Photocatalytic for Decolorization of Synthetic Dye by TiO$_2$ under UV light Irradiation in Batch Reactor

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Abstract – The photocatalytic degradations of Rhodamine B, Malachite Green Crystal, Benefix Blue G, and Benewol Red synthesized dyes solution were studied in the presence of TiO$_2$ powder photocatalyst and UV light irradiation. Decolorization of the synthetic dyes solution (20 mg/L) was evaluated using the photocatalytic batch reactor under UV light irradiation. The batch photoreactor was set up in the stainless tank ($\pi \times 20^2 \times 50$ cm) with 5 UV fluorescence black light 8W lamps. The UV lamps were installed by fixing inside the side wall of the tank compartment. The effects of TiO$_2$ powder concentration of 0.05-0.15 g/100 mL dye solution in decolorization efficiency, type of dye sample were operated. The concentration of dye solution and time required of decolorize synthetic dye solution in process of the TiO$_2$ powder substrate were measured. UV-vis technique was used to study in the part of degradation of dye solution. The TiO$_2$ powder can effectively be used to decolorize the synthesis dye under UV light irradiation. The optimum condition for degradation of 20 mg/L synthetic dye solution, power of UV light of 40 W, and catalysts loading of 0.10 g/100 mL for degradation of dye solution photoreactor.

Keyword: photocatalytic, titanium dioxide, decolorization, UV light irradiation, photoreactor
1. Introduction

The textile industry is expanding worldwide especially in the developing countries. One form of the latter is the releasing of dyes into the natural water systems. The discharge of wastewater that contains high concentrations of dyes is a well-known problem associated with dyestuff activities. The release of this colored wastewater in the eco-system is a dramatic source of aesthetic pollution, eutrophication, and perturbation in aquatic systems. Their highly variable and complex chemical structures also make them difficult to remove using conventional wastewater treatment systems for example activated sludge treatment [1]. The known wastewater treatment processes nowadays are rather inefficient for this ever increasing problem. This leads to search for more effective method, low cost, and ease of use to degrade the dye into environmentally compatible products.

Dyes are a group of complex organic materials which enter the environment due to various processes like dyeing and completion in textile industry. Concerning usages, they are divided into different types, reactive, basic, and acidic [2]. Dyes are aromatic organic compounds, and as such are based fundamentally on the structure of benzene. Color in dyes is invariably explained as a consequence of the presence of chromophore that is atomic configurations and complex chain structure which sustainable in nature. Therefore discharge containing of the dyestuff is usually poisonous, resistant to biodegradation, and sustainable in environment. The darkness of the water will against the lighting pass through water so biodegradation will not be occurred by photosynthetic bacteria.

Advanced oxidation processes, particularly photocatalytic oxidation technology, offer promising wastewater treatment alternatives. Photocatalytic degradation process has been widely applied as techniques of destruction of organic pollutants in effluents and wastewater [3]. Titanium dioxide (TiO$_2$) has been extensively investigated as one of the most active semiconductor photocatalyst, capable for oxidizing various pollutants, non-toxic, chemically stable, inexpensive, and commercially available [3, 4]. TiO$_2$ as the catalyst would be the most attractive for photocatalysis with UV irradiated formation of electron hole pairs occurs, as in equation (1) and photogenerated holes, water molecules, and hydroxyl ions were adsorbed on the TiO$_2$ surface and changed to hydroxyl radicals, as in equation (2), a strong oxidizing agent, capable of mineralizing organic compounds. To prevent the electron-hole recombination, it is necessary for the illumination to take place in the presence of an electron acceptor.

