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Review Paper

A Review on Azo Dyes Removal from Wastewater Using Biochar-Based Adsorbents: Materials, Mechanisms, and Perspectives

Navinda Ramadhan[1,2], Amanda Syafa Aliyah[1,2], Rabellia Juladika Sayeri[1,2], Neza Rahayu Palapa[3*]

[1] *Master Program of Material Science, Graduate School of Universitas Sriwijaya, Palembang, South Sumatra, 30139, Indonesia*
[2] *Research Centre of Inorganic Materials and Coordination Complexes, Universitas Sriwijaya, Palembang, South Sumatra, 30139, Indonesia*
[3] *Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir, South Sumatra, 30862, Indonesia*
[*] **Corresponding author**: Nezarahayu@mipa.unsri.ac.id

Abstract

Azo dyes are synthetic organic pollutants widely used in the textile, food, leather, and cosmetic industries. Effluents containing these dyes are often discharged into the aquatic environment without adequate treatment, causing serious pollution that is toxic, carcinogenic, and resistant to biological degradation. Among various effluent treatment methods, adsorption stands out as an efficient, simple, and economical technique. Biochar a porous solid resulting from biomass pyrolysis has been of great interest as a potential adsorbent due to its superior physical-chemical properties and abundant raw material availability. This article reviews recent developments in the utilization of biochar, both natural and modified, for adsorption of azo dyes from wastewater. It discusses the mechanism of interaction between biochar and dye, operational factors that affect efficiency, and various biochar modification strategies such as chemical activation, metal addition, composite formation, and the use of nano-biochar. Data from various literatures show that the adsorption capacity of biochar towards Rhodamine B and Congo Red can reach more than 1,000 mg/g, especially after advanced modifications. Nonetheless, technical and economic challenges in the widespread application of biochar still need to be overcome. This article provides an in-depth insight into the potential and future direction of biochar development as a sustainable solution in the treatment of wastewater polluted with azo dyes.

Keywords
Azo Dyes, Biochar Adsorbent, Water Treatment

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1. INTRODUCTION

Water pollution by synthetic dye effluents has become a pressing environmental issue, especially in industrialized areas that discharge their effluents directly into water bodies without adequate treatment (Fattahi et al., 2024). It is estimated that more than 700,000 tons of dyes are produced annually globally, and about 10-15% of the total production is discharged into the environment during the dyeing process, causing water quality degradation and impacting aquatic ecosystems (Wu et al., 2025). Azo dyes are the most widely used group of synthetic dyes in various industrial sectors such as textiles, leather, paper, plastics, food, and pharmaceuticals (Kumaravel and Shanmugam, 2024). Some common examples of azo dyes often found in industrial wastewater include Rhodamine B, Congo Red, and Methylene Blue (Almaz and Agircelik, 2023; Kumaravel and Shanmugam, 2024). These dyes are known to be toxic, carcinogenic, and resistant to natural biological degradation, which can cause accumulation in the environment and harm human health as well as aquatic organisms (Goswami et al., 2024).

Various methods have been developed to remove dyes from wastewater, either biologically, chemically, or physically (Tabish et al., 2024). Biological methods include the use of microorganisms to decompose dyes, while chemical methods include coagulation-flocculation, advanced oxidation, and photocatalysis processes (Deso et al., 2025). However, most of these methods are considered economically ineffective, difficult to operate, or produce harmful by-products, so few are widely applied on an industrial scale (Suryawan et al., 2021). Among the various approaches, adsorption stands out as one of the most promising methods due to its efficiency in removing dyes without generating additional hazardous waste. A major focus in the development of adsorption technology today is the creation of cheap, effective, and environmentally friendly adsorbents (Alkhair et al., 2024).

