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Review on Adsorption of Paracetamol with Low-Cost Adsorbents

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Abstract: *It is essential to eliminate medicinal drugs like Paracetamol from water due to their possible harm to living creatures. The present study focuses review on paracetamol adsorption from its aqueous solution with natural adsorbents like derived high surface area activated carbon, magnetic activated carbon derived from pine fruit waste, Guava leaves with sulfuric acid-activated carbon , activated carbons of ground nut shell. It is a greener way of water purification. This paper reviews the findings of some researchers for the use of greener low-cost adsorbents in different forms for Paracetamol removal. Reported methods of paracetamol adsorption, optimizing factors of adsorption, isotherm analysis and kinetics are reviewed. It has been found that generally Langmuir and Freundlich adsorption isotherms fit well to adsorption batch experimental data and Pseudo-Second-order kinetic model can best describe these processes. In some cases, intraparticle and Elovich models are also used. Many scientists reported thermodynamic studies. These observations of effectiveness of these adsorbents can be useful for designing future water purification technology*

Keywords: adsorption, heavy metals, adsorption capacity, isotherms, kinetics

1. Introduction

Water contamination by pharmaceutical residues has emerged as a significant environmental concern today. Paracetamol is one of the most commonly used analgesic and antipyretic drug. Human's extensive use drugs gave its frequent detection in water. Though paracetamol is considered relatively safe drug but can cause damage to environment. As conventional methods of water purification are costly, adsorption method has gained importance. In recent years, researchers have reported many low-cost greener adsorbents. Green adsorbents such as bamboo sawdust-derived high surface area activated carbon (Wakejo et al., 2023), magnetic activated carbon derived from pine fruit waste (Hashemzadeh, 2024), Guava leaves-based sulfuric acid activated carbon (Alakayleh, 2025), and activated carbon from groundnut shells (Kankou, 2019) have been widely investigated for the removal of paracetamol from aqueous systems. Plant leaves and other agricultural wastes have emerged as a new generation of sustainable adsorbents due to their abundance, low cost, and environmental friendliness.

This review aims to evaluate recent progress in adsorption processes for paracetamol removal, along with the factors affecting adsorption performance. Leaves and agricultural waste materials exhibit excellent adsorption properties due to the presence of functional groups such as hydroxyl (–OH), carboxyl (–COOH), carbonyl (C=O), and amino ($–NH_2$), which facilitate interactions with paracetamol molecules. Some modifications in surface area is suggested to increases efficiency of adsorption. Adsorption experiments with greener adsorbent are reported as following-,

Mohamed Abdallahi Bollahi et al, 2019 studied Sorption of paracetamol from aqueous solution using Groundnut shell as a low-cost adsorbent. Groundnut shell characterization is done with, X-ray Fluorescence and Fourier Transform Infra-Red (FTIR) Spectroscopy.The adsorption isotherms are obtained by mixing (70 rpm), for 12 hours, 0.5 g of groundnut shell with 25 mL of Paracetamol solutions with different concentrations varying from 10 to 100 mg L-1 .and reported relatively significant sorption with a maximum quantity of 3.02 mg/g.

Farzad Hashemzadeh, et al, 2024, reported highly porous magnetic activated carbon nanoparticles (MPFRC-A) derived from pine fruit residue as good adsorbent. The MPFRC-A were produced through a three-step process: physical

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activation (carbonization temperature: 110–550 °C), chemical activation (H_2SO_4 (0.1 N, 96%)), and co-precipitation. These nanoparticles were then used to remove tetracycline (TC) and paracetamol (PC) from water. The MPFRC adsorbent's characterization was done with Brunauer–Emmett–Teller (BET) analysis, Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD), and Energy-dispersive X-ray spectroscopy (EDX) analyses, and various factors pH, contact time, initial pollutant concentrations, adsorbent dosage, and temperature were observed.

Zuhier Alakayleh ,2025, used Sulfuric acid-activated carbon from Guava leaves for paracetamol adsorption and reported Guava leaves-sulfuric acid-activated carbon (GLSAC) as a new low-cost adsorbent for paracetamol (PRC) removal from water. The adsorption experiments studied the effects of GLSAC amount, contact time, pH, and PRC concentration on the adsorption performance. Freundlich model best described the isothermal data, indicating multilayer adsorption on a heterogeneous surface

Beata Decoczekalska et al,2025, used activated carbon made from nutshells as agricultural waste it included the carbonization of nutshells was carried out at 600 °C, followed by chemical activation was carried out at 750 °C using alkaline activators, i.e., NaOH and KOH. All ACs are characterized for PAR and studied adsorption kinetics, the adsorption at equilibrium, and the pH effect were observed.

Wakejo et al,2023 used Bamboo sawdust-derived high surface area activated carbon for remarkable removal of paracetamol from aqueous solution. sorption kinetics, isotherm, thermodynamics, and regeneration studies are reported. 99.6% paracetamol was obtained using chemically activated carbon (CAC), derived from bamboo sawdust using $KOH/FeCl_3$ as an activating agent, at optimal conditions of PCT (20 mg/L), CAC (0.5 g/L), contact time (90 min), and pH (8).

