent 10 hours of hydrothermal treatment in an autoclave at 403 K. To remove the organic components, the mixture was first dried at 373 K and then calcined in air at 873 K for 6 hours.

To synthesize the TiO_2/TUD-1 photocatalyst, TUD-1 was mixed with anatase titanium dioxide. The mixture will be stirred for 2 hours before undergoing aging and evaporation. The resulting solution will be allowed to evaporate at room temperature for 24 hours, resulting in the formation of a solid gel. The gel will then undergo 10 hours of hydrothermal treatment in an autoclave at 403 K. To remove the organic components, the mixture will first be dried at 373 K and then calcined for 6 hours in air at 873 K. The resulting samples were denoted as TiO_2/TUD-1(x), where x represents the Si/Ti molar ratio, ranging from 10 to 50.

The properties of the synthesized TiO_2/TUD-1 photocatalysts were studied using several technique and instruments such as PerkinElmer Fourier transform infrared (FTIR) spectrometer using KBr technique and X-ray diffraction (XRD) with Bruker Advance D8 transmission diffractometer.

Prior to the photocatalytic testing, a solution 0.1 g of the photocatalysts, 100 mL of 15 ppm methylene blue was kept in dark to allow occurrence of physical adsorption. If any. Photodegradation of methylene blue was carried out at room temperature under irradiation of visible light for 5 hours.

3. Results and Discussion

The synthesized materials, TiO_2/TUD-1 appeared to be as greyish fine powder. XRD patterns of the prepared TiO_2/TUD-1(x) samples with various molar ratios of Si/Ti are shown in Figure 1. As observed, TiO_2/TUD-1 shows amorphous phases.

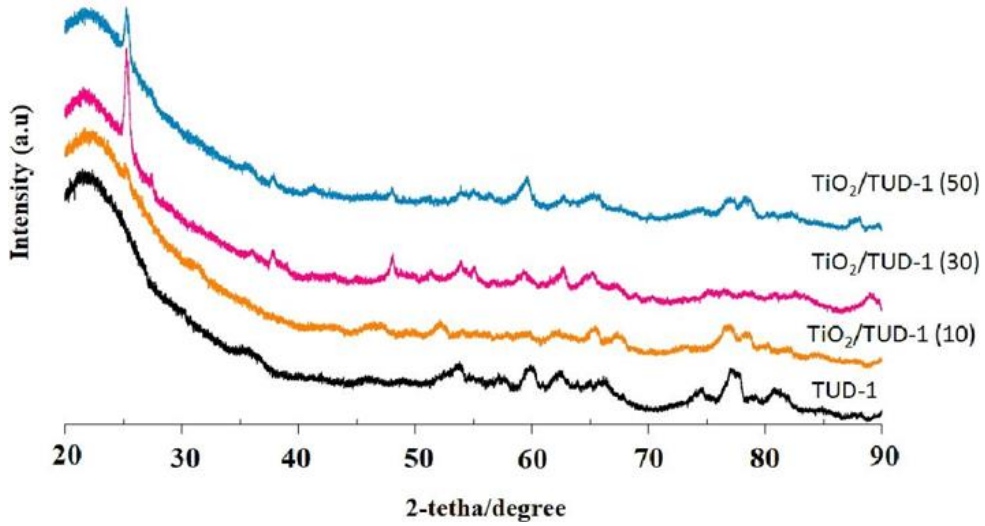

Figure 1. XRD patterns of TiO_2/TUD-1(x) materials with Si/Ti ratios

FTIR spectra of synthesized samples are shown in Figure 2. For the anatase TiO_2 sample, small peak at 1634 cm^{-1} was attributed to the bending of the O-H bonds of silanol groups and absorbed water (Harikrishnan, M. et al., 2018). The intensity of this band weakened with increasing Ti content, signifying a possible interaction of Ti with TUD-1. A broad band at around 3412 cm^{-1} was detected for anatase TiO_2, which was attributed to adsorbed H_2O molecule. For the TUD-1 and TUD-1 supported samples, bands at around 760 and 1100 cm^{-1} attributed to the symmetric stretching and asymmetric stretching of Si-O-Si, respectively were observed (Arora, S. et al., 2020). The presence of TiO_2 on TUD-1 decreased the intensities of TiO_2/TUD-1(30) and TiO_2/TUD-1(50).

