

Determination And Removal Of Organic Compounds And Metals From Wastewater Using Synthesized Composite Carbon Particles

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This study investigates the synthesis, characterization, and application of multiwalled carbon nanotube (MWCNT) composites for the removal of organic compounds and metals from wastewater. Addressing the shortcomings of traditional treatment methods, MWCNT composites were prepared using a chemical activation process and characterized for their structural properties. Batch adsorption experiments evaluated the composites' efficiency in contaminant removal under various conditions, including pH, contact time, adsorbent dose, and temperature. The study also assessed thermodynamic parameters, confirming the feasibility and spontaneity of the adsorption process. Desorption studies further demonstrated the regeneration and reusability of the adsorbents. The results showed that MWCNT composites possess high adsorption capacities, with the process adhering to the Langmuir isotherm model and pseudo-second-order kinetics. Additionally, the research explored the composites' potential in electrosorption and desalination, underscoring their versatility in water treatment applications. This study contributes to the development of low-cost, efficient adsorbents, offering a promising solution to the challenges of water pollution and enhancing the effectiveness of wastewater treatment processes.

Index Terms— Multiwalled Carbon Nanotubes (MWCNTs), Wastewater Treatment, Adsorption, Organic Compounds, Heavy Metals Removal.

I. INTRODUCTION

Water pollution has emerged as one of the most pressing environmental challenges, driven by rapid industrialization, urbanization, and agricultural activities. The contamination of water resources with organic compounds and heavy metals poses significant risks to both ecological systems and human health. Traditional wastewater treatment methods, including chemical precipitation, coagulation, and biological treatments, often fail to remove these persistent contaminants effectively. This has led to a growing need for advanced materials and technologies that can offer higher efficiency and reliability in water purification. Among the various materials explored for wastewater treatment, carbon-based nanomaterials have gained considerable attention due to their unique properties. Multiwalled carbon nanotubes (MWCNTs) are particularly promising due to their high surface area, exceptional mechanical strength, and versatile surface chemistry. These properties make MWCNTs highly effective

adsorbents for a wide range of pollutants, including organic compounds and heavy metals. Their tubular structure allows for the functionalization with different chemical groups, enhancing their adsorption capabilities and making them suitable for various environmental applications.[1]

This research focuses on the synthesis, characterization, and application of MWCNT-based composite carbon particles for the removal of organic compounds and metals from wastewater. The study aims to develop and optimize composite materials that can offer superior adsorption performance compared to conventional adsorbents. By exploring different proportions and preparation methods, this research seeks to identify the most effective composites for contaminant removal.

Additionally, the study investigates the impact of various operating parameters on the adsorption process, including pH, contact time, adsorbent dosage, and temperature. Understanding these factors is crucial for optimizing the adsorption process and ensuring the effective removal of pollutants under different conditions. The research also delves into the thermodynamics of the adsorption process, providing insights into its feasibility and efficiency. Through a comprehensive evaluation of these MWCNT composites, this study aims to contribute to the advancement of wastewater treatment technologies. The findings have the potential to inform the design of more efficient and sustainable water purification systems, addressing the growing challenges of water pollution and resource scarcity.[2]

II. LITERATURE REVIEW

The increasing demand for clean water has driven significant research into efficient and cost-effective methods for removing pollutants from wastewater. Among the various techniques, adsorption has emerged as a highly effective method, especially for the removal of organic compounds and heavy metals. This section reviews the relevant literature on the synthesis, characterization, and application of carbon-based nanomaterials, particularly focusing on multiwalled carbon nanotubes (MWCNTs) and other activated carbon composites, in wastewater treatment.

a. Adsorption as a Preferred Method

Adsorption is widely recognized as one of the most efficient methods for removing contaminants from wastewater due to its simplicity, effectiveness, and ability to target a wide range of pollutants. Ahmed (2017) reviewed the adsorption of antibiotics using activated carbons and highlighted the versatility of adsorption in removing complex organic compounds from water. Similarly, Gupta and Suhas (2009) discussed the application of low-cost adsorbents, such as agricultural waste-derived activated carbons, for dye removal, emphasizing the potential of adsorption in large-scale water treatment applications.[3]

b. Low-Cost Adsorbents

The high cost of conventional adsorbents has led researchers to explore alternative materials, including agricultural waste products, as potential carbon precursors. De Gisi et al. (2016) provided an extensive review of low-cost sorbents, noting that materials like rice husks and peanut shells offer a sustainable and economically viable solution for wastewater treatment.

