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Removal of(Methylene Blue Dye)From Aqueous Solution on to Tire Char Adsorption

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A B S T R A C T

Industrial wastewater is a major source of environmental pollution due to its complex and often hazardous pollutants. At the same time, the accumulation of end-of-life tires poses significant environmental challenges, as they are non-biodegradable and difficult to manage. This study explores the potential of using waste tires as an environmentally friendly and cost-effective adsorbent for treating industrial wastewater. Waste tires were chemically and thermally processed to produce a material resembling activated carbon with high surface area and porosity. The prepared material was tested for its effectiveness in removing methylene blue dye from aqueous solutions, achieving over 85% removal within one hour. The results demonstrated the promising adsorption capability of tire-derived adsorbents, highlighting their potential in removing dyes and heavy metals from wastewater. This approach not only provides a sustainable solution for tire waste management but also contributes to the development of low-cost technologies

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INTRODUCTION

Methylene blue (MB) is one of the most commonly used basic organic dyes as a pollutant model in water treatment studies due to its high solubility in water, chemical stability, and the ease with which its concentration can be tracked using UV-Vis spectroscopy. The presence of this dye in industrial wastewater, particularly from the textile and dyeing industries, is an environmental concern due to its potential negative impacts on aquatic ecosystems and public health [15]. This cationic dye with the chemical formula C16H18N3SCl ·3H2O appeared deep blue when dissolved in water [12].

Water pollution has become one of the most pressing environmental issues worldwide, primarily due to the rapid growth of industrial activities. Among the various pollutants, synthetic dyes used in textiles, leather, paper, plastics, and food industries are of major concern [5]. These dyes are often highly chemically stable, non-biodegradable, and resistant to light and heat, making their presence problem in aquatic environments [7]. many dyes and their degradation by-products are toxic, carcinogenic, effect on life and human health [8].

Over the years, several methods have been developed to treat wastewater with dye, such as chemical oxidation, coagulation–flocculation, membrane process, and ion exchange. However, most of these methods suffer from high costs and energy consumption, [16]. In contrast, adsorption has emerged as a simple, most efficient, technique for dye removal, due to high effectiveness and reusability of adsorbent [5].

In this field , char is the most common adsorbent due to its large surface area and strong adsorption capacity. Consequently, researchers search for low-cost, environmentally friendly alternative [8].

In this context, used car tires represent raw material for producing carbonaceous adsorbents. It is estimated that millions of tons of used tires are discarded annually, are dumped in landfills or incinerated in unsafe ways annually, causing severe air and soil pollution [13]. Converting waste tires into adsorbents not only provides an environmentally friendly disposal method but also produces a value-added product that can be applied in water treatment. Recent studies have shown these materials that tire-derived posses physical and chemical properties significant potential for dye adsorption due to their high surface area, the presence of active site, undergo the surface modification for functional groups [12,8].

LITERATURE REVIEW

This research aims to study the efficiency of carbon –based material prepared from used car tires for the removal of dyes from contaminated water. The research evaluates the influence of various factors, including contact time, pH, and sorbent dosage, and compares the performance with that of commercial activated carbon. This study highlights not only a promising approach for wastewater treatment but also a sustainable solution for managing one of the most problematic solid wastes globally.

METHODOLOGY

Experimental Work

Materials

Adsorbate : dye (methylene blue dye)

Table 1. Properties of Methylene Blue Dye [3]

Properties of Methylene Blue	
Property	**Details**
Chemical Name	Methylene Blue
Molecular Formula	$C_{16}H_{16}ClN_3S$
Molecular Weight	319.85 g/mol
Color	Dark Blue
Solubility	Soluble in Water
Maximum Absorption (λ_{max})	≈ 664 nm
Dye Type	Cationic Dye
Applications	Biological Stain, Redox Indicator, Adsorption Studies
Toxicity	Low at Laboratory Concentrations
Stability	Relatively Stable, Decomposes in Strong Light
Environmental Relevance	Model Contaminant for Wastewater Dye Removal

Adsorbate: Tire Char

Synthetic of Char

Preparation of Waste Tire Char

Firstly the rubber tires washed with tap water to remove impurities and dried in an oven at 110 °C for 24 h. The produced tire was sieved to a size of 1.5 mm, after that in oxygen free atmosphere pyrolysis takes place at 500°C for 1h this temperature was based on optimum results obtained. The final substance called char [1].

