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Photocatalytic Degradation of Azo Dyes in Textile Waste: Sustainable Use of Water

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ABSTRACT

Azo dyes are widely used in textile manufacturing for their vibrant colors and ease of application. However, their incomplete removal during textile processing results in significant quantities being discharged into wastewater streams, leading to water pollution and ecological damage. Azo dyes are extensively used in the textile industry but pose significant environmental and health risks due to their persistence and potential toxicity. Photocatalytic degradation emerges as a promising approach to treat textile wastewater and mitigate the environmental impact of azo dyes.
The paper focuses review of photocatalytic degradation of azo dyes present in textile waste with the aim of achieving sustainable water usage. It presents a comprehensive analysis of existing research in this field.

Key Words: *Azo dyes, textile waste, photocatalytic degradation, sustainable purification techniques.*

INTRODUCTION

Few reviews delve into the process of photocatalytic degradation, which involves the use of photocatalysts to break down azo dyes into harmless byproducts under the influence of light. This mechanism is highlighted as an effective method for treating textile wastewater, addressing the environmental concerns associated with azo dyes[1].
Photocatalytic degradation refers to a chemical process wherein a photocatalyst, typically a semiconductor material like titanium dioxide (TiO2) or zinc oxide (ZnO), is used to break down organic pollutants or contaminants into harmless byproducts under the influence of light. In this process, the photocatalyst absorbs photons from a light source, typically ultraviolet (UV) or visible light, and generates electron-hole pairs. These photo-induced charge carriers then react with oxygen and water molecules in the surrounding environment to produce highly reactive oxygen species, such as hydroxyl radicals (OH), superoxide radicals (O2−), and holes (h+). These reactive species subsequently oxidize and degrade organic compounds present in the solution or on the surface of the photocatalyst, leading to the mineralization of pollutants into carbon dioxide, water, and other environmentally benign substances. Photocatalytic degradation is widely employed in various environmental remediation applications, including the treatment of wastewater, air purification, and remediation of contaminated soils and surfaces, due to its effectiveness, versatility, and environmentally friendly nature.[2]
The process of photocatalytic degradation is a promising method for the treatment of textile wastewater contaminated with azo dyes. It involves the use of photocatalysts, such as

titanium dioxide (TiO_2) or zinc oxide (ZnO), to break down azo dyes into harmless byproducts under the influence of light, typically ultraviolet (UV) or visible light.[3]

A study emphasizes the effectiveness of photocatalytic degradation in addressing the environmental concerns associated with azo dyes. When exposed to light, the photocatalyst absorbs photons and generates electron-hole pairs, which initiate redox reactions on its surface. These reactive species, such as hydroxyl radicals (•OH) and superoxide radicals ($•O_2^-$), then react with the azo dye molecules adsorbed on the surface of the catalyst, leading to their degradation into smaller, less harmful compounds.[4]

Photocatalytic degradation offers several advantages for the treatment of textile wastewater. Firstly, it is a sustainable and environmentally friendly process that does not rely on the use of harmful chemicals or additives. Additionally, photocatalysts can be easily regenerated and reused, making the process cost-effective and suitable for large-scale applications.[5]

Moreover, photocatalytic degradation is highly efficient and selective, allowing for the complete mineralization of azo dyes into carbon dioxide, water, and other inert substances. This ensures that no harmful residues or byproducts are left behind, minimizing the environmental impact of the treatment process.[6]

The above reviews underscore the significance of photocatalytic degradation as an effective method for treating textile wastewater contaminated with azo dyes. By harnessing the power of photocatalysts and light energy, this process offers a sustainable and efficient solution to address the environmental challenges posed by azo dyes in the textile industry.[7]

Azo Dyes in Textile Waste: The literature reviews provide insights into the significance of azo dyes in textile waste, emphasizing their widespread use in the textile industry and their adverse effects on the environment and human health. The need for efficient and sustainable treatment methods to mitigate the impact of azo dyes on water resources is underscored.[8]

