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Adsorption of Dye on Peanut Shell-Based Activated Carbon: A Review Article

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Abstract

Agricultural by-products such as peanut shells provide a renewable alternative to coal-based activated carbon by combining wastewater-treatment potential with agricultural waste valorization. This review examines the performance of peanut shell-based activated carbon (PSAC) in dye adsorption and evaluates the kinetic, equilibrium, and mechanistic models used to describe dye-removal processes. The review synthesizes reported evidence concerning adsorption kinetics, including pseudo-first-order and pseudo-second-order models, and adsorption isotherms, particularly the Langmuir and Freundlich models. The findings demonstrate that PSAC exhibits a high adsorption capacity for dyes such as methylene blue and crystal violet, with adsorption predominantly characterized by chemisorption and monolayer surface interactions. These findings indicate that PSAC is an effective and economical biomass-derived adsorbent for removing dyes from wastewater while supporting the beneficial reuse of agricultural residues. The review contributes an integrated understanding of PSAC adsorption performance and the models used to explain its dye-removal mechanisms. Further research should prioritize improving adsorbent regeneration, developing advanced PSAC-based composite materials,

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and scaling up adsorption systems for industrial wastewater-treatment applications.

Keywords: Activated Carbon; Biomass-Derived Adsorbents; Dye Adsorption; Peanut Shell; Wastewater Treatment

Introduction

Any amount of dye in water streams has conventional impacts on microorganisms. Since 1,000,000 tons of dyes are produced worldwide, they are used by small- and large-scale enterprises such as tanneries, and the food, cosmetic, textile, and medicine sectors. The textile industry is mostly responsible for dye release into the environment [4].

Both natural and synthetic dyes may absorb light in the optical spectrum because they have complex structures made up of aromatic rings attached to different functional groups. The occurrence of color-releasing molecules enables the dyes to impart color. However, a lot of artificial dyes are extremely cancerous, and the production of azo groups has been connected to emissions of benzidine and amine. Some common synthetic dyes, such as Methylene Blue (MB) and Crystal Violet (CV), are known to be toxic to aquatic life and people, producing health problems like nausea, breathing difficulties, and tissue necrosis.

Adsorption is a technique used to extract dyes from colored effluents, and it is particularly efficient and clear. Adsorption is effective in treating wastewater since it entails the attachment of pollutants to the surface of an adsorbent substance. Activated carbon, natural chemicals, and agricultural wastes are frequently been utilized as adsorbents in removing dyes. Additionally, because of their excellent capacity for eliminating a variety of organic and inorganic contaminants, polymeric materials have emerged as viable substitutes for conventional adsorbents [1].

It has been demonstrated that activated carbon (AC) is effective at eliminating a wide range of contaminants, such as dyes, heavy metals, bisphenol A, carbon dioxide (CO_2), and chlorophenols. However, because it comes from non-renewable precursors like coal, commercially accessible AC is expensive. To solve this problem, several researchers have conducted extensive research on various options for novel precursors, particularly agricultural wastes, to generate affordable AC. An analysis of peanut shells as an adsorbent to extract dye from aqueous solutions is presented in this work. Due to its physical properties,

peanut shell, an agricultural waste, is a perfect precursor for the synthesis of AC, as millions of tons of peanuts are produced worldwide and are readily accessible [3].

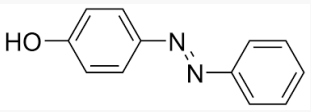
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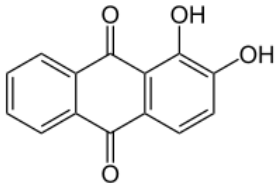
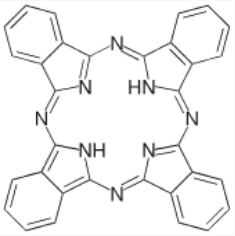
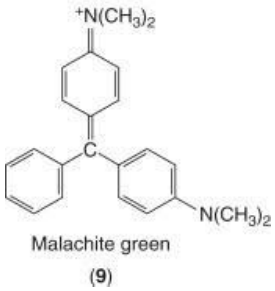
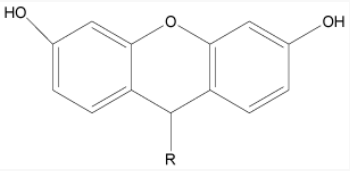
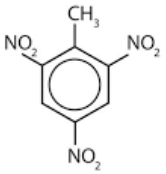
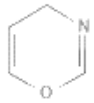
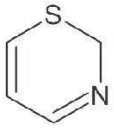
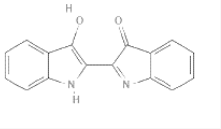
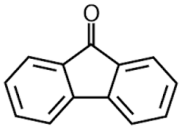
Dyes can be natural or Synthetic. Synthetic dyes are widely employed as additives in petroleum products and textile dyeing. During the dyeing process, over 10-15% of the approximately 10,000 different varieties of commercially available colors are lost in effluent [12]. The Color Index has nearly 9,000 unique dye kinds listed [27]. The purity of water is seriously threatened by visual pollution, which is made worse by concerns about toxicity. Because dyes are made of extremely stable molecules, they persist in the presence of perspiration, light, water, heat, or oxidizing chemicals. However, due to the dyeing process's ineffectiveness, a significant proportion of hazardous, non-biodegradable leftover dye baths are lost straight into wastewater. As a result, this hurts the ecosystem, including the soil and water, as well as the flora and wildlife [11].