The basic mechanism for generating OH$^*$ involves the adsorption of a photon, the generation of an electron-hole pair ($e^-_{cb} + h^+_{vb}$) and subsequently the production of OH$^*$ [5]. Anatase form of the TiO$_2$ nanoparticles has shown higher photocatalytic activity than rutile.

$$\text{TiO}_2 \xrightarrow{\text{hv}} \text{TiO}_2(e^- + h^+) \quad (1)$$

$$2h^* + H_2O \text{ (ads.)} + OH^-(\text{ads.}) \rightarrow 2OH^* + H^+ \quad (2)$$

The aim of the present study was to investigate the performances the photocatalytic decolorization activity of synthetic dye solution. Rhodamine B, Malachite Green Crystal, Benefix Blue G, and Benewol Red. The system developed consisting of a batch photoreactor fill with titanium dioxide (TiO$_2$) powder photocatalyst under UV blac klight source 40W power. The TiO$_2$ powder was anatase type and white color UV-vis spectral change of synthetic dye solution under UV light irradiation was determined. Effects of operating parameter such as amount of TiO$_2$ powder photocatalyst, type of dye solution, and reaction time were examined in dye removal efficiency in batch photoreactor.

2. Material and Methodology

2.1 Material

Synthetic dyes consisting of OT 70401 Rhodamine B 500% (Basic dye), OT 70701 Malachite Green Crystal (Basic dye), OT 406502 Benefix Blue G (reactive dye), and OT 60304 Benewol Red (acid dye). The UV-vis absorption spectrum of the dye samples are illustrated in Fig. 1. The main chemical is titanium dioxide (TiO$_2$) powder (Anatase, AR grade, Carlo Erba, Milano, Italy). The TiO$_2$ was characterized as anatase phase and tetragonal structure.

![Fig. 1. UV-vis absorption spectrum of dye aqueous solution.](image-url)

2.2 Experimental

The decolorization experiments were conducted in a batch-scale, photocatalytic reactor under UV light source (black light 8 W, 5 lamps). A batch photoreactor (π×20×50 cm) was set up in this study. For the
UV/TiO$_2$ powder photocatalytic process, irradiation was performed using 8 W fluorescence black light lamps with a wavelength of 366 nm, which was placed inside of the batch photoreactor (inside the stainless tank). The experimental setup is illustrated in Fig. 2. The UV irradiated photoreactor was placed on a magnetic stirrer to ensure homogenous mixing during the entire photocatalytic process. The aqueous dye solution was then magnetically stirred for 250 rpm in tightly closed stainless tank ($\pi \times 20^2 \times 50$ cm) to avoid interference from ambient light. The black light lamps were attached in a fixed position inside the side wall of the stainless tank.

In the photocatalysis studies, 0.10-0.15 g of TiO$_2$ powder were placed in Pyrex beaker with the total volume of 500 mL, which contained measured volume 400 mL of each synthetic dye solution at 20 mg/L synthetic dye solution. As the reaction progressed, samples solution of 20 mL was taken and the photocatalyst was separated by centrifugation at regular time intervals for further analysis using SPECORD S100 spectrophotometer.

2.3 Decolorization analysis

The change of dye concentration was determined quantitatively by the UV-vis photometer using the calibration curve of standard dye solution. After UV irradiation, the sample solutions were taken from the photoreactor every 30 minutes until getting the clear solution. The samples were centrifuged to separate the catalyst from solution for measuring an absorbance at 548 nm using UV-vis spectrophotometer (Specord S100, Analytik Jena GmbH, Germany). The concentrations of dye solution before and after each experiment were determined quantitatively. The calibration curve (straight line, $R^2 = 0.9990$) of the dye solution was constructed from standard solution of synthetic dye solution at various concentrations. The efficiency was defined as equation (3).

$$\% \text{ Decolorization Eff.} = \left( \frac{C_0 - C_t}{C_0} \right) \times 100 \quad (3)$$

Where $C_0$ (mg/L) and $C_t$ (mg/L) is original concentration of dye solution and the concentration of dye solution at time t, respectively.