Characterization of Char

Boehm titration

By using Boehm titration method it is possible to determine the nature of of surface if acid or base [4].

Thermal Analysis

The pyrolysis optimum temperature was determined under vacuum from 400-800°C with heating rate 10°C/min.

Regeneration Efficiency

In batch adsorption experiments, the regeneration efficiency of an adsorbent is determined. Studies were done in 40 mL of solution mix with 2g char kept at a constant temperature of 25°C and put on a rotary shaker at 150 rpm for 1hr. For desorption, the char was washed with distilled water and then added to 5M NaOH solution with agitation at 150 rpm for 1 h. the produced char is separated by filtration, then washed with distilled water, dried at 110 °C for 1 h, and kept for reuse[14].

Adsorption equilibrium studies

- Single Isotherm

The batch experiments was applied in a shaker using 5 flasks containing 40 ml of compounds solution at the varied initial concentration (50, 100, 150, 200, and 250 ppm). The sorbent (2g) was added to every flask and closed it. The shaker was operating at 120 rpm and after 24 by filtration and centrifuge device separating the sorbent from the solution then concentration was measured by UV for pure compound.

Adsorption Modelling

- Single component modelling

Two isotherm models were utilized to the experimental data, Freundlich, Langmuir. The Freundlich model is an empirical equation, and it is widely to describe much adsorption data for nonlinear sorption model with heterogeneous adsorbent surfaces. This model is expressed as

$qe=KFCe^{1/n}$ (1)

Where, (*q*e) is the solid-phase equilibrium concentration (mgg^{-1}); (*C*e) is the aqueous phase concentration of equilibrium (mgL^{-1}); (*K*F) is the Freundlich equilibrium parameter (mgg^{-1})(Lmg^{-1}) 1/n *n*), *n* represents the exponential parameter it ranges between zero and one [18]. The Langmuir model has a theoretical basis, and it is generally the most

Single Adsorption Isotherm

The adsorption isotherm for dye onto char of size 1.5mm at 25 °C). From results listed in table2) it is clear that R^2 value for langmuir isotherm higher than Freundlich therefore, the Langmuir isotherm had the best fit. This means that the sorption of dye by char is of the mono-layer type.

Table2. Adsorption Isotherm Parameters for Tire Char Systems

Lungmuir isotherm1		
qm (mg/g)	KL (1/mg)	R^2
306.2013	0.004257	0.96550
Freundlich isotherm		
KF((mg/g)(1/mg)1/n)	n	R^2
4.448140	1.4571	0.94714

RESULTS AND DISCUSSION

The experimental data obtained from the experiment show three main relationships that illustrate the effects of time, pH (hydrogen ion concentration), and the amount of adsorbent on the dye removal efficiency.

Effect of Temperature on the Waste Tire Rubber

Char was prepared from 300 to 800 °C under an oxygen-free atmosphere at 10 °C/min (Figure 1). Adsorption capacity increased with temperature, reaching a maximum of 180 mg/g at 500 °C, due to enhanced porosity and surface area, which improve adsorption efficiency for cationic dyes [3,2]. Above 500 °C, capacity decreased, likely due to micropore collapse and loss of surface functional groups [10]. Char yield decreased continuously with temperature due to enhanced volatilization, consistent with previous reports [17,14]. Thus, 500 °C is the optimal pyrolysis temperature for balancing high adsorption capacity and acceptable char yield

The results show that the adsorption capacity increases with temperature, reaching its highest value at 500 °C (180 mg/g), and then begins to decrease at higher temperatures. increasing the temperature during the preparation of carbon materials improves porosity and increases surface area, thereby enhancing the adsorption efficiency of cationic dyes like methylene blue [3,7]. Additionally, increasing the temperature to moderate levels helps remove volatile substances from the carbon structure, which opens up micropores and increases the number of active adsorption sites [2].
At temperatures above 500 °C, a decrease in adsorption capacity was observed, which can be explained by the collapse of some micropores or the loss of surface functional groups such as hydroxyl and carboxyl due to exposure to high temperatures.

On the other hand, coal yield results showed a continuous decrease with increasing temperature, as the yield percentage dropped significantly at high temperatures. This is attributed to increased thermal decomposition and the release of volatile materials during pyrolysis, reducing the amount of remaining carbon [10]. This trend is consistent with what was reported by Williams and Besler (1996) and Mui et al. (2010) regarding the impact of temperature on the coal yield from tires and polymeric wastes. Based on these results, a temperature of 500 °C can be identified as an optimal temperature.

