

Sustainable Removal of Cadmium and Chromium from Petroleum Wastewater Using Coconut Husk-Derived Activated Carbon

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Abstract

Toxic heavy metals in petroleum wastewater pose serious environmental and health risks due to their persistence and bioaccumulation. This study examined the adsorption of cadmium (Cd) and chromium (Cr) using coconut husk-derived activated carbon. Batch experiments assessed the effects of pH, contact time, adsorbent dosage, initial concentration, and temperature on removal efficiency. Equilibrium data were analyzed using the Langmuir and Freundlich models, while adsorption kinetics were evaluated using pseudo-first-order, pseudo-second-order, intraparticle diffusion, and Elovich models. Thermodynamic parameters were determined via Van't Hoff analysis. Results showed near-complete removal of Cd (≈ 99.8 – 100%) and Cr (≈ 98.6 – 99.0%) under optimal conditions. The Langmuir model provided the best fit ($R^2 = 0.99999$), confirming monolayer adsorption with maximum capacities of 100.80 mg/g for Cd and 10.05 mg/g for Cr. Kinetic analysis identified pseudo-second-order chemisorption as the dominant mechanism, with intraparticle diffusion contributing due to microporosity. Thermodynamic evaluation revealed endothermic Cr adsorption and negative Gibbs free-energy values for both metals, confirming spontaneity. Generally, coconut husk activated carbon demonstrates high efficiency and sustainability, with adsorption behavior strongly supported by physicochemical characterization, and shows strong potential for industrial-scale petroleum wastewater treatment.

Keywords: Coconut husk activated carbon, petroleum wastewater, Cadmium adsorption, sustainable wastewater treatment, biomass-derived adsorbents.

1.0 Introduction

Petroleum industrial wastewater is a complex effluent containing hydrocarbons, dissolved solids, and toxic heavy metals. Among these, cadmium (Cd) and chromium (Cr) are of particular concern due to their persistence, non-biodegradability, and bioaccumulation potential in aquatic systems. Cd is highly toxic even at trace levels, causing kidney damage and carcinogenic effects, while hexavalent chromium (Cr(VI)) is a potent carcinogen and a major environmental pollutant [1]–[4].

Conventional treatment methods such as chemical precipitation, membrane filtration, and ion exchange have been applied to petroleum wastewater, but their efficiency is often limited by competing ions and organic constituents [5], [6]. Adsorption has therefore emerged as a reliable and efficient alternative for heavy metal removal due to its simplicity, cost-effectiveness, and adaptability to complex wastewater matrices [7], [8]. Activated carbon is widely recognized as one of the most effective adsorbents, owing to its high surface area, porous structure, and functional groups that facilitate ion exchange, electrostatic attraction, and surface complexation [9]–[11]. Biomass-derived activated carbons have gained attention as sustainable adsorbents, with coconut husk identified as a promising precursor due to its high carbon content and ability to form well-developed porous structures upon activation [12]–[14].

Previous studies have demonstrated the effectiveness of coconut husk-based activated carbon in removing heavy metals from aqueous solutions, including Cd and Cr, with adsorption performance influenced by pH, contact time, and initial concentration [15]–[17]. However, most of these investigations used synthetic solutions, which do not adequately reflect the complexity of petroleum industrial wastewater [7], [18], [19]. This study addresses that gap by evaluating operational parameters (pH, contact time, adsorbent dosage, initial concentration, temperature) and by characterizing equilibrium (Langmuir, Freundlich), kinetics (pseudo-first/second order, intraparticle diffusion, Elovich), and thermodynamics (Van't Hoff) for Cd and Cr removal using coconut husk activated carbon. The work aims to demonstrate both the practical performance and the sustainability potential of this low-cost adsorbent for industrial wastewater remediation.

2.0 Material and Methods

2.1 Wastewater Sample and Chemicals

Petroleum industrial wastewater was collected from a processing facility and stored in pre-cleaned polyethylene containers at 4 °C until use. The concentrations of cadmium (Cd) and chromium (Cr) in the raw water were determined using an iCE 3000 Series Atomic Absorption Spectrophotometer (Thermo Scientific, USA). The measured values are shown in Table 1. These values are significantly above the allowable WHO limits. To obtain the desired experimental concentrations, the raw wastewater was diluted with distilled water. Analytical-grade reagents and distilled water were used throughout. Solution pH was adjusted using 0.1 M HCl and 0.1 M NaOH.