Azo dyes are a class of synthetic organic compounds widely used in the textile industry to impart vibrant colors to fabrics. They are characterized by the presence of azo groups (-N=N-) in their chemical structure. While azo dyes have contributed to the aesthetic appeal of textiles, their widespread use has raised concerns due to their adverse effects on the environment and human health.[9]

A study review highlights the significance of azo dyes in textile waste, emphasizing their ubiquitous presence in wastewater generated by textile manufacturing processes. Azo dyes are known to be persistent in the environment, resisting conventional treatment methods and posing risks to aquatic ecosystems. Moreover, some azo dyes and their degradation products have been identified as potential carcinogens, mutagens, and endocrine disruptors, raising concerns about their impact on human health.[10]

Given the environmental and health risks associated with azo dyes, there is a pressing need for efficient and sustainable treatment methods to mitigate their impact on water resources. Traditional wastewater treatment processes, such as biological and chemical treatments, may not be effective in removing azo dyes completely, leading to the discharge of contaminated effluents into water bodies. Therefore, the review underscores the importance of developing innovative and environmentally friendly approaches, such as photocatalytic degradation, for the efficient removal of azo dyes from textile wastewater.[11]

Hence, the literature review highlights the urgent need to address the environmental and health risks posed by azo dyes in textile waste through the adoption of efficient and sustainable treatment methods. By mitigating the release of azo dyes into water resources, such approaches can contribute to the protection of ecosystems and public health.[12]

Role of Photocatalysts: Various photocatalysts used in the degradation of azo dyes are discussed, including titanium dioxide (TiO2), zinc oxide (ZnO), and other metal oxide nanoparticles. The reviews examine the catalytic properties of these materials and their effectiveness in facilitating dye degradation.

The role of photocatalysts in the degradation of azo dyes is crucial for the efficient removal of these pollutants from textile wastewater. Several photocatalysts, including titanium dioxide (TiO2), zinc oxide (ZnO), and other metal oxide nanoparticles, have been extensively studied for their ability to facilitate the degradation of azo dyes through photocatalytic processes.[13]

Titanium Dioxide (TiO2): TiO2 is one of the most widely studied photocatalysts due to its excellent photocatalytic activity, stability, and low cost. It is particularly effective in degrading azo dyes under UV light irradiation. The photocatalytic activity of TiO2 is attributed to its ability to generate reactive oxygen species, such as hydroxyl radicals, upon light absorption, which can oxidize and degrade azo dyes into harmless byproducts.[14]

Zinc Oxide (ZnO): ZnO is another semiconductor photocatalyst with significant potential for azo dye degradation. Like TiO2, ZnO can generate reactive oxygen species under light irradiation, leading to the oxidation and degradation of azo dyes. ZnO nanoparticles offer advantages such as high photocatalytic activity, wide availability, and biocompatibility, making them promising candidates for wastewater treatment applications.[15]

Other Metal Oxide Nanoparticles: In addition to TiO2 and ZnO, other metal oxide nanoparticles, such as iron oxide (Fe2O3), cerium oxide (CeO2), and tungsten oxide (WO3), have also been investigated for their photocatalytic properties. These materials exhibit varying degrees of photocatalytic activity and stability, depending on factors such as crystal structure, surface morphology, and doping.[16] The study examines the catalytic properties of these photocatalysts, including their band gap energy, surface area, and surface chemistry, which influence their effectiveness in facilitating dye degradation. Furthermore, factors such as catalyst dosage, pH, temperature, and light intensity are also considered to optimize the photocatalytic degradation process.