3. Results and Discussion

3.1 Influence of TiO$_2$ amount on decolorization

The influence of TiO$_2$ photocatalyst amount in the dye solution on the decolorization under UV light irradiation performing was investigated in the range between 0.05 and 0.15 g TiO$_2$ powder. Decolorization result for Malachite Green Crystal solution in the presence of different concentrations of TiO$_2$ is shown in Fig. 3. The decolorizations were found to enhance by the increasing in catalyst amount from 0.5 to 0.15 g. They increase the number of active sites on the surface. Light scattering by the particles and the increase in opacity may be the other reason for the increase in the decolorization.

The photocatalytic degradation ratios of dye solution increase with the increase of TiO$_2$ up to 0.15 g and decreasing time required for 100% decolorization efficiency. The decolorization of the of Rhodamine B, Malachite Green Crystal, Benefix Blue G, and Benewol Red dye solution by UV irradiation using TiO$_2$ powder at 0.05, 0.10, and 0.15 g/100 mL are shown in Fig. 3-6. The results showed that Benewol Red and Benefix Blue G the decolorization efficiency was 60-80% and provided irradiation time only 3-4 h (0.05 g TiO$_2$ powder). However, after using TiO$_2$ powder at 0.15 g, the decolorization efficiency was found higher than 90% for 3.0-3.5 h. While, Malachite Green Crystal and Rhodamine B used time required 2.0-2.5 h for 90% decolorization efficiency (0.15 g TiO$_2$ powder). The optimal conditions for optimum degradation ratios of all dye solution are considered to be the addition amounts of 0.1g TiO$_2$ powder for the of 20 mg/L dye concentration.

![Fig. 3. The decolorization efficiency, $((C_0 - C_t)/C_0) \times 100$ of Malachite Green Crystal solution in 20 mg/L at various TiO$_2$ concentration as a function of time of UV irradiation.](image-url)

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3.2 Influence of type of dye solution on decolorization in photoreactor

The concentrations of dye solution before and after each experiment were determined quantitatively by UV–vis spectrophotometer. The calibration curve of the dye solution was constructed from standard solution of synthetic dye solution at various concentrations. The entire absorption spectrum of Rhodamine B, Malachite Green Crystal, Benefix Blue G, and Benewol Red were obtained. The UV-Vis spectral change results according to the decolorization of dye solution by the TiO₂ powder photoreactors under UV light irradiation are determine in this study. For the absence of TiO₂/UV irradiation, served as control experiments, had no any effect to decolorization of the dye solution. The presence of TiO₂/UV irradiation, the decolorization was effectively performed and completely obtained after 4.5 h (0.10 g TiO₂).

The UV–vis spectra of Malachite Green crystal and Rhodamine B solution under conditions are evaluated in this work. It was found that the characteristic absorption peaks of both Malachite Green crystal (618 nm) (Fig. 7) and Rhodamine B (548 nm) solutions declined under blacklight irradiation in the presence of TiO₂ powder (0.1 g). It indicates that the Malachite Green crystal and Rhodamine B (basic dye) in aqueous solution are mostly decomposed and disappeared gradually with time required lower than Benefix Blue and Benewol red. The data observed may be explained on the basis that, the Benefix Blue and Benewol red have a high molecular weight and complex structure.
comparing with the original solution. The results indicate that the disappearances of Malachite Green crystal and Rhodamine B are attributed to the photocatalyst degradation. However, the enhancement effect of TiO$_2$ powder on the photocatalyst degradation of Malachite Green crystal was much better than that of Rhodamine B, Benewol Red, and Benefix Blue G same at all condition (Fig 8).

4. Conclusion

Rhodamine B, Malachite Green Crystal, Benefix Blue G, and Benewol Red under UV black light source in aqueous solution can be obviously degraded by the method of photocatalytic degradation in the presence of TiO$_2$ powder. The Malachite Green crystal in aqueous solution are highly decomposed with using time required lower than other dye solution in this work. The optimal conditions for optimum degradation ratios of dye solution are considered to be the addition amounts of 0.1g TiO$_2$ powder for the initial concentration of 20 mg/L. The research results demonstrated the feasibilities of this method combining photocatalyst irradiation with TiO$_2$ powder and had a perfect application foreground.

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