Structure and Classification of DYES

Dyes are common in industrial processes, including textile dyeing, printing, and coloring various products. They come in a wide range of classes and structures, each with its unique chemical composition and properties. Some common classes of dyes include azo dyes, which are characterized by the presence of an azo group (-N=N-) linking two aromatic groups, anthraquinone dyes, triphenylmethane dyes, xanthene dyes, nitro dyes, indigoid dyes, phthalocyanine dyes, aminoketone dyes, and others. These classes encompass a diverse spectrum of colors and are utilized across various industries due to their versatility and application range [8][22].

Table 1: Difference classes of dyes, their chemical structure, and examples

S.No.	Class	Structure	Example
1	Azo Dyes		Methyl orange

S.No.	Class	Structure	Example
2	Anthraquinone Dyes		Disperse Blue 1
3	Phthalocyanine Dyes		Copper phthalocyanine
4	Triphenylmethane Dyes		Malachite Green
5	Xanthene Dyes		Rhodamine B
6	Nitro Dyes		Nitrobenzene
7	Oxazine Dyes		Methyl violet
8	Thiazine Dyes		Methylene blue
9	Indigoid Dyes		Indigo
10	Fluorone Dyes		Fluorescein

Source and distribution of DYES in the environment

The primary industrial sources of dye dispersal in the environment include the production of textiles, leather goods, paper, and dyes [16]. The textile sector is a notable contributor to dye pollution because of the large number of dyes it uses in the dyeing process. The main way that dyes get into the environment is through the untreated or poorly treated effluents that these businesses release into water bodies.

In addition, accidental spills and inappropriate disposal of used dyes and dyed products exacerbate environmental contamination. Dyes have a lengthy half-life in the environment because of their chemical stability, which can cause long-term contamination of water and water and soil resources.

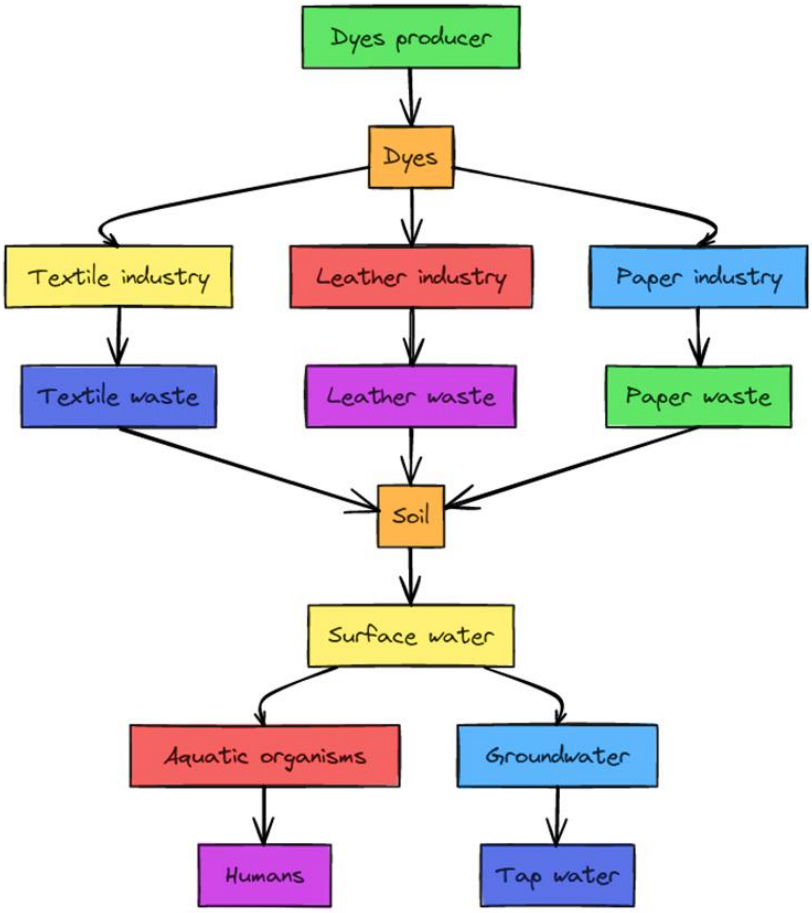


Fig. 1: Recent sources and distribution of dyes in the environment

Different techniques for the remediation of DYES

Diverse methods are utilized to eliminate dyes from sources of water and wastewater to reduce environmental pollution. Adsorption is one of these methods that is frequently

utilized because of its affordability, efficiency, and ease of usage. It entails binding dye molecules to the surface of an adsorbent substance, like nanoparticles, activated carbon, or biochar. Semi-permeable membranes are used in membrane filtration processes including ultrafiltration, nanofiltration, and reverse osmosis to physically separate dye molecules from water. By using microorganisms to break down or metabolize color molecules, biological treatment techniques provide eco-friendly alternatives. While electrochemical treatment approaches cause chemical reactions at electrode surfaces to remove dyes from water, chemical treatment methods use chemical agents to break down or precipitate dye molecules. These methods can be used separately or in combination, according to the particular dye pollutants [20].

Biomass-based adsorbents for the removal of dyes

Synthetic dyes are widely used and hurt ecosystems, thus the removal of dyes from water and wastewater sources is an important environmental concern [30]. Biomass-based adsorbents have shown promise as dye removal materials since they provide economical and eco-friendly alternatives. These adsorbents have large surface areas and functional groups which make them ideal for dye adsorption. They are made from a variety of biomass sources, including agricultural waste. One such biomass-derived adsorbent with great dye removal ability is activated carbon generated from peanut shells [26]. Biomass-based adsorbents can be modified to increase their capacity and effectiveness for adsorption by procedures including encapsulation and chemical treatment. Because these adsorbents can be recycled and renewed, they represent environmentally friendly alternatives for the treatment of dye wastewater [9].

