separations

MDPI

Editorial

Removal of Dye from Aquatic Environments: State-of-the-Art and Future Perspectives

Amin Mojiri

Department of Civil and Environmental Engineering, Graduate School of Advanced Science and Engineering, Hiroshima University, Higashihiroshima 739-8725, Japan; amin.mojiri@gmail.com

1. Introduction

Surface water sources play a vital role in numerous aspects of societal demand, including as sources of drinking water and water used for agricultural and industrial purposes. However, the quality of surface water can be affected by various natural factors (e.g., soil erosion and weathering), anthropogenic activities (e.g., agricultural and industrial activities), and urbanization [1]. The pollution of surface water is a severe global problem. The major contaminants of concern comprise organic contaminants (such as dye), suspended solids, heavy metals, and nutrients [2]. For instance, Hachad et al. [3] found that, in urban areas, the discharge of untreated sewage, stormwater, and street runoff are major pathways for wastewater organic pollutants and micropollutants that can affect human health, environments, and crops irrigated with water from these sources [4].

In recent years, the rapid development of industrialization and urbanization has resulted in a significant increase in the discharge of wastewater effluents contaminated with harmful organic contaminants (e.g., dyestuffs) into aquatic environments [5]. Consequently, the removal or separation of these contaminants from water bodies is a goal that must be accomplished for the sake of environmental safety and human health [6]. Dyes are classified as emerging concerns because of their chemical stability, high toxicity, and low biodegradability [5]. Dyes are considered to be compounds that are colored and considerably applied in the printing, cosmetic, textile, and plastic industries [7].

Moradi and Panahandeh [8] stated that 10–25% of the dyes applied in the textile industry are lost during the drying process, and that up to 20% reach the environment directly as effluent. Due to the presence of substances such as benzamide, naphthalene, and other aromatic compounds, these dyes can cause genetic alterations in organisms and are not easily degradable due to their chemical and biological stability; therefore, researchers are trying to develop methods for the efficient removal of dyes from water [9].

All of these issues have led to several researchers publishing high-quality papers about the elimination of dyes from water bodies in *Separations*. The current paper discusses state-of-the-art treatment of water- and wastewater-contaminated dyes using the different technologies that have been published in *Separations*.

2. Summary of Published Articles

Parthasarathy et al. [10] classified the dyes based on the chemical properties into 11 groups, including: (1) reactive dyes (applied extensively in the dyeing of cellulosic textile fibers, such as flax and cotton); (2) disperse dyes as non-ionic substances (applied in dying of polyesters, acetate, or nylon fabrics); (3) vat dyes (used in cellulosic fibers and material, including viscose, linen, and cotton), which contain a ketonic style chromophore; (4) direct dyes (applied to color viscose, cotton yarn, and loose cotton of fabrics), which do not need the fixation phase; (5) basic dye, Congo red, (mostly used in acrylic fibers), (6) acid dye (applied to nylon, silk and wool), which has a strong affinity for protein molecules; (7) azo dyes (used in various industries, including cosmetic, food processing, leather, pharmaceutical, and textile), which have one or more azo functional groups (-N=N-) as the

check for updates

Citation: Mojiri, A. Removal of Dye from Aquatic Environments: State-of-the-Art and Future Perspectives. *Separations* **2022**, *9*, 375. https://doi.org/10.3390/separations9110375

Received: 2 November 2022
Accepted: 16 November 2022
Published: 17 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

chromophoric species; (8) sulfur dyes (applied in cotton-related industries); (9) aniline dyes (used in wood, fabric and leather industries), which have one or several phenyl groups; (10) metal complex dyes (applied to color wool, silk, polyamides, and nylon), which include monoazo basic functional groups with attached hydroxyl, carboxyl and amino groups; and (11) mordant dyes (used in textile fibers).

At present, various physicochemical techniques (e.g., adsorption and advanced oxidation processes, and AOPs), biological approaches (e.g., activated sludge process and bioremediation), and hybrid techniques have been established to remove contaminants (dyes) from aquatic environments [11]. However, a treatment system with maximum effectiveness in eliminating dyes is still far from being realized. Recently, several original research and review articles on advanced methods employed to eliminate dyestuffs from water and wastewater have been published in *Separations*. Most of these published papers address the themes as below.