Various strategies have been investigated for the removal of azo dyes from wastewater, including membrane filtration (Jankowska et al., 2022), photocatalysis (Jia et al., 2021), flocculation (Bai et al., 2025), electrochemistry (Yang et al., 2025b), ozonation (Wen et al., 2025), and biological degradation (Rahimieh et al., 2024). Although these techniques have their own advantages, adsorption remains the method of choice because it is simple, flexible, does not require high energy, and has low operational costs (Hong et al., 2025). Another advantage of adsorption methods is their ability to remove dyes to very low concentrations, even from complex effluents. Therefore, the development and utilization of various types of adsorbents, particularly those derived from biomass sources such as biochar, has attracted great attention in the field of industrial wastewater treatment (Palapa et al., 2024a; Zhao, 2025).

Adsorption is a highly effective equilibrium-based separation process for water decontamination applications (Yu et al., 2023), particularly in the removal of organic pollutants such as azo dyes. The working principle of adsorption involves the accumulation of contaminant molecules on the surface of adsorbent solids (Ahmad et al., 2024), allowing the removal of harmful substances without significantly altering their chemical structure (Li et al., 2025). One adsorbent material that is increasingly attracting attention is biochar, which is a carbonaceous solid produced through pyrolysis of biomass at high temperatures under oxygen-limited conditions (Paul and Selvasembian, 2025). The advantages of biochar include wide availability of raw materials, low production cost, well-developed pore structure, and high chemical stability. In addition, the surface of biochar can be modified or functionalized to increase its adsorption capacity (Adawiyah et al., 2025; Zhang et al., 2025a), making it a flexible material that can be tailored to specific application needs.

This article aims to provide a review of the technical feasibility of biochar as an adsorbent for azo dye removal from wastewater. The main focus of the discussion includes the types of biochar based on biomass sources, the interaction mechanism between the dye and the biochar surface, and the operational parameters that affect adsorption efficiency, such as pH, contact time, and adsorbent dosage. By summarizing findings from various literatures, this article is expected to provide a comprehensive insight into the potential of biochar as a sustainable solution.

2. AZO DYES: CLASSIFICATION, CHARACTERISTICS, AND ENVIRONMENTAL IMPACT

Azo dyes are a group of synthetic dyes that are very widely used in the world, characterized by the presence of one or more azo groups ($-N=N-$) in their molecular structure (Goswami et al., 2024). These groups connect two aromatic groups, which can be modified to produce a variety of bright and stable colors (Parameshwarappa et al., 2025). The varied chemical structures allow azo dyes to have an affinity for different types of substrates, making them very popular in the textile, leather, paper printing, plastics, food, and cosmetics industries (Putri et al., 2022).

Based on the number of azo groups possessed, azo dyes can be classified into monoazo, diazo, triazo, and poly-azo. monoazo dyes (Oyetade et al., 2022), which have only one azo group are the most widely used type because their synthesis is relatively simple and economical. Common examples of azo dyes include Rhodamine B, Congo Red, Methylene Blue (Volavka et al., 2024), which are commonly found in industrial wastewater.

In general, azo dyes are characterized by high chemical stability, resistance to biological degradation, and high solubility in water, which makes them difficult to remove by conventional processes (Patil and Sekar, 2025). In an environmental context, azo dyes are known as refractory compounds, and some of their derivatives are carcinogenic, mutagenic, and toxic to aquatic organisms even at low concentrations (Wibiyan et al., 2024). The presence of these dyes in the aquatic environment not only disturbs the aesthetics of water and sunlight penetration, but also disrupts photosynthetic activities and the balance of aquatic ecosystems (Kayranli, 2025).

Therefore, the treatment of wastewater containing azo dyes is a priority in environmental protection efforts. Given the complexity of the structure and stability of azo compounds, a treatment approach capable of working efficiently and sustainably is required. Traditional methods such as biological degradation, chemical oxidation, and membrane filtration often face significant limitations, including incomplete dye removal, high operational costs, production of toxic by-products, and difficulties in handling complex industrial effluents (Al-asadi et al., 2025). In this context, adsorption has emerged as a highly promising alternative due to its simplicity, cost-effectiveness, and capability to achieve high removal efficiencies even at low pollutant concentrations.