Agricultural waste adsorbent

Agricultural waste-based adsorbents are abundant, inexpensive, and environmentally friendly, they have garnered a lot of attention for their potential in wastewater treatment. The efficacy of agricultural waste products like sugarcane bagasse, rice husks, and peanut shells in eliminating pollutants from water sources has been investigated in several research. The adsorption capacity of activated carbon derived from peanut shells (PSAC) has been thoroughly investigated. Because of its porous structure and large surface area, PSAC is a powerful adsorbent for a wide range of contaminants, including dyes and heavy metals. The work by [18] highlighted PSAC's potential for dye wastewater treatment by demonstrating

how well it removed methylene blue dye from aqueous solutions. Rice husk is another commonly investigated agricultural waste material for adsorbent preparation. Due to its high silica content, rice husk-based adsorbents possess excellent adsorption properties. Studies have shown that modified rice husk adsorbents can effectively remove dyes, heavy metals, and other pollutants from contaminated water sources. The research by [10] focused on the synthesis of magnetic biochar from rice husk for the removal of Pb (II) ions from aqueous solutions, demonstrating its high adsorption capacity and reusability.

Sugarcane bagasse, a byproduct of the sugar industry, has also been explored as a potential adsorbent for wastewater treatment. With its high cellulose content and porous structure, sugarcane bagasse-based adsorbents offer a sustainable solution for pollutant removal. The study by [7] investigated the use of sugarcane bagasse-based activated carbon for the removal of emerging contaminants from aqueous solutions, highlighting its effectiveness in adsorbing pharmaceutical compounds and personal care products.

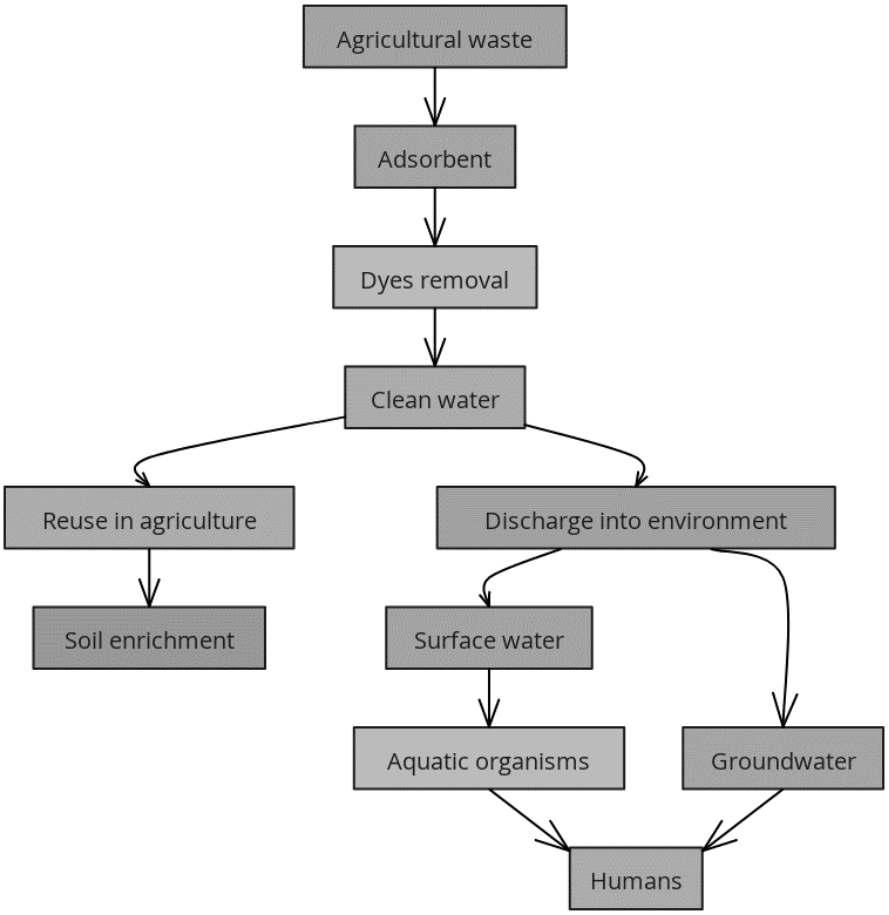


Fig 2: Chemistry involving the use of agricultural waste as adsorbent for DYES removal

Peanut shell materials as adsorbents

Many adsorbents, such as those derived from peanut shells, have a great deal of potential for the removal of antibiotics from wastewater treatment. According to [4], peanut shell-based activated carbon is significant due to its large surface area, many pore architectures, and adjustable surface functions, which make it a powerful adsorbent for the removal of antibiotics. Because of its porous structure and surface chemistry, activated carbon derived from peanut shells has been proven to be particularly successful in removing a variety of dyes, making it a suitable substitute for wastewater treatment [29]. High adsorption capability and the possibility for sustainable waste management characterize biochar derived from peanut shells.

Adsorption kinetics models: theoretical basis.

Practical adsorption systems frequently involve complex kinetic processes, and the kinetic models used for the adsorption of pollutants onto adsorbents understanding the adsorption mechanism and predicting the adsorption behavior are as follows: Adsorption kinetics measures the rate and mechanism of adsorption processes, particularly in water and wastewater treatment applications. Traditionally, the pseudo-first-order (PFO) and pseudo-second-order (PSO) kinetic models have been commonly employed.