Table 1. Cadmium and Chromium levels in petroleum wastewater

Heavy metal	Concentration of raw wastewater (mg/L)	WHO allowable Standard limit (mg/L)
Cd	33.8269	0.003
Cr	20.0921	0.05

2.2 Adsorbent Preparation

Coconut husk-activated carbon was used as the adsorbent in this study. Its preparation and physicochemical characterization have been previously reported in a study by Otayokh *et al.* [20]. In the study, Coconut Husk-Derived Activated Carbon was prepared by carbonizing powdered sample of Coconut Husk (>0.65 mm) at 600°C followed by washing and drying, acid activating using 2.5M NaOH followed by neutralization using 2.5M HCl, thorough washing using distilled water, and finally drying. The characterization— including proximate analysis (moisture content, ash content, bulk density, and pH), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray (EDX), Fourier Transform Infrared Spectroscopy (FTIR), and X-ray Diffraction (XRD)— provides detailed insights into structural and chemical properties relevant to adsorption performance. The results (Table 2) demonstrated that coconut husk-derived activated carbon exhibited lower ash content (8.99%) and reduced bulk density (0.1622 g/cm³) relative to almond leaf-based carbon, indicating improved packing efficiency and minimized inorganic interference. SEM analysis showed that coconut husk carbon possessed a more intricate and well-developed pore network, whereas almond leaf carbon displayed broader but less uniformly distributed pores. FTIR spectra confirmed the presence of hydroxyl, carboxyl, and carbonyl functional groups in both materials; however, almond leaf carbon demonstrated stronger –OH bands, suggesting greater availability of polar binding sites. EDX results highlighted higher carbon purity in coconut husk carbon, while almond leaf carbon retained greater amounts of oxygen and silica. Finally, XRD analysis verified that both adsorbents were predominantly amorphous with minor crystalline peaks.

Table 2. Summary of physicochemical characterization of Coconut husk-derived activated carbon compared with Almond leaf-derived activated carbon

Property	Coconut husk AC	Almond leaf AC	Adsorption implication
Ash content	8.99% (lower)	Higher	Lower ash reduces inorganic interference, improving sustainability [21], [22]
Bulk density	0.1622 g/cm ³ (lower)	Higher	Lower density supports better packing and diffusion [23], [24]
Pore structure (SEM)	Well-developed microporosity	Wider but less uniform pores	Micropores enhance intraparticle diffusion [25], [26]
Functional groups (FTIR)	Hydroxyl, carboxyl, carbonyl	Stronger –OH bands	Polar groups facilitate chemisorption and ion exchange [9], [11]
Carbon purity (EDX)	Higher carbon, fewer impurities	More oxygen and silica	Higher purity improves adsorption efficiency [27], [17]
Crystallinity (XRD)	Predominantly amorphous	Predominantly amorphous	Amorphous structure favors heterogeneous adsorption [28], [24]

*Data summarized from [20].

These findings suggest that coconut husk-derived activated carbon possesses structural and chemical features suitable for both intraparticle diffusion (due to microporosity) and chemisorption (via functional groups), while its lower ash content and higher carbon purity highlight its sustainability and reusability for petroleum wastewater treatment.

2.3 Batch Adsorption Experiments

Adsorption experiments were conducted in 100mL conical flasks containing 50mL of wastewater and a measured mass of coconut husk activated carbon. The mixtures were agitated at 150 rpm using a WHY2 digital water bath shaker (MKN Instruments, China). Operational parameters investigated included: pH (5–9), Contact time (10–50 min), Adsorbent dosage (0.5–2.5 g), Initial concentration (30–50mg/L), and Temperature (30–70°C). After each experiment, samples were filtered and analyzed for residual Cd and Cr using AAS (iCE 3000 series AAS, Thermo Scientific, USA). All experiments were performed in triplicate, and results are reported as mean $\pm$ standard deviation.

2.4 Adsorption Capacity and Removal Efficiency

The adsorption capacity (q_e) and removal efficiency (%R) were calculated using (1) and (2) respectively as described by Ayawei *et al.* [29].

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

$$\% \text{Removal/Adsorption efficiency} = \frac{C_0 - C_e}{C_0} \times 100 \quad (2)$$

where C_0 is initial concentration (mg/L), C_e is equilibrium concentration (mg/L), V is solution volume (L), m is adsorbent mass (g).