Among various adsorbent materials, biochar has attracted increasing attention owing to its high surface area, tunable porosity, and the presence of functional groups that can interact effectively with dye molecules (Jin et al., 2025). Moreover, biochar derived from different biomass sources offers the advantage of utilizing low-cost and renewable feedstocks, aligning well with the principles of sustainable and circular economy. However, despite these advantages, challenges remain regarding the large-scale application of biochar, particularly related to consistency in adsorptive performance, regeneration efficiency, and environmental safety of the used adsorbent. Consequently, ongoing research continues to focus on developing advanced biochar materials with enhanced adsorption capacities and improved practical applicability for the efficient removal of azo dyes from industrial wastewater (Al-asadi et al., 2025).

3. BIOCHAR AS A PROMISING ADSORBENT

Biochar is a carbonaceous solid produced from biomass pyrolysis, which is the process of heating organic materials such as agricultural waste (Oyebamiji et al., 2025), forestry waste (Xiang et al., 2025), algae (Myung et al., 2024) at high temperatures under oxygen-limited conditions. Initially widely known in agriculture as a soil ameliorant, biochar is now gaining attention as an alternative adsorbent material for wastewater treatment, including in the removal of azo dyes (Juleanti et al., 2021; Tran et al., 2025).

The advantages of biochar lie in its unique physical and chemical properties, such as high surface area, well-developed pore structure, and the presence of active functional groups on its surface that can interact with dye molecules through adsorption mechanisms (Raj et al., 2025). In addition, biochar is resistant to degradation, chemically stable, and has a relatively low production cost because it can be made from abundant organic waste.

Various types of feedstock have been explored for biochar production, including rice straw, areca nut shell, duku peel (Fitri and Ardiansyah, 2023; Palapa et al., 2024b), rice husks, wood waste, and microalgae such as *Spirulina platensis* (Myung et al., 2024). The choice of feedstock greatly influences the final characteristics of biochar, including pore type, number of active sites, and affinity to pollutants. Biochar from microalgae, for example, tends to have high nitrogen content and good pore distribution, which can enhance interaction with charged dye molecules.

In addition, the modifiability of biochar, whether chemically, physically, or biologically, allows for significantly improved adsorption performance. Activation with chemical agents such as KOH, H_3PO_4 (Liu et al., 2025), or incorporation with other materials such as metal oxides and carbon nanotubes, can increase the surface area and introduce new functional groups. This makes biochar a flexible material that can be customized for specific effluent treatment needs, including effluents containing azo dyes (Goswami et al., 2024). With these various advantages, biochar is seen as a promising adsorbent, both from technical and economic aspects, to support sustainable wastewater treatment systems. Therefore, the development and optimization of biochar as a functional material in adsorption applications continues to be the focus of many scientific studies in recent years (Cano et al., 2025).

4. ADSORPTION MECHANISM OF BIOCHAR WITH AZO DYES

The adsorption mechanism between biochar and azo dyes involves a combination of physical and chemical interactions, which are influenced by the surface characteristics of biochar and the molecular structure of the dye (Jin et al., 2025). Understanding this mechanism is important to optimize the adsorption efficiency as well as to design biochars with high performance in wastewater treatment applications . In general, adsorption of azo dyes on biochar can occur through various pathways, including:

a. Electrostatic interaction (Siregar et al., 2021), which depends on the surface charge of biochar and the ionic species of the dye at a certain pH. At low pH conditions, the biochar surface tends to be positively charged and can attract anionically charged azo dyes such as Congo Red and Orange II through electrostatic attraction. Conversely, at high pH, the negative charge of biochar can encourage interaction with cationic dyes such as Methylene Blue.

b. π-π interaction between the aromatic ring of the dye and the carbon aromatic structure on the biochar surface (Adawiyah et al., 2025). This mechanism is particularly relevant for dyes with broad aromatic structures, such as Rhodamine B and Methylene Blue, as well as biochar that has a high aromatic carbon content from medium to high temperature pyrolysis processes.

c. Hydrogen bonding (Siregar et al., 2021), which occurs between functional groups such as $-$OH and $-$COOH on the surface of biochar with polar groups on dye molecules. The presence of these polar groups allows for selective interactions, especially in biochars from oxygen- or nitrogen-rich biomass.

d. Surface complexation or metal coordination (Zhong et al., 2025), especially in biochar modified with metal ions or metal oxides, allows binding of dye molecules through complex formation. This extends the range of biochar applications towards dyes having electron donor groups, such as azo with amino or sulfonate groups.

