

ZIBELINE INTERNATIONAL
PUBLISHING

ISSN: 2521-0912 (Print)

ISSN: 2521-0513 (Online)

CODEN: JCOLBF



RESEARCH ARTICLE

OPTIMIZATION OF PHOTODEGRADATION CONDITIONS OF RHODAMINE B IN WATER WITH DYE-SENSITIZED TITANIUM DIOXIDE

Md. Moinul Islam, Abrar Zadeed Ahmed, Sumaya Farhana Kabir, Rafiqul Islam, Md. Ashraful Islam Molla*

Department of Applied Chemistry & Chemical Engineering, Faculty of Engineering & Technology, University of Dhaka, Dhaka-1000, Bangladesh.

*Corresponding author E-mail: ashraful.acce@du.ac.bd

This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 13 March 2020

Accepted 15 April 2020

Available online 27 April 2020

ABSTRACT

Rhodamine B (RhB) is widely employed in dyeing in textile, paper, paints and leather industry. The wastewater containing RhB dye can cause serious environmental and biological problems. Hence, the remediation of RhB treatment is necessary for the environment. In this study, the photodegradation of RhB in water under sunlight irradiation with dye-sensitized titanium dioxide (TiO_2) is investigated. The influence of various conditions, such as TiO_2 dosages, initial RhB concentration, temperature, pH, sunlight intensity and irradiation time on the photodegradation of RhB are also studied. About 96% of RhB is photodegraded within 20 min under the optimized conditions. Therefore, the photodegradation treatment for the wastewater including RhB under sunlight is very simple, easy and low cost technique.

KEYWORDS

Optimization, Photodegradation, Rhodamine B, Dye-sensitized TiO_2 , Sunlight.

1. INTRODUCTION

Organic dyes have a wide range of application areas in the textile and food industries. The residues of textile industries are the major pollutants to contaminate water and affect aquatic life as well as human life (Gao et al., 2019). Colored organic dyes from industries are mostly non-biodegradable, creating high toxicity to the aquatic creatures and drastically disturb the water ecosystem (Sakib et al., 2019; Ge et al., 2016). Among them, RhB dye is hazardous, dangerous, poisonous, carcinogenic, allergenic and teratogenic to human beings (Bhowmilk et al., 2015). It is necessary to degrade the dyes in effluents, at least to decolorize them before effluent disposal to the environment. The remediation of organic dyes has been performed to clear the dyeing effluents using various techniques, such as adsorption, flocculation, bioremediation and photocatalytic degradation (Chahm et al., 2018; Verma et al., 2012; Ramezani et al., 2013; Alansi et al., 2018). Recently, the semiconductor nanomaterials have been applied as promising photocatalyst for the effective degradation of organic dyes for purifying water (Dhanabal and Velmathi, 2016).

The complete degradation of harmful organic dyes into nontoxic compounds makes the photocatalytic process a widely preferred one. Furthermore, photocatalytic treatment is an economical, easy to employ, simple and green technique (Nikam et al., 2015). Dye-sensitization is one of the most promising pathways for utilizing visible light for environmental remediation. It can extend the light absorption range, enhance photon harvesting efficiency, provide extra exciting electron pairs from a dye and accelerate charge transfer, leading to the high efficiency of photoelectric conversion (Narayan, 2012). A group

researchers have reported that the dye-sensitization can be applied for the self-degradation of dyes (Park et al., 2013). In other study they have investigated the photocatalytic degradation mechanism of rhodamine B by dye-sensitized TiO_2 under visible light irradiation (Molla et al., 2017). Herein, the photocatalytic degradation of rhodamine B (RhB) in water under sunlight irradiation with dye-sensitized TiO_2 is investigated. Moreover, the optimal conditions for photodegradation of RhB with dye sensitized TiO_2 under sunlight irradiation are evaluated.

2. EXPERIMENTS

2.1 Chemicals

The following analytical grade chemicals were used in this study - rhodamine B, TiO_2 powder (80% anatase and 20% rutile), NaOH and HCl. All of the chemicals were obtained from Merck (Germany). The chemicals were not further purified. Deionized water was used for the preparation of solutions.