Hence, the role of photocatalysts, particularly TiO2, ZnO, and other metal oxide nanoparticles, is instrumental in the degradation of azo dyes in textile wastewater. By harnessing the photocatalytic activity of these materials, it is possible to develop efficient and sustainable treatment methods for mitigating the environmental impact of azo dyes.[17]

Sustainable Water Usage: A significant focus of the review is on the concept of sustainable water usage in the context of dye degradation processes. It explores strategies for minimizing water consumption, optimizing reaction conditions, and enhancing the efficiency of photocatalytic degradation to achieve sustainability goals.[18]

Sustainable water usage is a crucial aspect of the dye degradation processes discussed in the review. Given the global concerns regarding water scarcity and pollution, optimizing water usage and minimizing wastage are essential considerations in any water treatment method, including photocatalytic degradation of dyes.[19]

The studies explore various strategies aimed at promoting sustainable water usage in dye degradation processes:

Minimizing Water Consumption: Efforts are made to reduce the overall water consumption during the dye degradation process. This may involve optimizing the reaction conditions, such as pH, temperature, and catalyst dosage, to maximize the efficiency of the photocatalytic process while minimizing the volume of water required for treatment.[20]

Recycling and Reuse: Strategies for recycling and reusing water within the treatment system are explored to minimize the need for fresh water inputs. This may include implementing closed-loop systems where treated water is recirculated back into the process or employing advanced treatment technologies to purify and reuse wastewater.[21]

Integration with Water Reclamation Systems: Photocatalytic dye degradation processes can be integrated with water reclamation systems to recover and reuse valuable resources from wastewater streams. By treating wastewater to remove contaminants and pollutants, reclaimed water can be safely reused for non-potable applications, such as irrigation, industrial processes, or toilet flushing.[22]

Efficiency Improvement: The review discusses methods for enhancing the efficiency of photocatalytic dye degradation to reduce the overall treatment time and energy requirements. This may involve the development of novel photocatalysts with improved catalytic activity, surface area, and stability, as well as the optimization of reactor design and operating parameters.[23]

Life Cycle Assessment (LCA): A life cycle assessment approach may be employed to evaluate the environmental impact of dye degradation processes holistically. By considering the entire life cycle of the treatment system, from raw material extraction to end-of-life disposal, LCA can help identify opportunities for reducing water consumption, energy usage, and environmental emissions.[24]
Sustainable water usage is a key consideration in the design and implementation of dye degradation processes. By adopting strategies to minimize water consumption, optimize process efficiency, and integrate with water reclamation systems, photocatalytic dye degradation can contribute to sustainable water management practices and mitigate the environmental impact of dye pollution in water resources.[25]

Challenges and Future Directions: A study identifies challenges such as catalyst reusability, scalability of the process, and the need for cost-effective technologies. It also suggests future research directions, including the development of novel photocatalysts, exploration of advanced reactor designs, and integration of renewable energy sources to drive photocatalytic processes.[26, 27] The reviews highlight several challenges associated with photocatalytic dye degradation and proposes future research directions to address these challenges:

Catalyst Reusability: One of the challenges is the limited reusability of photocatalysts, which can lead to increased operational costs and waste generation. Future research could focus on developing strategies to enhance the stability and recyclability of photocatalysts, such as surface modification techniques or immobilization onto reusable supports.[28]

Scalability of the Process: Scaling up photocatalytic dye degradation processes from laboratory-scale to industrial-scale operations poses challenges in terms of reactor design, mass transfer limitations, and process control. Future research could explore innovative reactor configurations, such as continuous flow systems or immobilized catalyst beds, to improve process scalability and efficiency.[29]

Cost-Effective Technologies: The high cost of photocatalytic materials and energy-intensive light sources presents a barrier to widespread adoption of photocatalytic dye degradation technologies. Future research could focus on developing cost-effective photocatalysts with improved efficiency and stability, as well as exploring alternative light sources, such as solar or LED lighting, to reduce operational costs.[30]

Novel Photocatalysts: There is a need for the development of novel photocatalysts with enhanced catalytic activity, selectivity, and stability for efficient dye degradation. Future research could involve the synthesis and characterization of new materials, such as metal-organic frameworks (MOFs), carbon-based nanomaterials, or hybrid composites, tailored specifically for dye degradation applications.[31]

Advanced Reactor Designs: Exploring advanced reactor designs, such as microreactors, membrane reactors, or photocatalytic membranes, could improve mass transfer efficiency, enhance light utilization, and facilitate continuous operation of photocatalytic dye degradation processes.[32]