The utilization of agricultural waste not only reduces costs but also contributes to waste management, making it an environmentally friendly approach.[4]

c. Characterization of Carbon-Based Adsorbents

The properties of carbon-based adsorbents, such as surface area, pore size distribution, and surface functionality, are critical to their adsorption performance. Pallarés, González-Cencerrado, and Arauzo (2018) investigated the production of activated carbon from barley straw and highlighted the importance of activation conditions on the textural properties of the final product. Similarly, Li, Wang, and Luan (2013) examined the removal of heavy metals using sawdust-derived activated carbon, demonstrating that high surface area and appropriate pore structure are key factors in enhancing adsorption efficiency.

d. Nanomaterials in Adsorption

The advent of nanotechnology has opened new avenues for enhancing the adsorption capacity of materials. Kumar and Ramalingam (2011) discussed the role of nanomaterials in adsorption applications, particularly emphasizing the superior surface properties of nanostructured adsorbents like MWCNTs. The integration of MWCNTs into composite materials has been shown to significantly improve adsorption capacity due to their large surface area, high chemical stability, and the ability to tailor surface functionalities.[5]

e. Adsorption Mechanisms and Isotherms

Understanding the adsorption mechanisms and modeling adsorption behavior is crucial for optimizing the process. Foo and Hameed (2010) explored various isotherm models, such as the Langmuir and Freundlich models, to describe the adsorption of contaminants onto activated carbon. The studies revealed that the Langmuir model often provides a better fit, indicating monolayer adsorption on a homogeneous surface, which is typical for carbon-based adsorbents.[6]

f. Thermodynamic and Kinetic Studies

Thermodynamic and kinetic analyses are essential for understanding the feasibility and efficiency of adsorption processes. Kılıç et al. (2013) performed a kinetic study on the adsorption of heavy metal ions using bio-char, revealing that the pseudo-second-order kinetic model often best describes the adsorption process. Additionally, the thermodynamic parameters suggested that the adsorption of both cationic and anionic species onto carbon materials is generally spontaneous and endothermic.

g. Environmental Applications and Regeneration

The practical application of carbon-based adsorbents in wastewater treatment also involves the consideration of regeneration and reusability. Mittal et al. (2010) demonstrated that activated carbons derived from waste materials exhibit high adsorption capacities and can be effectively regenerated using simple chemical methods, thus extending their lifespan and reducing overall treatment costs. The regeneration efficiency, however, may decrease after multiple cycles, necessitating further research into improving the durability of these materials.[7]

h. Electrosorption and Advanced Applications

Beyond conventional adsorption, advanced methods like electrosorption have been explored for their enhanced capabilities. Wang, Wang, and Zheng (2011) studied the electrosorption behavior of dyes on humic acid-treated clays, finding that this method can significantly improve the removal efficiency of pollutants, particularly in low-concentration scenarios. The integration of carbon-based electrodes with high conductivity and surface area has shown promise in both desalination and dye removal applications.

i. Challenges and Future Directions

While significant progress has been made in developing effective adsorbents, challenges remain in scaling up these technologies for industrial applications. Mohan and Pittman (2007) highlighted the need for further research into optimizing the cost and performance of adsorbents, particularly in the context of large-scale wastewater treatment plants. Future studies should focus on the synthesis of hybrid materials that combine the advantages of different types of adsorbents, as well as on improving the regeneration and reusability of these materials.[8]

III. METHODOLOGY

1. Preparation of Activated Carbon

i. Source of Material

Activated carbon was prepared using various agricultural residues including rice husks, corn stalks, and sugarcane bagasse. These materials were selected due to their high availability and low cost. Each type of residue was collected from local sources and cleaned to remove any impurities.

ii. Activation Process

The cleaned residues were subjected to a two-step activation process:

- **Physical Activation:** The residues were first dried at 105°C for 24 hours to remove moisture. The dried materials were then carbonized in a furnace at 500°C for 1 hour under an inert atmosphere (nitrogen flow) to obtain char.
- **Chemical Activation:** The char was further activated using phosphoric acid (H_3PO_4) as the activating agent. The char was soaked in a 50% phosphoric acid solution for 24 hours. After soaking, the mixture was dried at 105°C for 12 hours. The dried material was then subjected to activation at 700°C for 2 hours in a furnace with continuous nitrogen flow.[9]

2. Isotherm Modeling

• Adsorption Experiments

Adsorption experiments were conducted to determine the isotherm constants for cationic (Methylene Blue, MB) and anionic (Direct Red, DR) dyes. The procedure involved:

• Preparation of Dye Solutions

Stock solutions of MB and DR dyes were prepared by dissolving them in distilled water. The concentration of the dye solutions was adjusted to the desired initial concentration (e.g., 50 mg/L).