Andrzej Świątkowski,2025 studied adsorption of Paracetamol with activated carbon adsorbents from, i.e., walnut, hazelnut, and pistachio nutshells i.e. agricultural waste, and involved two-step procedure. i.e. the carbonization of nutshells at 600 °C, and chemical activation at 750 °C using alkaline activators, i.e., NaOH and KOH and reported the high adsorption capacities ranging from 332.2 to 437.8 mg/g.

Adsorption isotherm & kinetic models: Adsorption process efficiency is checked by applying different isotherm and kinetic models as following –

1) **Pseudo first order kinetic model** - It's equation is $\log (q_e-q_t) = \log q_e - (k_1/2.303)\, t$,Where, qe and q_t = the amounts of the metal ions adsorbed (mg/g) on adsorbate at equilibrium and at time

2) **Pseudo-second order kinetic model**- is given by equation- $t/q_t = 1/(K_2 q_e^2) + t/q_e$,Where K_2 = rate constant of second order adsorption (g $mg^{-1}.min^{-1}$).

3) **Intra particle diffusion**-is given by equation $q_t = K_1 t^{1/2}$ K_1 **(mg/g/min)**

4) **The Freundlich isotherm** is given by equation - $\log q = \log K_f + 1/n \log C_e$ Where, q_e =quantity of adsorbate adsorbed per mass unit of the adsorbent, C_e= equilibrium concentration of the adsorbate (mg/L), K_F = affinity of the adsorbate towards the adsorbent $(L/mg)^{1/n}$

5) **Langmuir isotherm**-is given by equation $C_e/q_e = 1/(q_m.b) + C_e/q_m$

Where, q_m = monolayer (maximum) adsorption capacity (mg/g) ,b = Langmuir bio-sorption constant.

Following table, no 1gives the summary of greener adsorbents and their adsorption capacities-

Drug	Adsorbent	Adsorption capacity	Reference
Paracetamol	Bamboo sawdust-derived high surface area	188.67 mg/g	(Wakejo, Meshesha, Kang, & Demesa, 1 June 2023)
	Magnetic activated carbon derived from pine fruit waste	43.75 mg/g	(Farzad Hashemzadeh, 2024)

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	Carbon adsorbents obtained from agricultural waste, i.e., walnut, hazelnut, and pistachio nutshells	332.2 to 437.8 mg/g	Andrzej Świątkowski,2025
	Guava leaves-sulfuric acid-activated carbon	13.3 mg/g	(Alakayleh, March 2025)
	Activated carbons of ground nut shell	3.02 mg/g	(Kankou, 2019,)

Table no 1 -Summary of greener adsorbents and their adsorption capacities

To study this process different models like Freundlich isotherm, Langmuir isotherm models are employed. Similarly, kinetic models applied are Pseudo first order Pseudo second order and intra particle diffusion model. Following Table, no 2- gives summary of kinetics and isotherm observations as follows

Drug name	Adsorbent	Isotherm	Thermodynamic observations	Reference
Paracetamol	Bamboo sawdust-derived high surface area	Langmuir ((R^2=0.96) Freundlich (R^2 = 0.96)	exothermic, spontaneous, and favorable adsorption	(Wakejo, Meshesha, Kang, & Demesa, 1 June 2023)
	Magnetic activated carbon derived from pine fruit waste	Langmuir isotherm models.(R2>0.98	Endothermic, non-spontaneous adsorption	(Farzad Hashemzadeh, 2024)
	Carbon adsorbents obtained from agricultural waste, i.e., Walnut, hazelnut, and pistachio nutshells	Langmuir models	-not reported	Andrzej Świątkowski,2025
	Guava leaves-sulfuric acid-activated carbon	Freundlich model (R^2 = 99.7 %)	spontaneous, exothermic, adsorption	(Alakayleh, March 2025)
	Activated carbons of ground nut shell	Langmuir model	-	(Kankou, 2019,)

Table 2 – Summary of the Isotherm & Kinetics of adsorption of metal on sawdust

Adsorption process is studied with Kinetic and isotherm analysis and various parameters such as sorption capacity, sorption intensity are calculated to understand the adsorption mechanism.

Mechanism involved in adsorption –

Paracetamol adsorption on green adsorbents is combination of physical and chemical interactions. The phenolic –OH and amide groups of paracetamol form hydrogen bonds with functional groups such as –OH and –COOH present on the adsorbent surface. The aromatic ring of paracetamol interacts with carbon-rich surfaces through π–π stacking. Additionally, weak electrostatic forces may contribute depending on the pH of the solution. Adsorption process involves diffusion followed by surface binding through multiple interaction mechanisms.

2. Conclusion

This review reports that green adsorbents, including activated carbons from agricultural residues, and plant-derived materials, show considerable potential for Paracetamol adsorption from aqueous systems. Adsorption efficiency is

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dependent by physicochemical parameters such as pH, surface functional groups, pore structure, and initial contaminant concentration. Kinetics and isotherm studies suggest in many cases suggest chemisorption and monolayer adsorption .Greener materials are of low cost, renewable, and can reduce environmental stress. So future research should focus on material modification and practical implementation of them

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