Integration of Renewable Energy Sources: Incorporating renewable energy sources, such as solar or wind power, into photocatalytic processes could reduce energy costs and environmental impact. Future research could focus on developing hybrid systems that integrate photocatalysis with renewable energy generation technologies to achieve sustainable and energy-efficient dye degradation.[33]

Hence, addressing these challenges and pursuing innovative research directions could advance the field of photocatalytic dye degradation and contribute to the development of sustainable and cost-effective water treatment technologies.
Overall, the reviews provide a comprehensive overview of the current state of research on the photocatalytic degradation of azo dyes in textile waste, with a particular emphasis on sustainable water usage. It highlights the importance of continued innovation and collaboration in this field to address the environmental challenges posed by textile dyeing processes and ensure the sustainable management of water resources.

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REFERENCES

1. Arpita Paul Chowdhury, K. S. Anantharaju, K. Keshavamurthy, Samuel Lalthazuala Rokhum, "Recent Advances in Efficient Photocatalytic Degradation Approaches for Azo Dyes", Journal of Chemistry, vol. 2023, Article ID 9780955, 24 pages, 2023. https://doi.org/10.1155/2023/9780955
2. Pavel M, Anastasescu C, State R-N, Vasile A, Papa F, Balint I. Photocatalytic Degradation of Organic and Inorganic Pollutants to Harmless End Products: Assessment of Practical Application Potential for Water and Air Cleaning. Catalysts. 2023; 13(2):380. https://doi.org/10.3390/catal13020380
3. M.R. Al-Mamun, S. Kader, M.S. Islam, M.Z.H. Khan. Photocatalytic activity improvement and application of UV-TiO2 photocatalysis in textile wastewater treatment: A review, Journal of Environmental Chemical Engineering, Volume 7, Issue 5, 2019, 103248, ISSN 2213-3437, https://doi.org/10.1016/j.jece.2019.103248.
4. Al-Nuaim, M.A., Alwasiti, A.A. & Shnain, Z.Y. The photocatalytic process in the treatment of polluted water. Chem. Pap. 77,