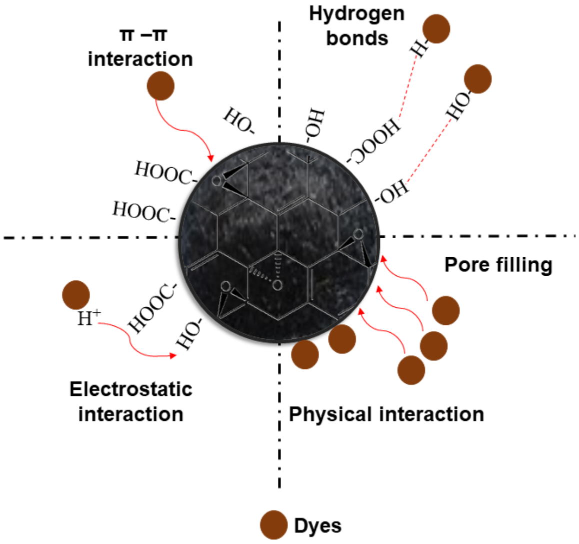

Figure 1. Schematic of Azo Dyes Adsorption Mechanism using Biochar (Wijaya and Yuliasari, 2023)

The effectiveness of this interaction is strongly influenced by operating conditions, such as solution pH, contact time, initial dye concentration, temperature, and biochar dosage. Adsorption kinetics studies often show that the adsorption mechanism follows a pseudo-second-order model, indicating the predominance of chemical interactions, while isotherm studies often conform to the Langmuir or Freundlich model (Ahmad et al., 2024), depending on the homogeneity of the biochar surface and the maximum adsorption capacity (Palapa et al., 2024b).

Thus, an in-depth understanding of these interaction mechanisms not only supports the optimization of the adsorption process, but also forms the basis for the design of biochars with targeted surface functionalities, in order to improve the selectivity and adsorption capacity towards specific azo dyes (Normah et al., 2021; Wijaya et al., 2021).

Figure 1 illustrates the diverse mechanisms involved in the adsorption of azo dyes onto biochar surfaces. The adsorption process is governed by multiple interactions, including π-π interactions between the aromatic rings of the dyes and the graphitic structures of biochar (Siregar et al., 2021), as well as hydrogen

Table 1. Adsorption Capacity of Various Biochars on Rhodamine B Dye

Adsorbents	Adsorption Capacity (mg/g)	Sources
Biochar Modified with CSB-PDA/ZIF	1,496	(Fan and Zhang, 2025)
Biochar with 200°C & 600°C Heating	540 & 402	(Ao et al., 2025)
Biochar from Red Wine Dregs	185	(Cano et al., 2025)
Biochar from Coconut Husk	172.41	(Minh et al., 2025)
Biochar from Banana Peel	148.5	(Yang et al., 2025a)
Biochar from *Zelkova serrata*	134.4	(Jeon and Shim, 2025)
Biochar from Almond Shells	112.3	(Kohzadi et al., 2023)
Biochar of Magnetic Rubber Seed	91.67	(Nguyen et al., 2025)
Biochar from Bearberry	87	(Radovanović et al., 2025)
Biochar from Wheat Husk & Straw	72.9	(Kayranli, 2025)
3D-based Biochar	70.11	(Ao et al., 2025)
Algae-doped Biochar	19.88	(Fu et al., 2025)
Biochar with Ball-Milled Sludge	11.587	(Mayilswamy et al., 2025)
Biochar Activated with $KMnO_4$	10	(Cano et al., 2025)
Biochar Doped with Nitrogen	9.91	(Chanda et al., 2025)

bonding facilitated by functional groups such as hydroxyl (−OH) and carboxyl (−COOH) present on the biochar surface. Electrostatic interactions play a significant role, particularly when charged dye molecules are attracted to oppositely charged sites on biochar under specific pH conditions (Rubangakene et al., 2023). Additionally, the adsorption process involves physical interactions and pore filling, whereby dye molecules diffuse into and become trapped within the porous structure of biochar. Together, these mechanisms contribute to the effective removal of azo dyes from aqueous solutions, highlighting the multifunctional adsorption capability of biochar as a promising adsorbent for wastewater treatment.