(a) Lagergren Pseudo-First-Order Model: $\frac{dq}{dt} = k_1 (q_e - q)$

This model shows that the adsorption rate is directly proportional to the number of unoccupied sites on the activated carbon surface. It follows first-order kinetics, indicating that the rate of dye adsorption is dependent on the concentration of the dye. This model is suitable for scenarios where physical adsorption dominates.

(b) Lagergren PseudoSecond-Order $\frac{dq}{dt} = k_2 (q_e - q)^2$

This model suggests that the adsorption process involves chemisorption, where the rate of dye adsorption is proportional to the square of the concentration of the dye. It propounds that adsorption capacity is limited by the availability of active sites on the activated carbon surface.

(c) Intraparticle Diffusion Model:

$$q = k_4 t^{0.5}$$

This model indicates that the adsorption process occurs in multiple steps, including film diffusion, pore diffusion, and adsorption on the interior surface of the activated carbon. The linear portion of the plot represents the rate-controlling step, and the intercept provides information about the boundary layer thickness.

(d) Kinetic Model of Avrami:

$$\ln(1 - X) = -k\, t^{n}$$

The Avrami model is based on the assumption that the adsorption process follows a pseudo-second-order mechanism and occurs on a heterogeneous surface. It describes the fractional conversion of adsorption over time.

(e) Bangham Kinetic Model:

$$q = k_4\, t^{0.5} \ln(t)$$

This model suggests that adsorption occurs through pore diffusion, with the rate of dye adsorption being directly proportional to the square root of time. It is commonly used to describe solute adsorption onto porous activated carbon.

(f) Boyd Kinetic Model:

$$\text{sub} - \text{bdqt} = k_{bd}t + c_t$$

The Boyd model incorporates both external mass transfer and intraparticle diffusion processes. It assumes that the adsorption rate is controlled by both film diffusion and intraparticle diffusion, aiding in understanding the adsorption mechanism and estimating rate parameters.

(g) Lovich Kinetic Model: $\frac{dq}{dt} = k_3\, e^{-\beta q}$

This model proposes a two-step adsorption process: an initial rapid adsorption phase followed by a gradual decrease in the adsorption rate. It assumes energetically heterogeneous adsorption sites, with adsorption energy decreasing exponentially with increasing surface coverage.

Adsorption Isotherm models: theoretical basis

Adsorption isotherm models play a crucial role in understanding the equilibrium relationship between the adsorbate concentration in the liquid phase and the adsorbate

concentration in the solid phase. Various isotherm models have been developed to describe this relationship, each based on different assumptions regarding adsorption behavior. Some commonly used adsorption isotherm models include:

(a) Langmuir Isotherm:

The Langmuir isotherm assumes monolayer adsorption onto a homogeneous surface with a finite sub-L identical site. It is represented by the equasub-tion:$q_e = \frac{q_{mK_LC_e}}{1+ K_LC_e}$

Where:

q is the amount of adsorbate adsorbed per unit mass of adsorbent,

q_m is the maximum adsorption capacity,

K_l is the Langmuir constant, and

C_e is the equilibrium concentration of the adsorbate in the solution.

(b) Freundlich Isotherm:

The Freundlich isotherm describes heterogeneous surfaces and multilayer adsorption. It is represented by the equation:

$$q_e = K_F C_e^{1/n}$$

where K_f and C_e are Freundlich constants related to adsorption capacity and intensity, respectively.

(c) Bohart-Adams Isotherm

The Bohart-Adams isotherm is used for describing the adsorption of solutes from dilute solutions onto adsorbents with a finite number of active sites. It is expressed as:

$$\ln(\frac{C_e}{C_0}) = \frac{K_{BA}N_{qz}}{F} - K_{BA}C_0t$$

where K_{BA} is the Bohart-Adams constant.

(d) Brunauer-Emmett-Teller (BET) Isotherm:

The BET isotherm is commonly used for the adsorption of gas molecules onto solid surfaces, particularly in physisorption. It is based on the assumption of a homogeneous surface and multilayer adsorption.

$$\frac{C_e}{(C_s - C_e)V} = \frac{1}{V_m C_B} + \frac{(C_e - 1)}{V_m C_B C_s}$$

(e) Dubinin-Radushkevich Isotherm:

The Dubinin-Radushkevich isotherm is suitable for describing adsorption onto heterogeneous surfaces and is often used for microporous adsorbents. It is represented by the equation:

$$q_e = q_s \exp(-B\epsilon^2)$$

Where q is the maximum adsorption capacity,

B is a constant related to the adsorption energy, and

ϵ is the Polanyi potential.

(f) Flory-Huggins Isotherm:

The Flory-Huggins isotherm is derived from the Flory-Huggins theory of polymer solutions and is applicable to systems with adsorbate-adsorbate interactions.

(g) Frenkel-Halsey-Hill Isotherm:

The Frenkel-Halsey-Hill isotherm accounts for multilayer adsorption on heterogeneous surfaces and is based on the assumption of molecular condensation. It considers the adsorbent's pore size distribution.

(h) Khan Isotherm:

The Khan isotherm is used for describing adsorption onto heterogeneous surfaces and accounts for both monolayer and multilayer adsorption. It involves parameters related to the adsorption energy and surface heterogeneity.

(i) Koble-Corrigan Isotherm:

The Koble-Corrigan isotherm is suitable for describing the adsorption of solutes from dilute solutions onto adsorbents with a finite number of active sites. It considers the competitive adsorption of multiple solutes.

(j) MacMillan-Teller Isotherm:

The MacMillan-Teller isotherm is used for describing multilayer adsorption on heterogeneous surfaces and considers the formation of adsorbate clusters.