677–701 (2023). https://doi.org/10.1007/s11696-022-02468-7
5. Deborah Tebogo Ruziwa, Abimbola E. Oluwalana, Mathew Mupa, Lucas Meili, Rangabhashiyam Selvasembian, Matthew M. Nindi, Mika Sillanpaa, Willis Gwenzi, Nhamo Chaukura, Pharmaceuticals in wastewater and their photocatalytic degradation using nano-enabled photocatalysts, Journal of Water Process Engineering, Volume 54, 2023, 103880, ISSN 2214-7144, https://doi.org/10.1016/j.jwpe.2023.103880.
6. Nanda, Kamala Kanta Chowdhury, Arpita Paul Anantharaju, K. S. Keshavamurthy, K. Rokhum, Samuel Lalthazuala 2023 Recent Advances in Efficient Photocatalytic Degradation Approaches for Azo Dyes 9780955 2023
7. Nyiko M. Chauke* Reagan L. Mohlala Siphelo Ngqoloda Mpfunzeni C. Raphulu , Front. Chem. Eng., 02 February 2024 Sec. Environmental Chemical Engineering Volume 6 - 2024 | https://doi.org/10.3389/fceng.2024.1356021
8. Joshua Akinropo Oyetade, Revocatus Lazaro Machunda, Askwar Hilonga, Photocatalytic degradation of azo dyes in textile wastewater by Polyaniline composite catalyst-a review, Scientific African, Volume 17, 2022, e01305, ISSN 2468-2276, https://doi.org/10.1016/j.sciaf.2022.e01305.
9. Benkhaya, S., M'rabet, S., & El Harfi, A. (2020). Classifications, properties, recent synthesis and applications of azo dyes. Heliyon, 6(1), e03271. https://doi.org/10.1016/j.heliyon.2020.e03271
10. Ngo, A. C. R., & Tischler, D. (2022). Microbial Degradation of Azo Dyes: Approaches and Prospects for a Hazard-Free Conversion by Microorganisms. International journal of environmental research and public health, 19(8), 4740. https://doi.org/10.3390/ijerph19084740
11. Leidy Rendón-Castrillón, Margarita Ramírez-Carmona, Carlos Ocampo-López, Federico González-López, Beatriz Cuartas-Uribe, José Antonio Mendoza-Roca, Treatment of water from the textile industry contaminated with indigo dye: A hybrid approach combining bioremediation and nanofiltration for sustainable reuse, Case Studies in Chemical and Environmental Engineering, Volume 8, 2023, 100498, ISSN 2666-0164, https://doi.org/10.1016/j.cscee.2023.100498.
12. Rania Al-Tohamy, Sameh S. Ali, Fanghua Li, Kamal M. Okasha, Yehia A.-G. Mahmoud, Tamer Elsamahy, Haixin Jiao, Yinyi Fu, Jianzhong Sun, A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety, Ecotoxicology and Environmental Safety, Volume 231, 2022, 113160, ISSN 0147-6513,https://doi.org/10.1016/j.ecoenv.2021.113160.
13. Joshua Akinropo Oyetade, Revocatus Lazaro Machunda, Askwar Hilonga, Photocatalytic degradation of azo dyes in textile wastewater by Polyaniline composite catalyst-a review, Scientific African, Volume 17, 2022, e01305, ISSN 2468-2276, https://doi.org/10.1016/j.sciaf.2022.e01305.
14. Armaković SJ, Savanović MM, Armaković S. Titanium Dioxide as the Most Used Photocatalyst for Water Purification: An Overview. Catalysts. 2023; 13(1):26. https://doi.org/10.3390/catal13010026
15. Umar, K., Mfarrej, M.F.B., Rahman, Q.I. et al. ZnO Nano-swirlings for Azo Dye AR183 photocatalytic degradation and antimycotic activity. Sci Rep 12, 14023 (2022). https://doi.org/10.1038/s41598-022-17924-3
16. Miyauchi, Masahiro & Nakajima, Akira & Watanabe, Toshiya & Hashimoto, Kazuhito. (2002). Photocatalysis and Photoinduced Hydrophilicity of Various Metal Oxide Thin Films. Chemistry of Materials - CHEM MATER. 14. 10.1021/cm020076p.
17. Zhengisbek Kuspanov, Baglan Bakbolat, Alzhan Baimenov, Aidos Issadykov, Mukhtar Yeleuov, Chingis Daulbayev, Photocatalysts for a sustainable future: Innovations in large-scale environmental and energy applications, Science of The Total Environment, Volume 885, 2023, 163914, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.163914.
18. Kumari, H., Sonia, Suman et al. A Review on Photocatalysis Used For Wastewater Treatment: Dye Degradation. Water Air Soil