5. PERFORMANCE OF VARIOUS BIOCHARS AGAINST AZO DYES

The effectiveness of biochar as an adsorbent for azo dye removal has been extensively evaluated in various experimental studies. The performance of biochar is greatly influenced by the type of feedstock, pyrolysis conditions (Ao et al., 2025), surface characteristics, as well as operational conditions during the adsorption process. Many literatures report that biochar produced from biomass waste with high lignocellulose content or from microalgae has high potential in azo dye removal.

Biochars from agricultural wastes such as rice straw, coconut husk, and corn cob generally exhibit good adsorption capacity as they have developed pore structures and polar functional groups capable of interacting with dye molecules. Meanwhile, biochar from microalgae such as *Spirulina platensis* displays special characteristics of higher nitrogen and essential metal content (Myung et al., 2024), which can enhance electrostatic interactions and complex formation ability with azo dyes.

Some studies show that the adsorption capacity of biochar to azo dyes such as Congo Red, Methylene Blue, and Rhodamine B can reach 10-1,000 mg/g, depending on the synthesis and use conditions. Biochar produced at medium to high pyrolysis temperatures (400-700°C) generally has a larger surface area, a more organized aromatic structure, and a smaller number of oxygen functional groups, which makes it more suitable for π-π interactions with dye molecules (Xiao, 2022).

In addition, operating conditions such as the pH of the solution play an important role in determining the adsorption efficiency. For example, Congo Red as an anionic dye is more easily adsorbed under acidic conditions when the biochar surface is positively charged, while Methylene Blue as a cationic dye shows high efficiency at neutral to alkaline pH.

In general, biochar shows competitive adsorption performance, even comparable to commercial adsorbents such as activated carbon, with advantages in terms of low cost, availability of raw materials, and sustainability of the production process (Wijaya and Yuliasari, 2023). Therefore, the use of biochar as an adsorbent in the treatment of wastewater containing azo dyes is a promising alternative from both a technical and economic perspective.

6. MODIFIED BIOCHAR FOR ADSORPTION ENHANCEMENT

Although natural biochar has shown promising performance in azo dye removal, limitations such as low surface area, nonspecific surface properties, and limited adsorption capacity prompt the need for biochar modification strategies to improve its efficiency. Various approaches have been developed to modify biochar, either physically, chemically, or compositely, with the aim of improving the pore structure, adding active functional groups, or introducing specific affinity to dye molecules.

6.1 Chemical Activation

Chemical activation is the most commonly used method (Liu et al., 2025), involving the treatment of biochar with chemical agents such as KOH, H_3PO_4, $ZnCl_2$, or HCl. Activation with KOH, for example, can increase the specific surface area and

Table 2. Adsorption Capacity of Various Biochars on Congo Red Dye

Adsorbents	Adsorption Capacity (mg/g)	Sources
Extensin-enriched Rice Straw Biochar	2,714	(Li et al., 2024)
NCBC (Urea $CaCl_2$-modified Biochar from *Modulus tetrapunacis*)	2,512.82	(Liu et al., 2025)
Magnetic Gelatin/CMC Cryogels	698.19	(Cui et al., 2025)
Jackfruit Seed Waste Magnetic Nanoparticles (JMNPs)	257.90	(Deivayanai et al., 2025)
Rosa roxburghii Magnetic Biochar	172.88	(Zhang et al., 2025b)
Microwave-Activated Orange Peel Biochar	136	(Yek et al., 2020)
Pecan Shell Biochar (PSC-800-20)	130.48	(Xu et al., 2024)
ZnO Green Pea Peel Biochar	114.94	(Rubangakene et al., 2023)
ZnO GPBC (Green Pea Peel Biochar)	62.11	(Rubangakene et al., 2023)
Breadfruit Leaf Biochar	17.81	(Laxmi Deepak Bhatlu et al., 2023)
Rice Husk Clay Hybrid (MRHCH)	4.01	(Ige et al., 2024)

the number of micropores, thereby increasing the adsorption capacity (Xiao, 2022). In addition, modification with acids or bases can introduce or enhance the presence of polar functional groups such as $-COOH$, $-OH$, and $-SO_3H$, which are important for electrostatic interactions and hydrogen bond formation with azo dyes.