2.2 Photodegradation of RhB Dye

The photodegradation experimental conditions are presented in Table 1. A 30 mL aqueous solution containing 5–20 mg/L RhB was put into a beaker (100 mL capacity). All experiments were conducted on a sunny day and cloudy day between 11:00 and 14:00. In photodegradation, 0–30 mg of TiO_2 powder was added into 30 mL aqueous RhB of 5–20 mg/L in the beakers. The pH of the solution was 4.2–11.3. The temperature was kept constant at 18–55 °C with a water bath. To equilibrate the suspension, a magnetic stirrer was used in the dark for 30 min. Then, the suspensions in the beakers were kept in sunlight for different time intervals. About 3 mL

Quick Response Code



Access this article online

Website:
www.jcleanwas.comDOI:
[10.26480/jcleanwas.01.2020.28.31](https://doi.org/10.26480/jcleanwas.01.2020.28.31)

of RhB solution was withdrawn and separated with an Advantec membrane filter 0.45 m. The RhB concentration was calculated using a UV-visible spectrometry (UV-1700 Pharma Spec, SHIMADZU, Kyoto, Japan). The relative RhB concentration (C/C_0) was determined at the relative absorbance (A/A_0) of $\lambda = 553$ nm, according to the Beer-Lambert law, where A_0 and A were the absorbance of aqueous RhB at a starting time (t_0) of photodegradation and at any time t , respectively.

Table 1: Detail experimental conditions.

Rhodamine B	5–20 mg/L (volume: 30 mL)
TiO ₂	0–30 mg
Temperature	18–55 °C
pH	4.2–11.3
Light source	Sunlight
Irradiation time	0–50 min

3. RESULTS AND DISCUSSION

3.1 Influence of TiO₂ dosages

The effect of the TiO₂ dosages on the photodegradation has been carried out in the range of 0 to 30 mg of the TiO₂ for 30 mL of RhB solution, as displayed in Figure 1a. The UV-visible absorption spectrum of RhB dye shows a peak at 553 nm (Figure 1b). The absorption intensity of the peak decrease with increasing TiO₂ dosages, which confirms the progress of the photodegradation of the RhB. The photodegradation of RhB increases with an increase in TiO₂ up to 15 mg, and after that, the increase in TiO₂ dosage does not affect the degradation significantly (Molla et al., 2018a). This observation can be explained in terms of the availability of active sites on the TiO₂ surface and the penetration of light into the suspension. The total active surface area increases with increasing TiO₂ dosage. At the same time, due to an increase in the turbidity of the suspension, there is a decrease in light penetration as a result of increased scattering effect, and hence the photoactivated volume of suspension decreases. Further, at high TiO₂ dosages, it is difficult to maintain the suspension homogenous due to particle agglomeration, which decreases the number of active sites (Mohammadzadeh et al., 2015). Since the most effective degradation of RhB is observed with 15 mg (0.3 g/L) of TiO₂, the sequential experiments are performed in this concentration.

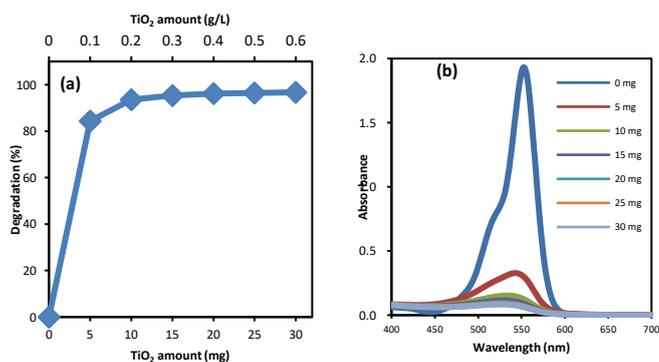


Figure 1: (a) Effect of TiO₂ amount on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of TiO₂ amount. (RhB: 10 mg/L; irradiation time: 20 min; light intensity: 3.5 mW/cm² (290–390 nm); temperature: 30 °C; pH: 8.4).