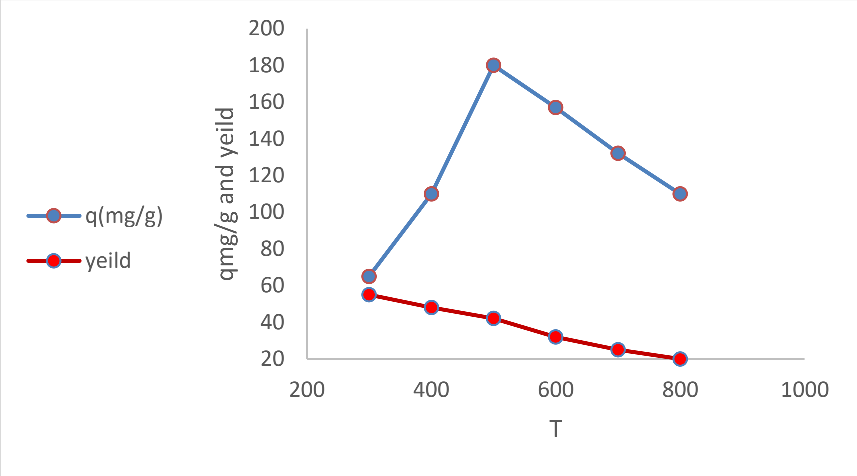

Figure 1. Effect of Temperature on Adsorption Capacity and Yeild

The Impact of Contact Time on Removal Efficiency (Contact Time)

Figure (2) illustrates the relationship between time (from 10 to 60 minutes) and the percentage of methylene blue dye removal. It is can be seen that in the first 10 minutes, 45% of the dye was removed. After 30minutes, the percentage increased to 74%. At 60 minutes, the removal percentage reached 88%. Analysis: The rapid increase in the first 30 minutes indicates the availability of a large number of active sites on the adsorbent surface [19]. The slowing increase after 40 minutes suggests that these sites are gradually becoming saturated. Conclusion: Contact time has a direct impact on adsorption efficiency, and 60 minutes is sufficient to reach a steady state.

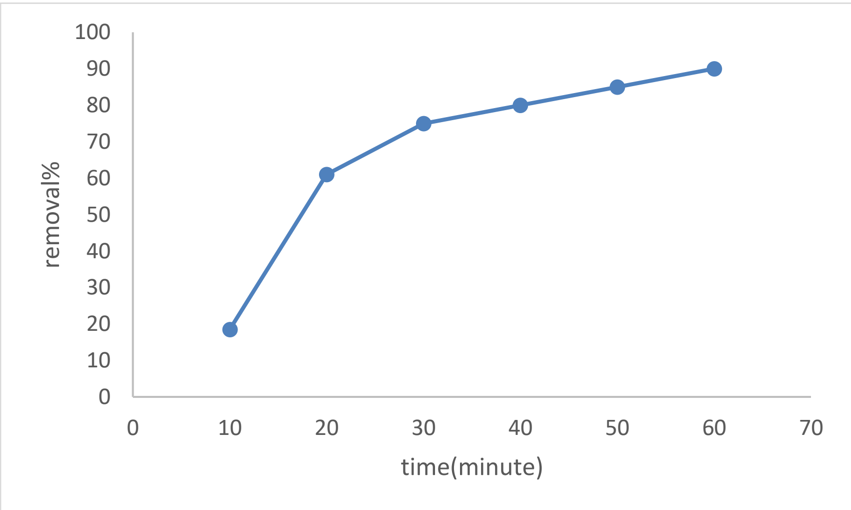

Figure 2. Effect of Contact Time on Dye Removal

TheEffectofpH

Figure (3) shows the relationship between pH value (from 3 to 9) and dye removal efficiency. At pH = 3, the removal was low (only 40%)while at pH = 8 the efficiency gradually improved until it reached 88%.It is shown from figure in acidic medium, the surface of the adsorbent is subjected to protonation, which reduces its capacity to absorb positively charged dyes and in basic medium, the surface is negatively charged, enhancing the electrostatic attraction between it and the positively charged dye molecules which mean the best removal efficiency was observed at pH = 8, indicating the sensitivity of the adsorption process to the chemical environment [3].