6.2 Doping with Metals or Metal Oxides

Biochar can also be modified by inserting metal ions or metal oxides, such as Fe, Mn, ZnO, or TiO_2, to improve selectivity and adsorption capacity (Jadhav et al., 2025). Fe-based (magnetic) biochars have the added advantage of easy post-adsorption separation with a magnetic field. Moreover, these metals are able to extend the adsorption mechanism through metal complexation, enhancing specific interactions with electron donor groups on azo molecules.

6.3 Biochar Composite Formation

Another rapidly developing approach is the fabrication of biochar composites, which is the combination of biochar with other materials such as graphene, zeolite, clay, or polymers (Kalderis et al., 2024), to produce multifunctional adsorbents. These composites enable a balance to be achieved between surface area, hydrophilic properties and structural stability, all of which are crucial in real-scale water treatment systems.

6.4 Stepwise Pyrolysis and Controlled Temperature

Besides post-production modifications, setting pyrolysis parameters such as temperature, heating rate, and residence time can also significantly affect biochar characteristics (Ao et al., 2025). For example, stepwise pyrolysis with multi-stage heating can create a hierarchical pore structure which is more ideal for the diffusion of dye molecules.

These modifications have been shown to consistently increase the adsorption capacity of biochar towards various azo dyes in various studies. However, it should be noted that the increase in adsorption efficiency must also be balanced with considerations of cost, process complexity, and environmental impact of the modified materials used. Thus, the development of modified biochar is an important focus in adsorption research, in order to bridge the need between high performance and sustainability in industrial waste treatment.

6.5 Nano-Biochar

Nano biochar is an advanced engineered form of conventional biochar with particle sizes in the nanometer range (1-100 nm) (Adawiyah et al., 2025). This miniaturization results in a significant increase in specific surface area, surface reactivity, and the number of active sites available for interaction with dye molecules. In addition, the functional properties of nano biochar can be customized through various modification techniques, whether chemical, physical, or biological (Shahzad et al., 2025). Besides high efficiency, nano biochar also shows advantages in terms of faster dye adsorption, due to more accessible micro pore sizes and stronger electrostatic interactions. Overall, nano biochar represents a promising new generation of carbon-based adsorbents for high-intensity water decontamination applications, particularly for the removal of complex and difficult-to-degrade azo dyes. The combination of superior physicochemical properties and modification flexibility makes nano biochar a focus of future adsorption research.

The results presented in Table 1 show that the adsorption capacity of biochar to Rhodamine B varied greatly, depending on the type of feedstock and the surface modification technique. Biochar modified with composite structures structure such as CSB/PDA/ZIF showed the highest adsorption capacity of 1,496 mg/g, indicating that the presence of active functional groups and micro-mesopically controlled pore structure micro-mesopore controlled pore structure greatly contributed to the improved adsorption performance. On the other hand, natural biochar from feedstocks such as banana peel or almond shell display lower capacities (around 100-150 mg/g), but are still relevant for low-cost applications.

Meanwhile, Table 2 displays the adsorption capacity of various biochars towards Congo Red, a more complex and refractory anionic azo dye. A similar pattern is seen where modified biochars such as extensin-enriched rice straw biochar and NCBC (urea/$CaCl_2$-modified biochar) show exceptionally high adsorption capacities (up to 2,714 mg/g), signifying the importance of nitrogen-based modifications and divalent cations in strengthening electrostatic interactions with negatively charged dyes. Biochar modified magnetically or with metal oxides also showed better adsorption performance than natural biochar.

