Textile Waste Water Treatment Using Biochar

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Abstract: Textile effluent is a significant environmental pollutant, containing various dyes, heavy metals, and organic compounds that pose serious risks to aquatic ecosystems and human health. This study investigates the application of biochar as an effective treatment medium for textile wastewater. Biochar, a carbon-rich material produced through pyrolysis of organic matter, offers high surface area, porosity, and adsorption properties. We evaluated the efficacy of biochar in removing dyes and heavy metals from simulated textile effluent under varying conditions of contact time, pH, and biochar dosage. Results indicated that biochar significantly reduced dye concentration and metal ions, with optimal removal rates achieved at specific pH levels and higher biochar amounts. Mechanistic studies suggested that adsorption, electrostatic interactions, and ion exchange were the primary removal processes. This research highlights the potential of biochar not only as a sustainable solution for textile effluent treatment but also as a means to recycle organic waste, contributing to a circular economy. Further investigations into the regeneration and reuse of biochar in wastewater treatment are recommended to enhance its practical applicability.

Key words: Textile Effluent, Biochar, Adsorption, Pyrolysis

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Introduction:

The importance of textile wastewater treatment in reducing pollution and preserving water quality. Textile wastewater contains harmful pollutants like dyes, heavy metals, and organic compounds, which can harm aquatic ecosystems and human health if untreated. Biochar, a carbon-rich material produced from biomass pyrolysis, has the potential to adsorb and remove pollutants from wastewater (kumar & Saravanan, 2017). Biochar, a carbon-rich material produced from biomass pyrolysis, has the potential to adsorb and remove pollutants from wastewater. (Chetan et al., 2022) For example, biochar can effectively treat textile wastewater by adsorbing contaminants and reducing pollutant levels prior to discharge into water bodies. This process helps to significantly reduce the environmental impact of textile manufacturing on local ecosystems.Biochar has shown great promise in not only treating textile wastewater but also in reducing the overall carbon footprint of the textile industry. Its ability to effectively remove pollutants and contaminants from wastewater makes it a valuable tool in promoting sustainable practices in textile manufacturing. Moreover, the cost-effectiveness of biochar makes it an appealing option for companies seeking to enhance their environmental footprint and reduce operational costs. Overall, the use of biochar in textile wastewater treatment presents a win-win solution for both the industry and the environment (Sutar et al., 2022). For instance, a textile factory in India implemented a biochar filtration system to treat their wastewater, resulting in a 50% reduction in pollutants and an overall improvement in water quality downstream. This innovative approach not only benefits the environment but also saves the company money on traditional treatment methods (Gunarathne et al., 2018). By heating biomass in a low-oxygen environment, biochar is a highly porous carbon material. When added to textile wastewater, biochar acts as a filter, trapping pollutants and heavy metals as the water passes through. This process efficiently purifies the water, enhancing the safety of local ecosystems and downstream communities. Furthermore, biochar is a sustainable option as it can be produced from agricultural waste or other biomass sources, reducing the overall environmental impact of textile manufacturing (Qi, 2017). One such case study conducted in India showed that the use of biochar in textile wastewater treatment significantly reduced levels of pollutants such as dyes and heavy metals, improving the overall water quality. Another study in China demonstrated that biochar is more cost-effective and environmentally friendly than conventional wastewater treatment methods. These findings highlight the potential for biochar to revolutionize the textile industry by providing a sustainable solution for wastewater management. In India, biochar was used in a pilot-scale treatment system for textile wastewater, resulting in a 70% reduction in dye concentration and a 50% reduction in heavy metal content. The biochar also proved to be highly efficient in adsorbing pollutants, making it a promising alternative for sustainable water treatment solutions in the textile industry. Additionally, the use of biochar in this textile wastewater treatment system also led to a significant decrease in chemical oxygen demand and total suspended solids, further improving the overall water quality. This successful pilot study demonstrates the potential for biochar to not only mitigate environmental impact but also improve water treatment efficiency in industrial settings. Additionally, exploring different activation methods or incorporating other sustainable materials into the treatment system could further enhance its effectiveness. In general, ongoing advancements in biochar technology could revolutionize water treatment processes not only in the textile industry but also beyond.

Materials and Methods:

To make a 1000 mg/L CV stock solution, 1 g of dye was mixed with 1 L of distilled water in a volumetric jar. To keep the stock solution from becoming depolarized, it was kept in a dark place. According to APHA, all of the solutions used in this study were made with the right amounts. In the current. In the current study the palm shell was used for the preparation of biochar. The dried palm shells were crushed well. It is then sieved through 1.18 mm sieve. Then the contents are washed in deionized water. After removal of impurities the contents were dried at 110℃ for a day. After that the biochar contents are placed in the desiccator.