3.2 Influence of temperature

The effect of temperature on the solar photodegradation of RhB in water using TiO₂ is checked in the range of 12–55 °C (Figure 2a). The absorption peak of the RhB spectra rapidly decreases with increasing temperature and almost disappears at 55 °C as shown in Figure 2b. The photodegradation of RhB gradually increases as the temperature increases up to 30 °C, and after that, increasing temperature scarcely affects dye degradation (Molla et al., 2019a). The photodegradation of RhB is about 96% at the temperature of 30 °C under the optimized conditions.

Consequently, all subsequent irradiations are performed at 30 °C because of the operating cost for the photodegradation system. The thermal activation energy may be apparent for the processes containing the adsorption, degradation and desorption. Molla et al. have studied the photodegradation of Fenitrothion and Diazinon in TiO₂/H₂O suspension under solar irradiation, and also reported the activation energy (E_a) of Fenitrothion (20.6 kJ/mol) and Diazinon (14.7 kJ/mol) (Molla et al., 2018b; Molla et al., 2019b). Linear behaviour is obtained by plotting the natural logarithm of the rate constant as a function of reciprocal absolute temperature, as shown in Figure 2c. The activation energy (E_a) of RhB of photodegradation is measured as 18.7 kJ/mol.

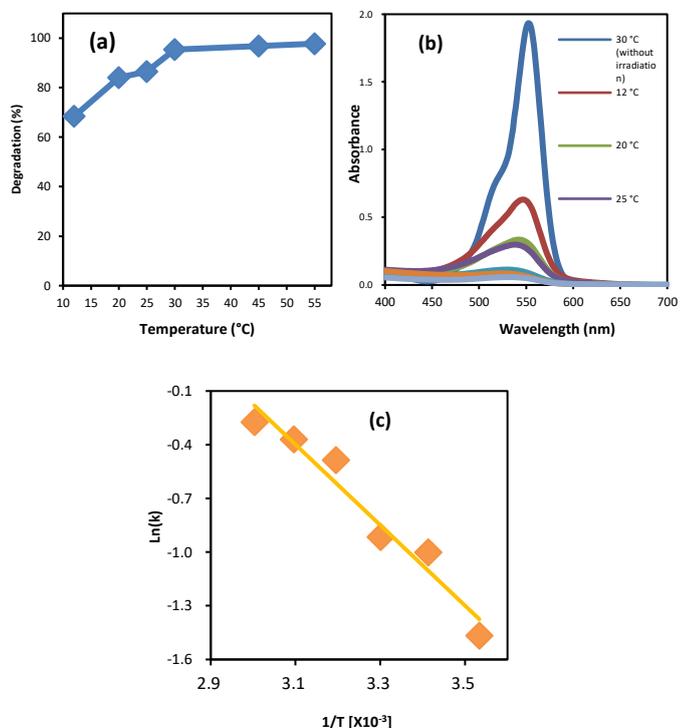


Figure 2: (a) Effect of temperature on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of different temperature. (c) Plot of Ln(k) versus 1/T. (RhB: 10 mg/L; irradiation time: 20 min; TiO₂: 15 mg; light intensity: 3.5 mW/cm² (290–390 nm); pH: 8.4).

3.3 Influence of initial pH

The role of initial pH on the photodegradation of RhB has been investigated in the pH range of 4.2–11.3 (Figure 3a). The absorption peak of the spectra slowly decreases with increasing pH, as observed in Figure 3b. As shown in Figure 3a, the photodegradation of RhB is observed at natural pH 8.4 is about 96%. The zero-point charge (zpc) pH_{zpc} of TiO₂ is around 6 (Hsiung et al., 2016).

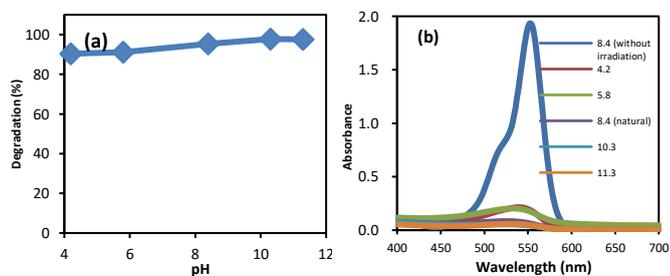


Figure 3: (a) Effect of pH on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of different pH. (RhB: 10 mg/L; irradiation time: 20 min; TiO₂: 15 mg; light intensity: 3.5 mW/cm² (290–390 nm); temperature: 30 °C).