7. CHALLENGES AND FUTURE PROSPECTS OF USING BIOCHAR IN AZO DYESTUFF TREATMENT

Although biochar shows great potential as an adsorbent for azo dye removal from wastewater, its application on an industrial scale still faces a number of technical, economic and environmental challenges. Therefore, an understanding of the existing barriers and future prospects is essential to steer biochar development in a more applicable and sustainable direction.

7.1 Technical Challenges

One of the main challenges is the high variation in biochar properties depending on the biomass type and pyrolysis conditions, which leads to non-uniformity in adsorption performance. Consistency and reproducibility of the adsorbent material are important issues in its field application. In addition, most studies are still at the laboratory level, so scale-up of biochar production processes and adsorption applications in real water treatment systems have not been tested practically. Another issue is the regeneration efficiency and reusability of biochar. Although some studies show biochar can be reused after desorption, its adsorption efficiency generally decreases after several cycles, especially when the adsorption mechanism is chemical (Fitri et al., 2024).

Despite these challenges, this review article offers valuable insights by consolidating recent developments in the use of biochar for azo dye removal from wastewater, covering diverse biomass sources, modification techniques, adsorption mechanisms, and comparative performance data. One of the strengths of this review is its focus on both natural and modified biochar, providing a broad perspective on their practical potential and limitations. However, a limitation of this review lies in the variability of experimental conditions across the studies discussed, which can complicate direct comparisons of adsorption capacities and operational performance. Additionally, while the review highlights promising laboratory-scale results, there remains a need for more comprehensive discussion on techno-economic analysis and environmental impact assessments to bridge the gap toward industrial applications. Nonetheless, this work serves as a valuable reference for researchers and practitioners seeking sustainable solutions for dye-contaminated wastewater treatment.

7.2 Economic and Environmental Considerations

From an economic aspect, although biochar is derived from inexpensive biomass waste (Rafatullah et al., 2010), chemical or physical modification processes to improve its performance can add significantly to production costs. In addition, it is necessary to consider the environmental impact of the modification chemicals, as well as the waste generated from the adsorbent regeneration process. Regarding sustainability, the approach of recycling local biomass that does not compete with food needs, such as algae, agricultural residues, or industrial waste, is highly relevant in creating an environmentally friendly adsorption system.

7.3 Future Prospects

In the next few years, the direction of research and application of biochar as an azo dye adsorbent is expected to expand into several sectors:

a. Targeted functional biochar design, based on molecular understanding of dye-adsorbent interactions.

b. Integration of biochar in hybrid water treatment systems, for example combined with photocatalysis or membrane filtration.

c. Development of biochar based on a circular economy, where its production and application are aligned with the concept of zero waste and low energy.

d. Utilization of artificial intelligence and predictive modeling for design and operation optimization of biochar-based adsorption systems.

With the support of multidisciplinary research and an integrated technological approach, biochar has a great opportunity to become an efficient, low-cost, and sustainable solution in the treatment of wastewater containing azo dyes, especially in developing countries that require low-cost yet effective technologies.

8. CONCLUSIONS

Environmental pollution due to azo dye effluents from various industries, especially textiles, is a serious challenge that requires effective and sustainable solutions. Adsorption has proven to be a superior effluent treatment method due to its operational simplicity, high efficiency and low cost. This review shows that biochar from various biomass sources, possesses physical and chemical characteristics that support the adsorption process of azo dyes, such as high surface area, presence of active functional groups, and modifiability. Modified biochars, either through chemical activation, metal doping, composite formation, or conversion to nanoscale, show significant improvement in adsorption capacity, even surpassing some conventional adsorbents. Some studies recorded adsorption capacities towards Rhodamine B and Congo Red of more than 1,000 mg/g, indicating great applicative potential. However, challenges such as the inconsistency of biochar properties, limited regeneration efficiency, as well as the economic and environmental aspects of the modification process are still barriers to industrial-scale application. Therefore, future research needs to focus on more specific functional biochar designs, integration of hybrid technologies, as well as circular economy and sustainability-based approaches.

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