Membrane methods are promising options for the removal and recovery of dyes from wastewater [12]. Wang et al. [13] modified the polyethersulfone (PES) ultrafiltration (UF) membrane to remove more than 60% of methylene blue (MB) from aqueous solutions. To enhance the hydrophilicity, antifouling capacity, and permeability of the UF, the membrane was modified with molybdenum disulfide-iron oxyhydroxide (MoS_2-FeOOH)/PES. In addition, the membrane flux recovery ratio of the modified UF increased from 25% of blank PES-UF to more than 70% after two cycles of hydraulic cleaning and bovine serum albumin filtration. In another study, 61% of MB and 86% of Congo red (CR) were removed via an acrylic fiber-grafted membrane (AFGM) [14]. In comparison with the blank membrane (with a swelling performance [%] of 420), the swelling performance of AFGM was 320, which indicates that voids and pores might occur within the membrane as well as on the membrane surface. In addition, AFGM showed maximum performance in the removal of dyes at a pH of 5 and a contact time of 15 h.

Another effective method for the removal of dye, due to its low cost and easy installation, is adsorption [15]. El Mansouri et al. [16] removed up to 62% of Eriochrome Black T (EBT) using H_3PO_4-modified activated carbon (derived from *Cannabis sativa* L.) at a pH of 7, a contact time of 3 h, and an initial concentration of dye at 10 $mg{\cdot}L^{-1}$. Moreover, in this study, the maximum adsorption capacity was 14.02 ($mg{\cdot}g^{-1}$) in terms of the Langmuir isotherm study. In another study, 98–100% of azo dyes, anionic dyes/stains and textile dyes were removed using acidic alumina as an adsorbent [15] at an acidic pH and a contact time of more than 30 min. More than 90% of Disperse Red (DR) and Disperse Orange (DO) were removed using olive pomace as a biosorbent [17]. Parthasarathy et al. [10] investigated the removal of dyes using biochars in several previously published papers. Up to 75% of Remazol BO 3R was eliminated using biochar (derived from marine microalgae), and 66–97% of CR was removed by biochar (derived from rice husk) [10]. In addition, Parthasarathy et al. [10] stated that a greater pyrolysis temperature can cause greater dye adsorption capacity since the dye adsorption potential is extremely linked to the surface area of biochar.

Photocatalysis is another appropriate technique for eliminating stable and non-biodegradable organic contaminants (such as dyes) [18]. Photocatalytic remediation comprises four steps. First, contaminants are transferred from the water to the surface. Afterwards, contaminants are attached to the surface of the semiconductors. Then, photocatalytic reactions occur between the contaminants and the semiconductor. Finally, the contaminants are degraded and discharged into the environment [19]. Based on [19], more than 91% of CR was photodegraded in 1.5 h, whereas 95% of RB dye was photodegraded after 0.5 h. Shaalan et al. [20] stated that the NiO-Ga_2O_2-Graphene heterostructures can increase CR photodegradation. According to other studies [10], hybrid techniques are capable of removing more dyestuffs. For example, more than 90% of CR was eliminated by Arjuna seeds along with microorganisms and ozonation [10].