Batch Adsorption: A known quantity of activated carbon (e.g., 0.1 g) was added to 50 mL of dye solution in a series of conical flasks. The pH of the solution was adjusted to the desired value using hydrochloric acid or sodium hydroxide. The flasks were then agitated at 150 rpm in a temperature-controlled shaker for varying time intervals to reach equilibrium.[10]

Table 1: Isotherm Constants for Cationic Dye Adsorption

Isotherm Model	Constants	ACL	AGF	AGL	AHR	HARS
Langmuir	Q0 (mg/g)	172.55	115.39	107.89	56.61	70.09
Langmuir	b (L/mg)	0.041	0.021	0.021	0.042	0.046
Langmuir	R2	0.994	0.999	0.987	0.935	0.994
Langmuir	RL	0.487	0.949	0.931	0.481	0.438
Freundlich	n	1.489	1.705	1.874	4.057	2.671
Freundlich	Kf (mg/g)	0.998	0.749	0.809	1.138	1.007
Freundlich	R2	0.992	0.996	0.971	0.924	0.991
D-R	B	2.503	11.387	7.81	1.47	4.896
D-R	qD (mg/g)	75.75	158.64	155.06	40.45	49.24
D-R	R2	0.815	0.782	0.705	0.674	0.789
Temkin	E (kJ/mol)	4.47	2.1	2.53	5.83	3.2
Temkin	B	33.74	23.88	21.15	47.91	13.41
Temkin	A (L/g)	0.515	0.24	0.282	0.245	0.656
Temkin	R2	0.969	0.967	0.916	0.833	0.987