The TiO₂ surface will be charged negatively when $pH > pzc$, positively when $pH < pzc$, and neutrally when $pH \approx pzc$. Also, the structural

properties of the dye pollutant will change with pH. The effect of pH on the photodegradation can be explained as electrostatic interaction between the TiO₂ surface and the target material. Such interaction can be expected to affect the encounter probability of the generated hydroxyl radicals with the compound. It follows that the overall reaction would be enhanced or hindered depending on whether attractive or repulsive forces prevail, respectively. At high initial pH, more hydroxide ion (OH⁻) in the solution induced the generation of hydroxyl radicals (\bullet OH), which come from the oxidation of OH⁻ by holes (Molla et al., 2019c). Therefore, the pH-dependence on the photodegradation can be attributed to the balance between the induced generation of hydroxyl radicals and the electrostatic attraction of RhB molecular for the TiO₂ surface. In this study, pH 8.4 is selected for the optimal experimental conditions.

3.4 Influence of light intensity

The influence of light intensity on the solar photodegradation of RhB in water with TiO₂ is studied (Figure 4a). The absorption peak of the spectra gradually decreases with increasing light intensity, as seen in Figure 4b. The degradation experiments are performed with various light intensities on sunny and cloudy days. With increasing the intensity, the photodegradation increases gradually because the light intensity will affect the degree of absorption of light by the TiO₂ surface (Molla et al., 2018b). Therefore, the results obtained in the solar photodegradation of RhB in water TiO₂ suspension are reasonable.

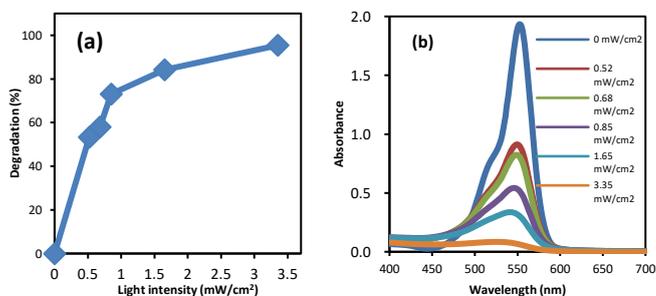


Figure 4: (a) Effect light intensity on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of light intensity. (RhB: 10 mg/L; irradiation time: 20 min; TiO₂: 15 mg; temperature: 30 °C; pH: 8.4).

3.5 Influence of irradiation time

The irradiation time plays an important role in the photodegradation of RhB. The effects of irradiation times on the photodegradation of RhB with TiO₂ are investigated (Figure 5a). The UV-vis absorbance spectra of RhB at different time intervals are presented in Figure 5b. As the irradiation time prolongs, the RhB absorbance peak at 553 nm starts decreasing as the irradiation time continues. The photodegradation of RhB during the first 20 min of irradiation is fast, and the degradation is completed within 50 min. About 96% of RhB is photodegraded within 20 min under the optimized conditions. Therefore, 20 min irradiation time is selected for the optimal experimental conditions.

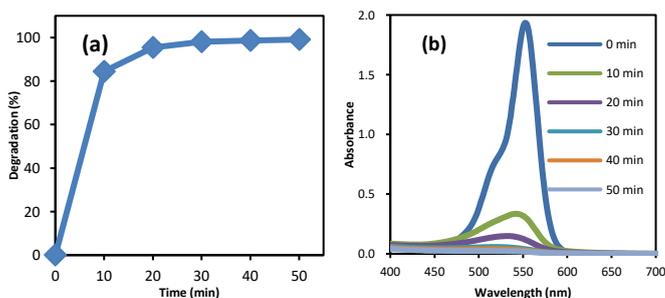


Figure 5: (a) Effect of irradiation time on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of different irradiation time. (RhB: 10 mg/L; TiO₂: 15 mg; light intensity: 3.5 mW/cm² (290–390 nm); temperature: 30 °C; pH: 8.4).