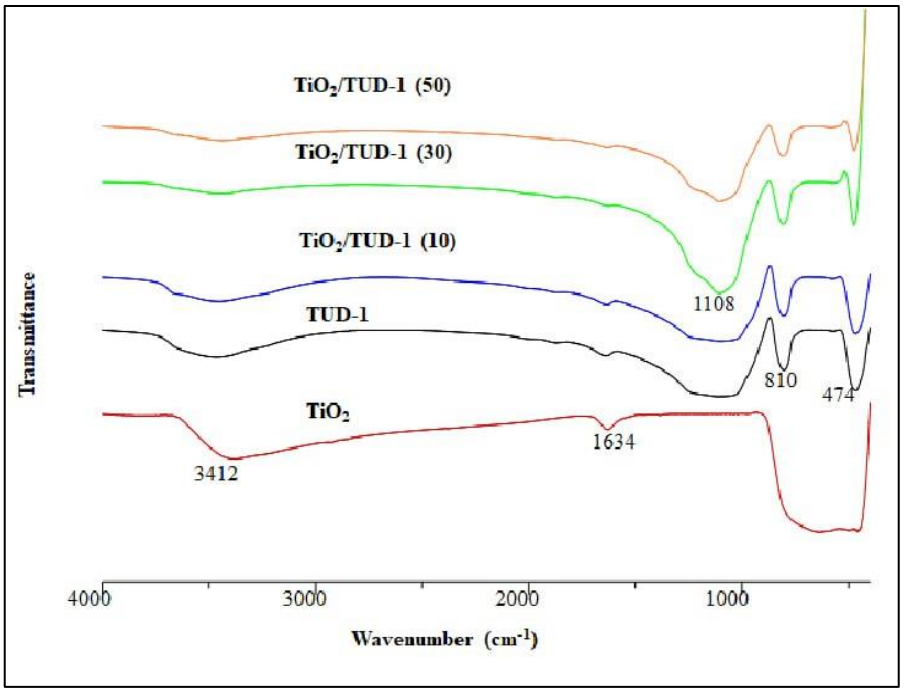

Figure 2. FTIR spectra of the synthesized samples

The photocatalytic activity of the materials was evaluated by assessing the photodegradation of methylene blue under visible light at room temperature. As can be seen in Figure 3, the photocatalytic degradation of all TUD-1-supported TiO_2 samples was higher than that of anatase TiO_2. The highest level of photocatalytic degradation was achieved when TiO_2/TUD-1(30) was used as the photocatalyst. The functionality of the support material, TUD-1, was proven by the increased photocatalytic conversion

of methylene blue compared to bare TiO_2. The results strongly suggested that the large surface area and high pore volume of the samples facilitated the dye's photodegradation.

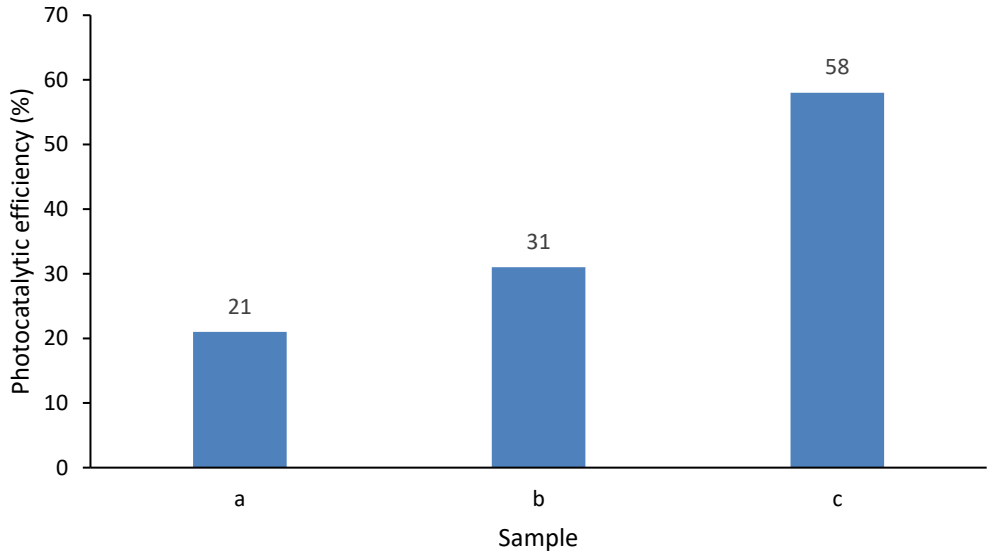

Figure 3. Photocatalytic performance of the synthesized samples (a) TiO_2, (b) TiO_2/TUD-1(10), (c) TiO_2/TUD-1(30)

4. Conclusion

The photocatalytic activity of TiO_2 was significantly enhanced of about 3-fold when supported on TUD-1 under visible light irradiation. The TiO_2/TUD-1(30) composite exhibited the highest photodegradation efficiency of 58% for methylene blue under visible light irradiation. Based on the obtained results, it can be concluded that TUD-1 could be a potential support material for commercial TiO_2 photocatalyst.

Acknowledgement

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