2.5 Adsorption Isotherm Models

Equilibrium data were analyzed using the Langmuir [30], [29] and Freundlich [24], [29] models.

$$\frac{C_e}{q_e} = \frac{1}{q_{\max}K_L} + \frac{C_e}{q_{\max}} \quad (3)$$

where q_e is adsorption capacity at equilibrium (mg/g), C_e is equilibrium concentration (mg/L), $q_{\max}$ is maximum adsorption capacity (mg/g), K_L is Langmuir constant (L/mg)

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (4)$$

where K_F is Freundlich constant (mg/g)(L/mg)(1/n), n is adsorption intensity

2.6 Adsorption Kinetic Models

Time-dependent adsorption data were fitted to pseudo-first-order and pseudo-second-order models [25], intraparticle diffusion [23], [26], and the Elovich model [31].

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \quad (5)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q^2} + \frac{t}{q_e} \quad (6)$$

$$q_t = k_{id} t^{0.5} + C \quad (7)$$

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \quad (8)$$

where q_e is adsorption capacity at time t (mg/g), q_e is equilibrium adsorption capacity (mg/g), k_1 is PFO rate constant (1/min), k_2 is PSO rate constant (g/mg·min), k_{id} is intraparticle diffusion rate constant (mg/g·min^{0.5}), C is boundary layer constant, α is initial adsorption rate (mg/g·min), β is desorption constant (g/mg).

2.7 Thermodynamic Analysis

Thermodynamic parameters— Equilibrium constants (K_c), Gibbs free energy (ΔG^0), enthalpy (ΔH^0), and entropy (ΔS^0)— were derived using the Van't Hoff approach [29], [32].

$$K_c = \frac{q_e}{c_e} \quad (9)$$

$$\Delta G^0 = -RT \ln K_c \quad (10)$$

$$\ln K_c = -\frac{\Delta H^0}{R} \left(\frac{1}{T}\right) + \frac{\Delta S^0}{R} \quad (11)$$

where R is universal gas constant ($8.314 \text{ J/mol}\cdot\text{K}$), T is absolute temperature (K), K_c is equilibrium constant, ΔG^0 is Gibbs free energy change (kJ/mol), ΔH^0 is enthalpy change (kJ/mol), ΔS^0 is entropy change ($\text{J/mol}\cdot\text{K}$)

3.0 Result and Discussion

3.1 Effect of Temperature

As shown in Figure 1, the adsorption efficiency of Cd remained consistently high ($\approx 99.82\%$ to 99.88%) across $30\text{--}70^\circ\text{C}$, indicating minimal temperature dependence. This suggests that Cd removal is controlled by favorable surface interactions and does not require additional energy for optimum performance, making the process both cost-effective and sustainable [25], [33]. In contrast, Cr adsorption (Figure 1) increased slightly with temperature ($98.64\text{--}98.99\%$), reflecting an endothermic process. Elevated temperatures enhanced ion diffusion into pores and reduced boundary layer resistance, thereby improving Cr uptake [27], [32]. Overall, the results confirm that coconut husk-derived activated carbon can achieve near-complete removal of Cd without external energy input, while Cr adsorption benefits modestly from higher temperatures.

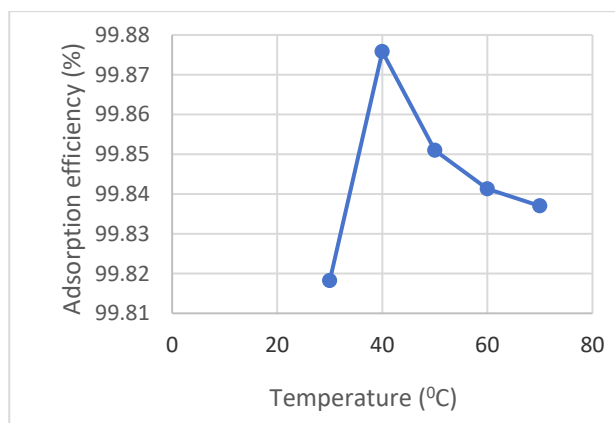


Figure 2. Effect of temperature on adsorption efficiency of Cd using Coconut husk activated carbon