3.6 Influence of initial RhB concentration

The photodegradation of dye depends on its initial concentration, and it is necessary to investigate the effect of dye concentrations because of their practical application. The solar photodegradation with different initial RhB dye concentrations in the presence of TiO₂ is studied, as shown in Figure 6a. The UV-vis absorbance spectra of RhB at different initial dye concentrations are illustrated in Figure 6b. It is observed that as initial RhB dye concentrations increase from 5 mg/L to 20 mg/L, the photodegradation of dye gradually decreases (Molla et al., 2018c). In this study, RhB of 10 mg/L solution is selected to evaluate the photodegradation of dye under sunlight, because of the high concentration of real wastewater.

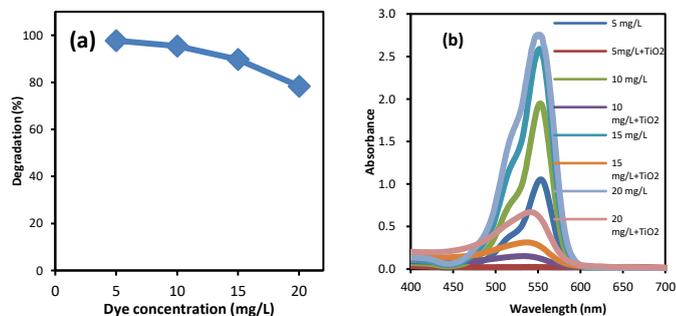


Figure 6: (a) Effect of initial dye concentration on the solar photodegradation of RhB in water. (b) Absorption spectra of RhB photodegradation with function of initial dye concentration. (irradiation time: 20 min; TiO₂: 15 mg; light intensity: 3.5 mW/cm² (290–390 nm); temperature: 30 °C; pH: 8.4).

4. CONCLUSION

The photodegradation conditions of RhB in water with dye-sensitized TiO₂ under sunlight irradiation have been optimized. Typical optimum photodegradation conditions are as follows: TiO₂ loading: 0.3 g/L, temperature: 30 °C, pH 8.4, irradiation time 20 min and RhB concentration 10 mg/L. Under optimum conditions, the photodegradation of RhB is about 96% within 20 min. The proposed photodegradation technique seems to be a very powerful method for the treatment of wastewater including RhB in the presence of sunlight.

ACKNOWLEDGMENTS

This research was funded by the Bangladesh University Grand Commission (UGC) with collaboration of University of Dhaka, Bangladesh.

REFERENCES

- Alansi, A.M., Al-qunaibit, M., Alade, I.O., Qahtan, T.F., Saleh, T.A., 2018. Visible-light responsive BiOBr nanoparticles loaded on reduced graphene oxide for photocatalytic degradation of dye. *Journal of Molecular Liquids*, 253, Pp. 297–304.
- Bhowmik, T., Kundu, M.K., Barman, S., 2015. Non-ultra-small gold nanoparticles– graphitic carbon nitride composite: an efficient catalyst for ultrafast reduction of 4-nitrophenol and removal of organic dyes from water. *RSC Advances*, 5, Pp. 38760–38773.
- Chahm, T., Martins, B.A., Rodrigues, C.A., 2018. Adsorption of methylene blue and crystal violet on low-cost adsorbent: waste fruits of *Rapanea ferruginea* (ethanol-treated and H₂SO₄-treated). *Environmental Earth Sciences*, 77, Pp. 508.
- Dhanabal, R., Velmathi, S.A., 2016. Chandra Bose, High-efficiency new visible light-driven Ag₂MoO₄–Ag₃PO₄ composite photocatalyst towards degradation of industrial dyes. *Catalysis Science & Technology*, 6, Pp. 8449–8463.
- Gao, Q., Xu, J., Bu, X.H., 2019. Recent advances about metal-organic frameworks in the removal of pollutants from wastewater. *Coordination Chemistry Reviews*, 378, Pp. 17–31.