Pollut 234, 349 (2023). https://doi.org/10.1007/s11270-023-06359-9

19. Rania Al-Tohamy, Sameh S. Ali, Fanghua Li, Kamal M. Okasha, Yehia A.-G. Mahmoud, Tamer Elsamahy, Haixin Jiao, Yinyi Fu, Jianzhong Sun, A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety, Ecotoxicology and Environmental Safety, Volume 231, 2022, 113160, ISSN 0147-6513, https://doi.org/10.1016/j.ecoenv.2021.113160.
20. Reza, K.M., Kurny, A. & Gulshan, F. Parameters affecting the photocatalytic degradation of dyes using TiO2: a review. Appl Water Sci 7, 1569–1578 (2017). https://doi.org/10.1007/s13201-015-0367-y
21. sha P Tom, Jayalekshmi S Jayakumar, Minnu Biju, Jithin Somarajan, Muhammad Ajas Ibrahim, Aquaculture wastewater treatment technologies and their sustainability: A review, Energy Nexus, Volume 4, 2021, 100022, ISSN 2772-4271, https://doi.org/10.1016/j.nexus.2021.100022.
22. Bismark Sarkodie, Jeremiah Amesimeku, Charles Frimpong, Ebenezer Kofi Howard, Quan Feng, Zhenzhen Xu, Photocatalytic degradation of dyes by novel electrospun nanofibers: A review, Chemosphere, Volume 313, 2023, 137654, ISSN 0045-6535, https://doi.org/10.1016/j.chemosphere.2022.137654.
23. Rashid SS, Harun SN, Hanafiah MM, Razman KK, Liu Y-Q, Tholibon DA. Life Cycle Assessment and Its Application in Wastewater Treatment: A Brief Overview. Processes. 2023; 11(1):208. https://doi.org/10.3390/pr11010208
24. Costa, Andréa & Aragão, José & Duarte, Armando & Milanez, Victória & Silva, Gilson & Sarubbo, Leonie. (2021). Analysis of the Environmental Life Cycle of Dyeing in Textiles. Chemical Engineering Transactions. 86. 727-732.
25. Pranav H. Nakhate, Keyur K. Moradiya, Hrushikesh G. Patil, Kumudini V. Marathe, Ganapati D. Yadav, Case study on sustainability of textile wastewater treatment plant based on lifecycle assessment approach, Journal of Cleaner Production, Volume 245, 2020, 118929, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.118929.
26. Zhong-Hua Xue, Deyan Luan, Huabin Zhang, Xiong Wen (David) Lou, Single-atom catalysts for photocatalytic energy conversion, Joule, Volume 6, Issue 1, 2022, Pages 92-133, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2021.12.011.
27. Progress in Development of Photocatalytic Processes for Synthesis of Fuels and Organic Compounds under Outdoor Solar Light Alexey Galushchinskiy, Roberto González-Gómez, Kathryn McCarthy, Pau Farràs, and Aleksandr Savateev Energy & Fuels 2022 36 (9), 4625-4639 DOI: 10.1021/acs.energyfuels.2c00178
28. Xinru Li, Yao Chen, Ying Tao, Li Shen, Zhenmin Xu, Zhenfeng Bian, Hexing Li, Challenges of photocatalysis and their coping strategies, Chem Catalysis, Volume 2, Issue 6, 2022, Pages 1315-1345, ISSN 2667-1093, https://doi.org/10.1016/j.checat.2022.04.007.
29. Zhengisbek Kuspanov, Baglan Bakbolat, Alzhan Baimenov, Aidos Issadykov, Mukhtar Yeleuov, Chingis Daulbayev, Photocatalysts for a sustainable future: Innovations in large-scale environmental and energy applications, Science of The Total Environment, Volume 885, 2023, 163914, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.163914.
30. Xinru Li, Yao Chen, Ying Tao, Li Shen, Zhenmin Xu, Zhenfeng Bian, Hexing Li, Challenges of photocatalysis and their coping strategies, Chem Catalysis, Volume 2, Issue 6, 2022, Pages 1315-1345, ISSN 2667-1093, https://doi.org/10.1016/j.checat.2022.04.007.
31. Ying Chen, Boyin Zhai, Yuning Liang, Yongchao Li, Jing Li, Preparation of CdS/ g-C3N4/ MOF composite with enhanced visible-light photocatalytic activity for dye degradation, Journal of Solid State Chemistry, Volume 274, 2019, Pages 32-39, ISSN 0022-4596,
https://doi.org/10.1016/j.jssc.2019.01.038.
Pages 32-39, ISSN 0022-4596, https://doi.org/10.1016/j.jssc.2019.01.038.
32. Zhengisbek Kuspanov, Baglan Bakbolat, Alzhan Baimenov, Aidos Issadykov, Mukhtar Yeleuov, Chingis Daulbayev, Photocatalysts for a sustainable future: Innovations in large-

scale environmental and energy applications, Science of The Total Environment, Volume 885, 2023, 163914, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.163914.

33. Valerie Bei-Yuan Oh, Sue-Faye Ng, Wee-Jun Ong, Is photocatalytic hydrogen production sustainable? – Assessing the potential environmental enhancement of photocatalytic technology against steam methane reforming and electrocatalysis, Journal of Cleaner Production, Volume 379, Part 2, 2022, 134673, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2022.134673.

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