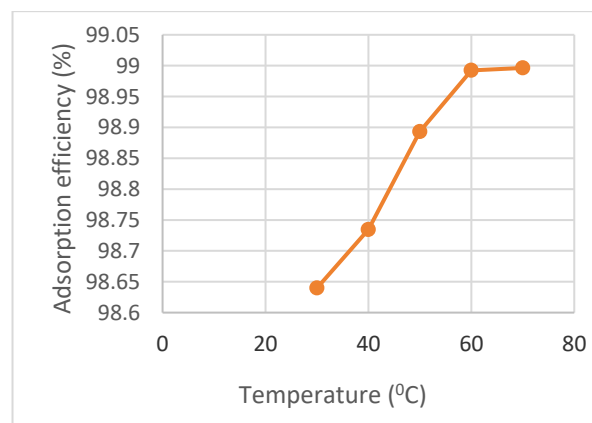


Figure 3. Effect of temperature on adsorption efficiency of Cr using Coconut husk activated carbon

3.2 Effect of Adsorbent Dosage

Removal efficiencies for both Cd and Cr improved with increasing adsorbent dosage (Figures 3 and 4), reaching near-complete removal ($\sim 99.95\text{--}99.98\%$) at approximately 2.0g . At low dosage (0.5g), the limited number of active sites restricted adsorption capacity. Beyond 2.0g , efficiency slowed down, indicating equilibrium and possible site aggregation or underutilization of available sites. This trend aligns with previous reports on biomass-derived carbons [11], [24], [33].

The observed slowdown at higher dosages reflects site aggregation or underutilization of binding sites, consistent with the physicochemical characterization. The microporous structure (BET) and abundant functional groups ($-\text{OH}$, $-\text{COOH}$) identified in FTIR analysis enhance adsorption efficiency at lower dosages by providing accessible binding sites. At higher dosages, however, particle overlap and aggregation can reduce effective site accessibility, while the amorphous carbon structure (XRD) contributes to heterogeneous binding but eventually reaches equilibrium. These structural features explain the plateauing trend and confirm that optimal adsorption occurs before excessive dosage leads to diminishing returns [11], [24], [25], [26], [33].

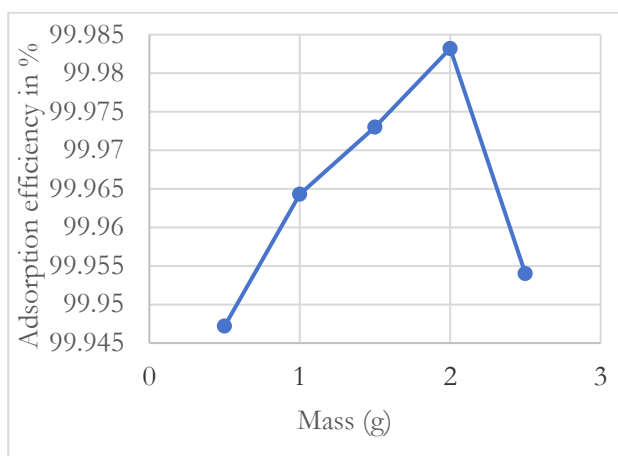


Figure 4. Effect of adsorbent dosage on Cd removal from petroleum wastewater

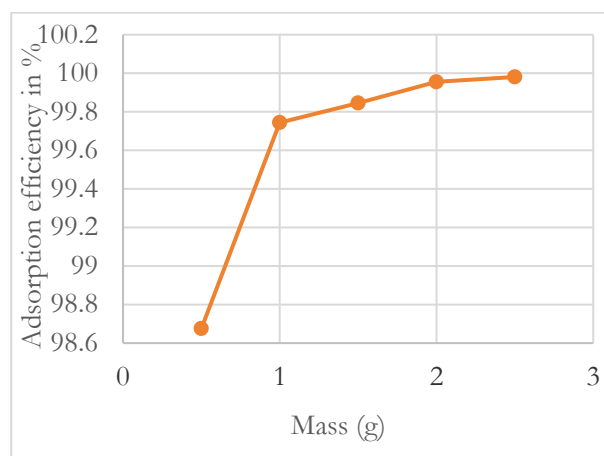


Figure 5. Effect of adsorbent dosage on Cr removal from petroleum wastewater

3.3 Effect of Contact Time

The effect of contact time on adsorption efficiency is presented in Figures 5 and 6. Adsorption efficiency increased sharply within the first 30–40 minutes, after which equilibrium was attained. Cd removal remained consistently higher (≈ 99.92 – 99.98%) than Cr (≈ 98.29 – 98.78%), reflecting the stronger affinity of Cd ions for the adsorbent surface. The initial rapid uptake corresponds to the abundance of vacant adsorption sites, while the subsequent plateau indicates site saturation and a reduced adsorption rate [25], [24].