(k) Radke-Prausnitz Isotherm:

The Radke-Prausnitz isotherm is applicable to the adsorption of solutes from dilute solutions onto porous adsorbents and considers the competition between solute molecules for adsorption sites.

(l) Redlich-Peterson Isotherm:

The Redlich-Peterson isotherm is a generalized form of the Langmuir and Freundlich isotherms and is suitable for describing both monolayer and multilayer adsorption.

(m) Sips Isotherm:

The Sips isotherm is derived from the Langmuir and Freundlich isotherms and is suitable for describing heterogeneous surfaces and multilayer adsorption.

(n) Temkin Isotherm:

The Temkin isotherm accounts for the non-uniform distribution of heat of adsorption and assumes a linear decrease in adsorption energy with increasing surface coverage.

(o) Toth Isotherm:

The Toth isotherm is a generalized form of the Langmuir and Freundlich isotherms and is suitable for describing both monolayer and multilayer adsorption onto heterogeneous surfaces.

(p) Wolborska Isotherm:

The Wolborska isotherm is used for describing multilayer adsorption on heterogeneous surfaces and considers the adsorbate-adsorbate interactions.

(q) Yoon-Nelson Isotherm:

The Yoon-Nelson isotherm is applicable to the adsorption of solutes from dilute solutions onto porous adsorbents and considers the competitive adsorption of multiple solutes.

(r) Harkin-Jura Isotherm:

The Harkin-Jura isotherm is suitable for describing multilayer adsorption on heterogeneous surfaces and considers the interaction between adsorbate molecules in the bulk phase.

(s) Halsey Isotherm:

The Halsey isotherm is a modification of the BET isotherm and accounts for the surface energetics of porous adsorbents.

(t) Elovich-Larionov Isotherm:

The Elovich-Larionov isotherm is used for describing multilayer adsorption on heterogeneous surfaces and considers the formation of adsorbate clusters.

Experimental insight into the application of kinetics and isotherm to DYES adsorption

The adsorption of dyes from aqueous solutions has been extensively studied over the last decade, focusing on various adsorbents, mechanisms, and efficiencies. Numerous materials have been investigated for their efficacy in adsorbing dyes from aqueous solutions. These include natural clays, modified clays, activated carbons, metal oxides, and various composite materials.

Pristine and modified clays have been widely studied for their adsorption capabilities. Studies such as those by [25] have highlighted the effectiveness of these materials in adsorbing both dyes and heavy metals. Transition metal oxides, such as those discussed by have shown promise in removing dyes from water due to their high surface area and reactive sites. The mechanisms of dye adsorption include physisorption, chemisorption, ion exchange, and complexation. These mechanisms depend on the nature of the adsorbent and the dye. Studies on activated carbon demonstrated that both physisorption and chemisorption are involved, particularly when dealing with ionic dyes. Clay and metal oxide adsorbents often exhibit ion exchange properties, allowing them to effectively capture dyes from solutions.

Various isotherm models have been used to describe the adsorption processes, including Langmuir, Freundlich, and Dubinin-Radushkevich isotherms. The Langmuir model, suitable for monolayer adsorption on homogeneous surfaces, has been applied in many studies to describe the adsorption capacity and efficiency of different adsorbents. The Freundlich isotherm, used for heterogeneous surfaces and multilayer adsorption, has been employed to understand the adsorption behavior of clays and activated carbons. The Dubinin-Radushkevich isotherm, applicable for microporous adsorbents, has been used in

studies involving activated carbons and metal oxides to describe the adsorption process and energy distribution.

Kinetic studies provide insights into the rate and mechanism of adsorption. The common models include pseudo-first-order, pseudo-second-order, and intra-particle diffusion models. The pseudo-second-order kinetics model has been frequently observed, indicating that the adsorption process is more dependent on the availability of adsorption sites than on the concentration of the dye. Intra-particle diffusion has also been highlighted in many studies, such as those by [15], showing that it importance in the adsorption process, particularly in porous adsorbents.

Recent studies have explored advanced materials and techniques to enhance dye adsorption efficiency. Innovations in composite materials have led to the development of adsorbents with higher capacities and faster adsorption rates.

Kinetics of Dyes Adsorption

In recent years, there has been a significant amount of research done on the kinetics of dye adsorption onto different adsorbents. [32] research looked on the kinetics of the methylene blue (MB) adsorption onto peanut shell-derived activated carbon. The experimental data were fitted with pseudo-first-order and pseudo-second-order kinetic models. The experimental data was closely fitted by the pseudo-second-order kinetic model, indicating that a chemisorption mechanism underpinned the adsorption process. The kinetics of Reactive Red 120 (RR120) adsorption onto magnetic biochar made from peanut shells were also examined in a study by [28] The adsorption process was found to be accurately described by the pseudo-second-order kinetic model, showing that the interaction between RR120 and the magnetic biochar was chemisorption in nature.

Isotherms of Dyes Adsorption

A number of isotherm models have been used to explain how dyes adsorb onto different types of adsorbents. [26] examined into the adsorption of Acid Blue 92 (AB92) onto activated carbon made from peanut shells. Fits between the Langmuir and Freundlich isotherm models and the experimental data were computed. A superior fit to the experimental data was given by the Langmuir isotherm, which suggested that AB92 was adsorbed onto the activated carbon in a monolayer pattern. [13] investigated the adsorption of Congo Red (CR) onto peanut shell biochar in a similar manner. The models of Freundlich, Temkin, and Langmuir isotherms were used to examine the experimental results. It was

discovered that the Langmuir isotherm best captured the adsorption process, indicating the creation of a CR molecule monolayer.