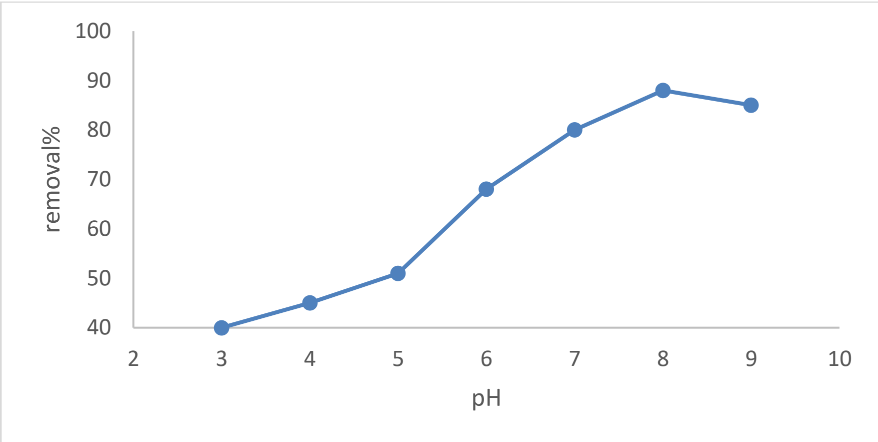

Figure 3. Effect of Ph on Dye Removal

Effect of Adsorbent Dosage

Figure(4) shows the effect of increasing the amount of adsorbent from 0.5 grams to 2.0 grams when using 0.5 grams, the removal rate was 56%,when the quantity was increased to 2.0 grams, the efficiency rose to 95%. This may be explained by fact that increasing the amount means an increase in the number of active sites available for the absorption of dye molecules. After a certain point (above 2 grams), clustering of the material may occur, reducing efficiency , which mean Increasing the amount leads to improved removal efficiency, but the ideal balance must be found to avoid waste or clustering[9,14].

General conclusion from the charts: All charts confirm that: The process follows a physical adsorption behavior with components of chemical adsorption. Efficiency is high under appropriate conditions, competing with commercial activated carbon. The material derived from used tires is considered an effective economic and environmental alternative.

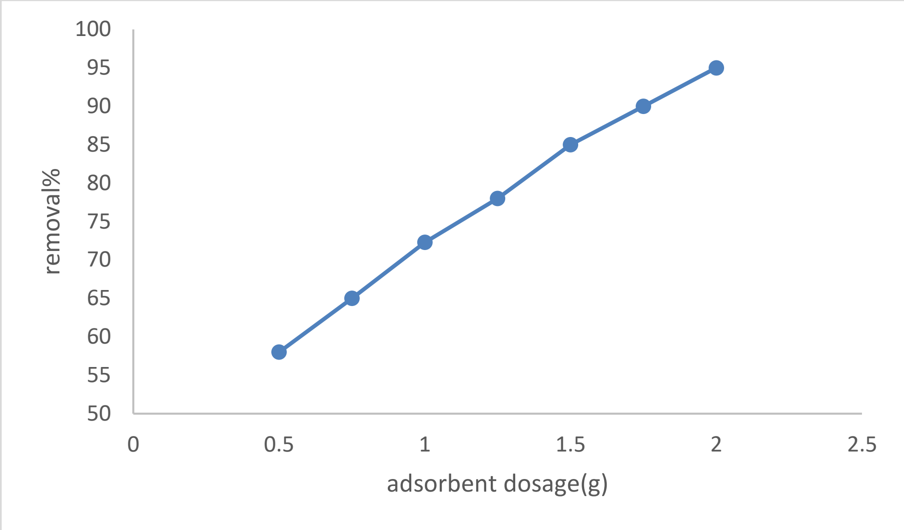

Figure 4. Effect of adsorbent dosage on dye removal

CONCLUSIONS AND RECOMMENDATIONS

Tire Char is an effective and economical adsorbent for dye removal from aqueous solutions. Its use promotes sustainability, reduces environmental pollution, and provides a practical alternative to expensive activated carbon. Adsorption efficiency depends on several factors, including pH, initial dye concentration, adsorbent dosage, and temperature

FURTHER STUDY

This research still has limitations so that further research is needed on the topic of Removal of) methylene blue dye (from Aqueous Solution on to Tire Char adsorption) in order to perfect the research and increase the insight of readers and writers.

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