Experiments:

The study was conducted in batch mode. 500 mg of the biochar is mixed with 30 ml of textile effluent. It is rotated with a speed of 100 rpm in shakers. Temperature was maintained as 25-degree Celsius. The study was conducted for half an hour to 24 hours. Initial concentration was varied between 50 to 500 mg/l. 500 mg mixed with 30 ml of textile effluent was subjected to different temperature ranges from 5 to 35-degree Celsius at an interval of 10 for one day. The pH of the solutions is also measured. The same experimental work was carried for different concentrations of biochar such as 100,300,500, and 900 mg in every 30 ml of the textile effluent.

Analysis:

The Langmuir and Freundlich adsorption isotherms are widely used models for describing adsorption behavior on solid surfaces.The Langmuir isotherm assumes monolayer adsorption on a homogeneous surface with finite, identical sites. Once a site is occupied, no further adsorption occurs there.

The Langmuir equation is:

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e}$$

where:

q_e is the amount of adsorbate adsorbed per unit mass of adsorbent at equilibrium,

q_{max} is the maximum adsorption capacity (monolayer capacity),

K_L is the Langmuir constant related to the affinity between the adsorbate and adsorbent,

C_e is the concentration of adsorbate in solution at equilibrium.

. The Freundlich isotherm describes adsorption on a heterogeneous surface with sites that have different energies. It is an empirical model and can apply to both monolayer and multilayer adsorption.

The Freundlich equation is:

$$q_e = K_F C_e^{\frac{1}{n}}$$

KF is the Freundlich constant indicating adsorption capacity,

1/n is the adsorption intensity, with n indicating the favorability of adsorption (if n>1n > 1n>1, adsorption is favorable)

C_e is the concentration of adsorbate in solution at equilibrium.

Results and Discussions:

The adsorption of pollutants from textile effluent by biochar is influenced by various factors, including the properties of both the biochar and the effluent. Key factors are biochar surface area andporosity—higher surface area and more pores enhance adsorption sites, allowing for more pollutant molecules to attach. Surface functional groups on biochar, such as hydroxyl, carboxyl, and carbonyl groups, significantly affect adsorption as they interact with specific pollutant molecules through mechanisms like ion exchange and hydrogen bonding. The pH of the effluent plays a crucial role, as it affects the ionization state of pollutants and the surface charge of the biochar, influencing adsorption efficiency. Additionally, temperature impacts the adsorption kinetics and capacity; generally, higher temperatures increase adsorption up to a certain limit. Contact timeandinitial concentration of pollutants in the effluent also affect the adsorption process, as longer contact time allows for equilibrium to be reached, and higher initial concentrations drive faster adsorption rates.The kinetic study was carried for various contact time ranging from 30 minutes to a day. The initial concentration was maintained as 400 mg/l. the adsorption showed a higher value during the initial period and then it declined later on. After some time, the adsorption efficiency declines because the pores get clogged & lowered concentration of pollutants in effluent after treatment.

Table 1: Kinetics parameters for adsorption by biochar.

Adsorbent	Pseudo-First Order			Pseudo-Second Order		
Palm Shell Biochar	q_e	K_1	R^2	q_e	K_2	R^2
	15	2.5	0.79	16	0.2	0.85

For varying concentrations of initial value,the adsorption isotherms were analyzed. The isotherm values were calculated. In adsorption isotherms, R^2 (the coefficient of determination) is a statistical metric used to assess how well a chosen isotherm model fits the experimental adsorption data. Specifically, R^2quantifies the proportion of the variance in the observed data that can be explained by the model.

An R^2 value close to 1 indicates a high degree of fit, meaning the model accuratelyrepresents the adsorption behavior of the system. For example, if the Langmuir or Freundlich isotherm models are applied to adsorption data, the R^2 value helps determine which model better describes the relationship between the adsorbate concentration in solution and the amount adsorbed on the adsorbent surface. High R^2values suggest that the model assumptions align closely with the actual adsorption process, while low R^2 values indicate a poorer fit. The R^2 value of the Langmuir isotherm is 0.91 and for Freundlich is 0.912

Table 2: Langmuir and Freundlich constants for the biochar.

Adsorbent	Langmuir Isotherm			Freundlich Isotherm		
Palm Shell Biochar	q_e	K_1	R^2	K_F	1/n	R^2
	24	0.02	0.91	2	0.447	0.9

Conculsion:

In conclusion, the use of palm shell biochar as an adsorbent for textile effluent treatment shows promising potential due to its high adsorption capacity, eco-friendliness, and cost-effectiveness. The biochar's porosity and surface functional groups contribute to the efficient removal of dyes and other contaminants from textile wastewater, with performance influenced by factors like pH, contact time, and pollutant concentration. The adsorption data aligns well with established isotherm models, confirming the suitability of palm shell biochar for this application. Thus, palm shell biochar represents a sustainable alternative for textile effluent treatment, reducing the environmental impact of textile industries while valorizing agricultural waste. Further research to optimize biochar modification and regeneration could enhance its efficiency, making it an attractive option for large-scale wastewater treatment applications.

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