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The author would like to express his gratitude to all authors for their excellent contributions in writing high-quality articles published in *Separations*. Additionally, he thanks all reviewers for their great contributions and efforts.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, X.; Zhang, M.; Liu, L.; Wang, Z.; Lin, K. Using EEM-PARAFAC to identify and trace the pollution sources of surface water with receptor models in Taihu Lake Basin, China. *J. Environ. Manag.* **2022**, *321*, 115925. [CrossRef] [PubMed]
2. Loi, J.X.; Chua, A.S.M.; Rabuni, M.F.; Tan, C.K.; Lai, S.H.; Takemura, Y.; Syutsubo, K. Water quality assessment and pollution threat to safe water supply for three river basins in Malaysia. *Sci. Total Environ.* **2022**, *832*, 155067. [CrossRef]
3. Hachad, M.; Yarahmadi, H.; Vo Duy, S.; Sauvé, S.; Prévost, M.; Dorner, S. Occurrence and partitioning behavior of *E. coli* and wastewater micropollutants following rainfall events. *Resour. Environ. Sustain.* **2022**, *9*, 100067. [CrossRef]
4. Kargol, A.K.; Cao, C.; James, C.A.; Gough, H.L. Wastewater reuse for tree irrigation: Influence on rhizosphere microbial communities. *Resour. Environ. Sustain.* **2022**, *9*, 100063. [CrossRef]
5. Vakili, M.; Zwain, H.M.; Mojiri, A.; Wang, W.; Gholami, F.; Gholami, Z.; Giwa, A.S.; Wang, B.; Cagnetta, G.; Salamatinia, B. Effective Adsorption of Reactive Black 5 onto Hybrid Hexadecylamine Impregnated Chitosan-Powdered Activated Carbon Beads. *Water* **2020**, *12*, 2242. [CrossRef]
6. Farraji, H.; Robinson, B.; Mohajeri, P.; Abedi, T. Phytoremediation: Green technology for improving aquatic and terrestrial environments. *Nippon. J. Environ. Sci.* **2020**, *1*, 1–30. [CrossRef]
7. Kausar, A.; Zohra, S.T.; Ijaz, S.; Iqbal, M.; Iqbal, J.; Bibi, I.; Nouren, S.; El Messaoudi, N.; Nazir, A. Cellulose-based materials and their adsorptive removal efficiency for dyes: A review. *Int. J. Biol. Macromol.* 2022; *in press*. [CrossRef]
8. Moradi, O.; Panahandeh, S. Fabrication of different adsorbents based on zirconium oxide, graphene oxide, and dextrin for removal of green malachite dye from aqueous solutions. *Environ. Res.* **2022**, *214*, 114042. [CrossRef] [PubMed]
9. Mohajershojaei, K.; Mahmoodi, N.M.; Khosravi, A. Immobilization of laccase enzyme onto titania nanoparticle and decolorization of dyes from single and binary systems. *Biotechnol. Bioprocess Eng.* **2015**, *20*, 109–116. [CrossRef]
10. Parthasarathy, P.; Sajjad, S.; Saleem, J.; Alherbawi, M.; Mckay, G. A Review of the Removal of Dyestuffs from Effluents onto Biochar. *Separations* **2022**, *9*, 139. [CrossRef]
11. Mojiri, A.; Bashir, M.J.K. Wastewater Treatment: Current and Future Techniques. *Water* **2022**, *14*, 448. [CrossRef]
12. Moradihamedani, P. Recent advances in dye removal from wastewater by membrane technology: A review. *Polym. Bull.* **2022**, *79*, 2603–2631. [CrossRef]
13. Wang, M.; Sun, F.; Zeng, H.; Su, X.; Zhou, G.; Liu, H.; Xing, D. Modified Polyethersulfone Ultrafiltration Membrane for Enhanced Antifouling Capacity and Dye Catalytic Degradation Efficiency. *Separations* **2022**, *9*, 92. [CrossRef]
14. Labena, A.; Abdelhamid, A.E.; Husien, S.; Youssef, T.; Azab, E.; Gobouri, A.A.; Safwat, G. Grafting of Acrylic Membrane Prepared from Fibers Waste for Dyes Removal: Methylene Blue and Congo Red. *Separations* **2021**, *8*, 42. [CrossRef]
15. Bankole, A.A.; Poulose, V.; Ramachandran, T.; Hamed, F.; Thiemann, T. Comparative Study of the Selective Sorption of Organic Dyes on Inorganic Materials—A Cost-Effective Method for Waste Treatment in Educational and Small Research Laboratories. *Separations* **2022**, *9*, 144. [CrossRef]
16. El Mansouri, F.; Pelaz, G.; Morán, A.; Da Silva, J.C.G.E.; Cacciola, F.; El Farissi, H.; Tayeq, H.; Zerrouk, M.H.; Brigui, J. Efficient Removal of Eriochrome Black T Dye Using Activated Carbon of Waste Hemp (*Cannabis sativa* L.) Grown in Northern Morocco Enhanced by New Mathematical Models. *Separations* **2022**, *9*, 283. [CrossRef]
17. Rizzi, V.; D'Agostino, F.; Gubitosa, J.; Fini, P.; Petrella, A.; Agostiano, A.; Semeraro, P.; Cosma, P. An Alternative Use of Olive Pomace as a Wide-Ranging Bioremediation Strategy to Adsorb and Recover Disperse Orange and Disperse Red Industrial Dyes from Wastewater. *Separations* **2017**, *4*, 29. [CrossRef]
18. Cheng, L.; Zhang, Y.; Fan, W.; Ji, Y. Synergistic adsorption-photocatalysis for dyes removal by a novel biochar–based Z-scheme heterojunction BC/2ZIS/WO3: Mechanistic investigation and degradation pathways. *Chem. Eng. J.* **2022**, *445*, 136677. [CrossRef]
19. Alahmadi, N. Recent Progress in Photocatalytic Removal of Environmental Pollution Hazards in Water Using Nanostructured Materials. *Separations* **2022**, *9*, 264. [CrossRef]
20. Shaalan, N.M.; Rashad, M.; Awada, C. Synergistic Effect of NiO-Ga_2O_2-Graphene Heterostructures on Congo Red Photodegradation in Water. *Separations* **2022**, *9*, 201. [CrossRef]