Thermodynamics of Dyes Adsorption

Thermodynamic parameters offer significant insights into the adsorption process's feasibility and spontaneity. [32] looked into the thermodynamics of Malachite Green (MG) adsorption onto biochar made from peanut husks. The results showed that the adsorption process was exothermic and spontaneous, with ΔH° and ΔG° having negative values. Enhanced randomization at the solid-liquid interface during the adsorption process was shown by the positive value of ΔS°.

These studies demonstrate the importance of understanding the kinetics, isotherms, and thermodynamics of dyes adsorption for the design and optimization of adsorption processes for wastewater treatment.

Table 2: Comparation of Different Models.

Material	Dye	Experimental Conditions	Adsorption Capacity/ Removal Efficiency	Kinetic Model	Isotherm Model	Mechanisms	Reference
Peanut shell activated carbon	Methylene Blue	Initial concentration: 50-100 mg/L Adsorbent dose: 0.5-2.5 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 10-90 mg/g Removal efficiency: 70-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[3]
Peanut shell biochar	Reactive Black 5	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 8.25-84.74 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[2]
Peanut shell activated carbon	Malachite Green	Initial concentration: 10-50 mg/L Adsorbent dose: 0.5-3 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 12.6-56.82 mg/g Removal efficiency: 65-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[23]
Peanut shell activated carbon	Acid Blue 29	Initial concentration: 20-100 mg/L Adsorbent dose: 0.2-1.0 g/L pH:	Adsorption capacity: 8.32-53.68 mg/g Removal	Pseudo-first-order, Pseudo-	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[12]

Material	Dye	Experimental Conditions	Adsorption Capacity/ Removal Efficiency	Kinetic Model	Isotherm Model	Mechanisms	Reference
		2-12 Temperature: 20-60°C	efficiency: 70-98%	second-order			
Peanut shell biochar	Rhodamine B	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 10.38-88.21 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[17]
Peanut shell powder	Reactive Red 120	Initial concentration: 20-100 mg/L Adsorbent dose: 0.5-3 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 15.25-60.48 mg/g Removal efficiency: 65-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[24]
Peanut shell biochar	Basic Red 46	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 8.82-84.19 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[2]
Peanut shell activated carbon	Direct Red 80	Initial concentration: 20-100 mg/L Adsorbent dose: 0.5-3 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 18.67-62.35 mg/g Removal efficiency: 65-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[12]
Peanut shell biochar	Crystal Violet	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 9.65-79.35 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[20]
Peanut shell Biochar supported with clay mineral kaolinite	Acid Orange 7	Initial concentration: 50-100 mg/L Adsorbent dose: 0.5-2.5 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 10-90 mg/g Removal efficiency: 70-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[15]
Peanut shell biochar	Acid Red 18	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-	Adsorption capacity: 8.58-81.94 mg/g Removal	Pseudo-first-order, Pseudo-	Langmuir, Freundlich	π-π electron donor-acceptor interaction,	

Material	Dye	Experimental Conditions	Adsorption Capacity/ Removal Efficiency	Kinetic Model	Isotherm Model	Mechanisms	Reference
		10 Temperature: 20-60°C	efficiency: 60-98%	second-order		electrostatic interaction	
Peanut shell activated carbon	Acid Blue 25	Initial concentration: 50-100 mg/L Adsorbent dose: 0.5-2.5 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 10-90 mg/g Removal efficiency: 70-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[26]
Peanut shell biochar	Acid Blue 25	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 8.49-85.72 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[28]
Peanut shell activated carbon	Direct Blue 71	Initial concentration: 20-100 mg/L Adsorbent dose: 0.5-3 g/L pH: 6-9 Temperature: 25-45°C	Adsorption capacity: 14.97-59.42 mg/g Removal efficiency: 65-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	Surface adsorption, electrostatic interaction	[31]
Peanut shell biochar	Direct Blue 71	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 8.75-82.64 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	
Peanut shell biochar	Reactive Blue 19	Initial concentration: 10-100 mg/L Adsorbent dose: 0.5-5 g/L pH: 2-10 Temperature: 20-60°C	Adsorption capacity: 9.12-87.34 mg/g Removal efficiency: 60-98%	Pseudo-first-order, Pseudo-second-order	Langmuir, Freundlich	π-π electron donor-acceptor interaction, electrostatic interaction	[28]

Regeneration of adsorbent

Adsorbents are relevant in wastewater treatment, but their effectiveness diminishes over time due to saturation with adsorbates. Regeneration of adsorbents is essential to maintain their efficiency and sustainability. Achieving complete desorption of adsorbates from the adsorbent surface is challenging. Adsorbates may strongly adhere to the adsorbent surface, requiring harsh desorption conditions that can damage the adsorbent material.

Regeneration processes can affect the stability and integrity of the adsorbent material. Harsh regeneration conditions may lead to structural damage, loss of surface area, and decreased adsorption capacity. Additionally, regeneration processes often involve the use of chemicals or high temperatures, which can have environmental implications. Chemical regeneration may result in the generation of toxic by-products or the release of adsorbates back into the environment.

Thermal regeneration, which involves heating the adsorbent to high temperatures to desorb adsorbates, is effective but can lead to structural damage and reduced adsorbent performance over time. Chemical regeneration, which uses desorbing agents such as acids, bases, or organic solvents to remove adsorbates from the adsorbent surface, can be effective but may result in the generation of toxic waste. Biological regeneration, which utilizes microorganisms to degrade adsorbates or enhance desorption from the adsorbent surface, is environmentally friendly but may be slower and less efficient compared to thermal or chemical regeneration.