- Ge, Y., Xiang, Y., Hu, Y., Ji, M., Song, G., 2016. Preparation of Zn-TiO₂/RH/Fe₃O₄ composite material and its photocatalytic degradation for the dyes in wastewater. *Desalination and Water Treatment*, 57, Pp. 9837–9844.
- Hsiung, C.E., Lien, H.L., Galliano, A.E3., Yeh, C.S., Shih, Y.H., 2016. Effects of water chemistry on the destabilization and sedimentation of commercial TiO₂ nanoparticles: Role of double-layer compression and charge neutralization. *Chemosphere*, 151, Pp. 145–151.
- Mohammadzadeh, S., Olya, M.E., Arabi, A.M., Shariati, A., Nikou, M.R.K., 2015. Synthesis, characterization and application of ZnO-Ag as a nanophotocatalyst for organic compounds degradation, mechanism and economic study. *Journal of Environmental Sciences*, 35, Pp. 194–207.
- Molla, M.A.I., Ahsan, S., Tateishi, I., Furukawa, M., Katsumata, H., Suzuki, T., Kaneco, S., 2018a. Degradation, Kinetics, and Mineralization in the solar photocatalytic treatment of aqueous amitrole solution with titanium dioxide. *Environmental Engineering Science*, 35, Pp. 401–407.
- Molla, M.A.I., Furukawa, M., Tateishi, I., Katsumata, H., Kaneco, S., 2019a. Nano-photocatalytic mineralization of Diazinon with TiO₂ in water under solar illumination: reaction mechanism and optimization of degradation conditions. *Environmental Technology*, DOI: 10.1080/09593330.2019.1615129.
- Molla, M.A.I., Furukawa, M., Tateishi, I., Katsumata, H., Kaneco, S., 2019b. Optimization of Alachlor photocatalytic degradation with nano-TiO₂ in water under solar illumination: reaction pathway and mineralization. *Clean Technologies*, 1, Pp. 141–153.
- Molla, M.A.I., Furukawa, M., Tateishi, I., Katsumata, H., Kaneco, S., 2018b. Solar Photocatalytic decomposition of Probenazole in water with TiO₂ in the presence of H₂O₂. *Journal of Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 40, Pp. 2432–2441.
- Molla, M.A.I., Furukawa, M., Tateishi, I., Katsumata, H., Suzuki, T., Kaneco, S., 2018c. Photocatalytic degradation of Fenitrothion in water with TiO₂ under solar irradiation. *Water Conservation and Management*, 2, Pp. 1–5.
- Molla, M.A.I., Tateishi, I., Furukawa, M., Katsumata, H., Suzuki, T., Kaneco, S., 2017. Evaluation of reaction mechanism for photocatalytic degradation of dye with self-sensitized TiO₂ under visible light irradiation. *Open Journal of Inorganic Non-metallic Materials*, 7, Pp. 1–7.
- Narayan, M.R., 2012. Review: dye sensitized solar cells based on natural photosensitizers. *Renewable and Sustainable Energy Reviews*, 16, Pp. 208–215.
- Nikam, L., Panmand, R., Kadam, S., Naik, S., Kale, B., 2015. Enhanced hydrogen production under a visible light source and dye degradation under natural sunlight using nanostructured doped zinc orthotitanates. *New Journal of Chemistry*, 39, Pp. 3821–3834.
- Park, H., Park, Y., Kim, W. and Choi, W., 2013. Surface modification of TiO₂ photocatalyst for environmental applications. *Journal of Photochemistry and Photobiology C: Photochemistry Review*, 15, Pp. 1–20.
- Ramezani, S., Pourbabaee, A.A., Javaheri, H.D., 2013. Biodegradation of malachite green by *Klebsiella Terrigenaptcc 1650*: the critical parameters were optimized using Taguchi optimization method. *Journal of Bioremediation and Biodegradation*, 4, Pp. 1000175–1000180.
- Sakib, A.A.M., Masum, S.M., Hoinkis, J., Islam, R., Molla, M.A.I., 2019. Synthesis of CuO/ZnO Nanocomposites and Their Application in Photodegradation of Toxic Textile Dye. *Journal of Composites Science* 3, Pp. 91; DOI: 10.3390/jcs3030091.
- Verma, A.K., Dash, R.R., Bhunia, P., 2012. A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. *Journal of Environmental Management*, 93, Pp. 154–168.