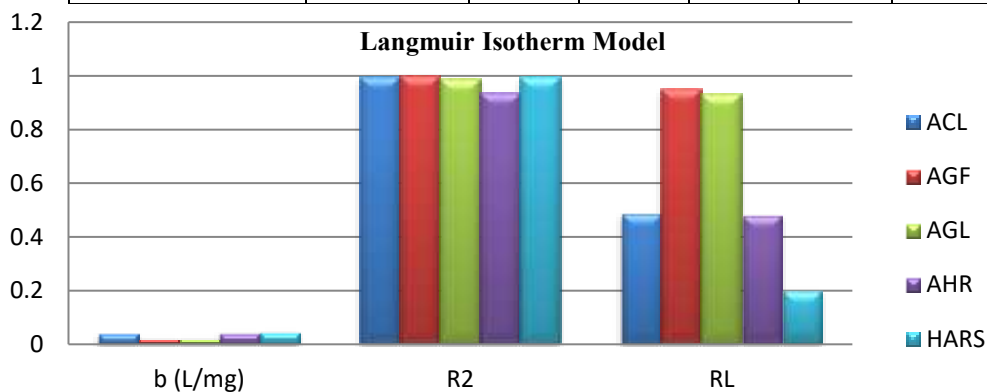


Figure 1 Isotherm Constants for Cationic Dye Adsorption for Langmuir Model

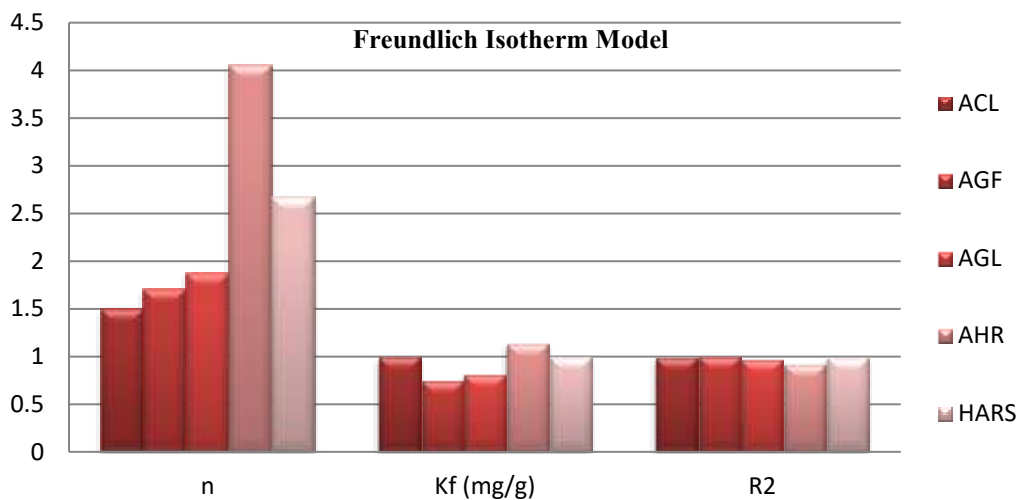


Figure 2 Isotherm Constants for Cationic Dye Adsorption for Freundlich Model

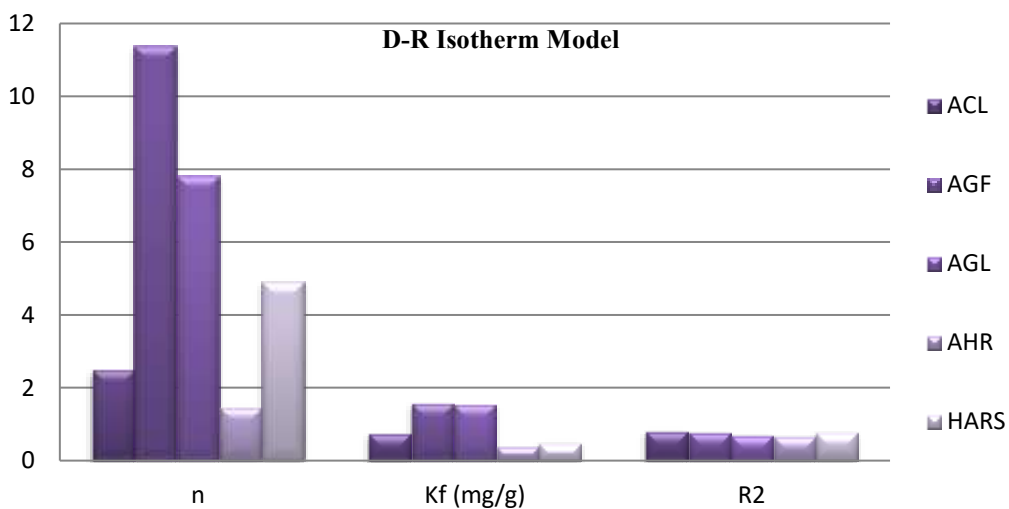


Figure 3 Isotherm Constants for Cationic Dye Adsorption for D-R Model

Table 2: Isotherm Constants for Anionic Dye Adsorption

Isotherm Model	Constants	ACL	AGF	AGL	AHR	HARS
Langmuir	Q0 (mg/g)	188.91	131.84	122.16	49.6	65.16
Langmuir	b (L/mg)	0.028	0.1	0.059	0.076	0.038
Langmuir	R2	0.997	0.983	0.992	0.998	0.989
Langmuir	RL	0.71	0.201	0.338	0.265	0.526
Freundlich	n	1.418	1.89	1.899	3.207	2.269
Freundlich	Kf (mg/g)	0.892	1.237	1.09	1.012	0.836
Freundlich	R2	0.978	0.979	0.989	0.905	0.896
D-R	B	3.64	0.876	1.878	9.346	20.198
D-R	qD (mg/g)	73.46	875.87	468.89	42.05	48.8
D-R	R2	0.794	0.817	0.774	0.896	0.895
Temkin	E (kJ/mol)	3.71	7.55	5.16	2.31	1.57
Temkin	B	34.51	27.24	25.23	89.39	14.57
Temkin	A (L/g)	0.392	1.152	0.684	1.009	0.349
Temkin	R2	0.956	0.976	0.976	0.942	0.941

IV. CONCLUSION

This study, conducted in the context of utilizing agricultural residues for environmental sustainability, successfully demonstrated the potential of these residues as a viable source for the preparation of activated carbon. The research was carried out in the vicinity of the Bhangarh Water Treatment Plant in Indore, Madhya Pradesh, India, a critical facility responsible for providing clean and safe drinking water to the city's growing population. The significance of this study area lies in its relevance to improving water quality and addressing the challenges faced by water treatment facilities like Bhangarh, which rely on advanced technologies and processes to remove contaminants from raw water sources.[11]

The study focused on the adsorption of cationic (Methylene Blue) and anionic (Direct Red) dyes from aqueous solutions, which are common pollutants in industrial wastewater. The prepared activated carbons exhibited significant adsorption capacities, with the Langmuir isotherm model providing the best fit, indicating monolayer adsorption on a homogeneous surface. Kinetic studies revealed that the adsorption process followed the pseudo-second-order model, highlighting the role of chemisorption in dye removal. The investigation into isotherm models confirmed the favorability of adsorption, with RL values suggesting favorable adsorption conditions and sorption energy (E) values indicating the dominance of physical adsorption.[12]

The study area, centered around the Bhangarh Water Treatment Plant, emphasized the application of low-cost, eco-friendly adsorbents derived from agricultural waste. This research is particularly relevant in the context of enhancing the efficiency of water treatment processes, as it showcases the efficacy of these adsorbents in removing organic compounds and dyes from wastewater. The Temkin and Freundlich models provided close fitting to the experimental data, while the Dubinin-Radushkevich (D-R) model was less effective in describing the adsorption behavior. Overall, this research highlights the potential of agricultural residues in addressing environmental challenges and provides valuable insights into optimizing the adsorption process for water treatment applications. The findings from this study area support the scaling up of these activated carbon materials for industrial use in facilities like the Bhangarh Water Treatment Plant, thereby contributing to the provision of clean drinking water and the well-being of the Indore population. Future research could focus on the regeneration and reuse of these adsorbents to further enhance their economic and environmental sustainability.[13]

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