Conclusion

In conclusion, the adsorption of dyes from aqueous solutions remains a critical area of research, with numerous studies highlighting the effectiveness of different adsorbents and the underlying mechanisms. Peanut shell-based activated carbon (PSAC) is sustainable, and cost-effective solution for the adsorption of dyes from wastewater. Its high adsorption capacity, extensive surface area, and abundance as an agricultural by-product. The adsorption of dyes using PSAC is primarily governed by physicochemical parameters such as pH, temperature, dye concentration, and adsorbent dosage, with adsorption mechanisms involving chemisorption and electrostatic interactions.

Kinetic studies, predominantly modeled by pseudo-second-order kinetics, demonstrate the dependence of the adsorption rate on active site availability. Isotherm analyses, particularly Langmuir and Freundlich models shows PSAC's ability to facilitate both monolayer and heterogeneous adsorption processes. Thermodynamic experiments indicate that the dye adsorption process is exothermic and spontaneous. Advances in material science and adsorption techniques continue to enhance the efficiency and applicability of these processes.

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References

[1] Abdi, J., Bastani, D., Abdi, J., Mahmoodi, N. M., Shokrollahi, A., & Mohammadi, A. H. (2014). Assessment of competitive dye removal using a reliable method. *Journal of Environmental Chemical Engineering, 2*(3), 1672–1683. https://doi.org/10.1016/j.jece.2014.06.002

[2] Acemioğlu, B. (2022). Removal of a reactive dye using NaOH-activated biochar prepared from peanut shell by pyrolysis process. *International Journal of Coal Preparation and Utilization, 42*(3), 671–693. https://doi.org/10.1080/19392699.2019.1644326

[3] Ahmad, M. A., Mohamad Yusop, M. F., Zakaria, R., Karim, J., Yahaya, N. K. E. M., Mohamed Yusoff, M. A., Hashim, N. H. F., & Abdullah, N. S. (2021). Adsorption of methylene blue from aqueous solution by peanut shell-based activated carbon. *Materials Today: Proceedings, 47*, 1246–1251. https://doi.org/10.1016/j.matpr.2021.02.789

[4] Aladeokin, O., & Fletcher, A. (2024). A novel activated carbon material from peanut shells for the removal of methyl orange and methylene blue dyes from wastewater: Kinetics, isotherms, and mechanism. *Adsorption Science & Technology, 42*, 1–24. https://doi.org/10.1177/02636174241256843

[5] Avrami, M. (1939). Kinetics of phase change. I. General theory. *The Journal of Chemical Physics, 7*(12), 1103–1112. https://doi.org/10.1063/1.1750380

[6] Bangham, D. H., & Burt, F. P. (1924). The behaviour of gases in contact with glass surfaces. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, 105*(732), 481–488. https://doi.org/10.1098/rspa.1924.0032

[7] Dai, Y., Sun, Q., Wang, W., Lu, L., Liu, M., Li, J., Yang, S., Sun, Y., Zhang, K., Xu, J., Zheng, W., Hu, Z., Yang, Y., Gao, Y., Chen, Y., Zhang, X., Gao, F., & Zhang, Y. (2018). Utilizations of agricultural waste as adsorbent for the removal of contaminants: A review. *Chemosphere, 211*, 235–253. https://doi.org/10.1016/j.chemosphere.2018.06.179\

[8] Grintzalis, K., Georgiou, C. D., & Schneider, Y.-J. (2015). An accurate and sensitive Coomassie Brilliant Blue G-250-based assay for protein determination. *Analytical Biochemistry*, 480, 28–30. https://doi.org/10.1016/j.ab.2015.03.024

[9] Elwakeel, K. Z., El-Bindary, A. A., El-Sonbati, A. Z., & Hawas, A. R. (2017). Magnetic alginate beads with high basic dye removal potential and excellent regeneration ability. *Canadian Journal of Chemistry, 95*(8), 807–815. https://doi.org/10.1139/cjc-2016-0641

[10] Eniola, J. O., Kumar, R., & Barakat, M. A. (2019). Adsorptive removal of antibiotics from water over natural and modified adsorbents. *Environmental Science and Pollution Research, 26*(34), 34775–34788. https://doi.org/10.1007/s11356-019-06641-6

[11] Foo, K. Y., & Hameed, B. H. (2010). An overview of dye removal via activated carbon adsorption process. *Desalination and Water Treatment, 19*(1–3), 255–274. https://doi.org/10.5004/dwt.2010.1214

[12] Garg, D., Kumar, S., Sharma, K., & Majumder, C. B. (2019). Application of waste peanut shells to form activated carbon and its utilization for the removal of Acid Yellow 36 from wastewater. *Groundwater for Sustainable Development, 8*, 512–519. https://doi.org/10.1016/j.gsd.2019.01.010

[13] Garg, D., Majumder, C. B., Kumar, S., & Sarkar, B. (2019). Removal of Direct Blue-86 dye from aqueous solution using alginate-encapsulated activated carbon (PnsAC-alginate) prepared from waste peanut shell. *Journal of Environmental Chemical Engineering, 7*(5), Article 103365. https://doi.org/10.1016/j.jece.2019.103365

[14] Hammari, A. M., Misau, M. I., Aroke, U. O., Hamza, U. D., & Yusuf, A. A. (2021). Adsorption equilibrium and kinetics studies of Congo red dye using groundnut shell and sorghum husk biosorbent. *Journal of Biochemistry, Microbiology and Biotechnology, 9*(1), 29–36. https://doi.org/10.54987/jobimb.v9i1.573

[15] Ho, Y. S., & McKay, G. (1998). Sorption of dye from aqueous solution by peat. *Chemical Engineering Journal, 70*(2), 115–124. https://doi.org/10.1016/S0923-0467(98)00076-1

[16] Ho, Y. S., & McKay, G. (1999). Pseudo-second order model for sorption processes. *Process Biochemistry, 34*(5), 451–465. https://doi.org/10.1016/S0032-9592(98)00112-5

[17] Hynes, N. R. J., Kumar, J. S., Kamyab, H., Sujana, J. A. J., Al-Khashman, O. A., Kuslu, Y., Ene, A., & Suresh Kumar, B. (2020). Modern enabling techniques and adsorbents based dye removal with sustainability concerns in textile industrial sector—A comprehensive review. *Journal of Cleaner Production, 272*, Article 122636. https://doi.org/10.1016/j.jclepro.2020.122636

[18] Imam, S. S., & Panneerselvam, P. (2015). Enhanced Rhodamine B dye adsorption by groundnut shell activated carbon coated with Fe_3O_4. *Elixir Applied Chemistry, 86*, 34984–34989.

[19] Khalil, F., Franzmann, E., Ramcke, J., Dakischew, O., Lips, K. S., Reinhardt, A., Heisig, P., & Maison, W. (2014). Biomimetic PEG-catecholates for stabile antifouling coatings on metal surfaces: Applications on TiO_2 and stainless steel. *Colloids and Surfaces B: Biointerfaces, 117*, 185–192. https://doi.org/10.1016/j.colsurfb.2014.02.022

[20] Lagergren, S. (1898). Zur Theorie der sogenannten Adsorption gelöster Stoffe. *Kungliga Svenska Vetenskapsakademiens Handlingar, 24*(4), 1–39.

[21] Liu, J., Wang, Z., Li, H., Hu, C., Raymer, P., & Huang, Q. (2018). Effect of solid-state fermentation of peanut shell on its dye adsorption performance. *Bioresource Technology, 249*, 307–314. https://doi.org/10.1016/j.biortech.2017.10.010

[22] Maheshwari, K., Agrawal, M., & Gupta, A. B. (2021). Dye pollution in water and wastewater. In S. S. Muthu & A. Khadir (Eds.), *Novel materials for dye-containing wastewater treatment* (pp. 1–25). Springer. https://doi.org/10.1007/978-981-16-2892-4_1

[23] Malik, R., Ramteke, D. S., & Wate, S. R. (2006). Physico-chemical and surface characterization of adsorbent prepared from groundnut shell by $ZnCl_2$ activation and its ability to adsorb colour. *Indian Journal of Chemical Technology, 13*(4), 319–328.

[24] Nadi, H., Alizadeh, M., Ahmadabadi, M., Yari, A. R., & Hashemi, S. (2012). Removal of reactive dyes (green, orange, and yellow) from aqueous solutions by peanut shell powder as a natural adsorbent. *Archives of Hygiene Sciences, 1*(2), 41–47.

[25] Palanisamy, P. N., & Sivakumar, P. (2009). Kinetic and isotherm studies of the adsorption of Acid Blue 92 using a low-cost non-conventional activated carbon. *Desalination, 249*(1), 388–397. https://doi.org/10.1016/j.desal.2009.09.006

[26] Pinto, A. H., Taylor, J. K., Chandradat, R., Lam, E., Liu, Y., Leung, A. C. W., Keating, M., & Sunasee, R. (2020). Wood-based cellulose nanocrystals as adsorbent of cationic toxic dye, Auramine O, for water treatment. *Journal of Environmental Chemical Engineering, 8*(5), Article 104187. https://doi.org/10.1016/j.jece.2020.104187

[27] Renita, A. A., Amarnath, D. J., & Duraikannu, S. L. (2021). Synthesis of peanut-shell magnetized biocarbon for Acid Fuchsin dye removal. *Materials Today: Proceedings, 43*, 3075–3078. https://doi.org/10.1016/j.matpr.2021.01.407

[28] Wu, H., Chen, R., Du, H., Zhang, J., Shi, L., Qin, Y., Yue, L., & Wang, J. (2019). Synthesis of activated carbon from peanut shell as dye adsorbents for wastewater treatment. *Adsorption Science & Technology, 37*(1–2), 34–48. https://doi.org/10.1177/0263617418807856

[29] Yadav, P., Yadav, H., Shah, V. G., Shah, G., & Dhaka, G. (2015). Biomedical biopolymers, their origin and evolution in biomedical sciences: A systematic review. *Journal of Clinical and Diagnostic Research, 9*(9), ZE21–ZE25. https://doi.org/10.7860/JCDR/2015/13907.6565

[30] Yaseen, D. A., & Scholz, M. (2019). Textile dye wastewater characteristics and constituents of synthetic effluents: A critical review. *International Journal of Environmental Science and Technology, 16*(2), 1193–1226. https://doi.org/10.1007/s13762-018-2130-z

[31] Weber, W. J., Jr., & Morris, J. C. (1963). Kinetics of adsorption on carbon from solution. *Journal of the Sanitary Engineering Division, 89*(2), 31–59. https://doi.org/10.1061/JSEDAI.0000430

[32] Zhao, X., Hua, Q., Wang, C., Wang, X., Zhang, H., Zhang, K., Zheng, B., Yang, J., & Niu, J. (2023). Study on adsorption performance and mechanism of peanut hull-derived magnetic biochar for removal of malachite green from water. *Materials Research Express, 10*(9), Article 095504. https://doi.org/10.1088/2053-1591/acf756