Although the early adsorption phase was not captured in detail, heavy metal adsorption is typically characterized by significant uptake within the first few minutes. Future studies should therefore incorporate shorter time intervals (e.g., 1, 3, 5, and 8 minutes) to better describe the fast adsorption kinetics and confirm equilibrium behavior. This adjustment will provide a more comprehensive understanding of the adsorption mechanism and ensure accurate kinetic modeling.

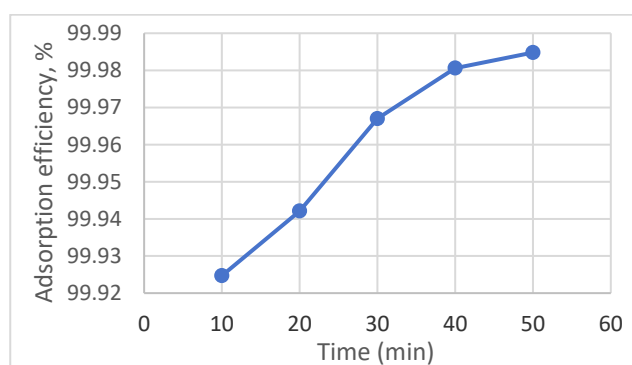


Figure 6. Effect of contact time on adsorption efficiency of Cd

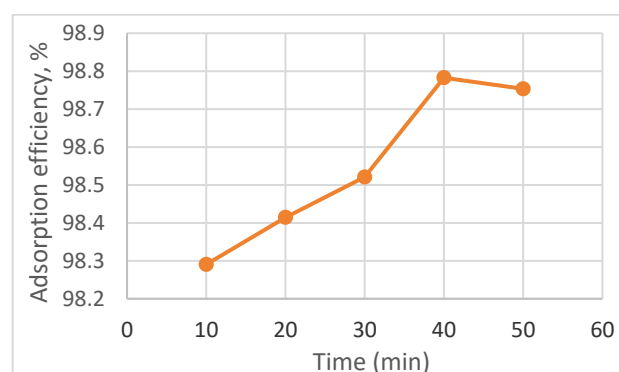


Figure 7. Effect of contact time on adsorption efficiency of Cr

3.4 Effect of pH

As revealed by Figures 7 and 8, Cd exhibited consistently high removal (~ 99.91 – 99.97%) across pH 5–9, while Cr removal increased from 97.00% at pH 5 to $\approx 98.95\%$ at pH 8–9. At low pH, proton competition reduced adsorption efficiency, as excess H^+ ions competed with Cd^{2+} and Cr^{3+} for active binding sites. At higher pH, electrostatic attraction between negatively charged adsorbent surfaces and metal cations was enhanced, leading to improved uptake [7], [32], [33]. Optimal adsorption occurred under slightly alkaline conditions (pH 7–9), consistent with previous studies [34], [35].

The observed pH dependence of Cd and Cr adsorption is consistent with the physicochemical characterization: functional groups ($-OH$, $-COOH$) identified in FTIR analysis drive electrostatic interactions, becoming more available upon deprotonation at higher pH; microporosity (BET) enhances ion diffusion toward these sites; and the amorphous carbon structure (XRD) provides heterogeneous binding environments that sustain high adsorption efficiency across varying pH conditions.

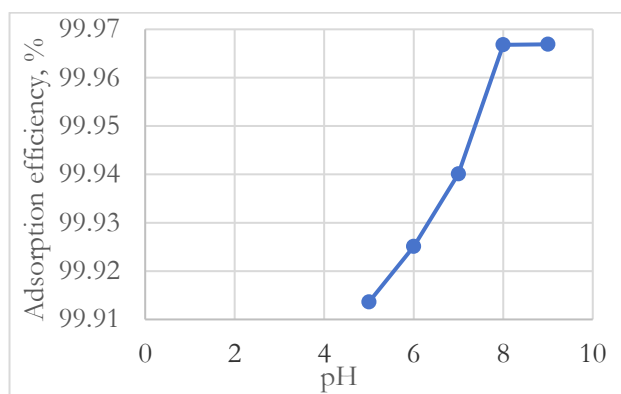


Figure 8. Effect of solution pH on Cd adsorption efficiency

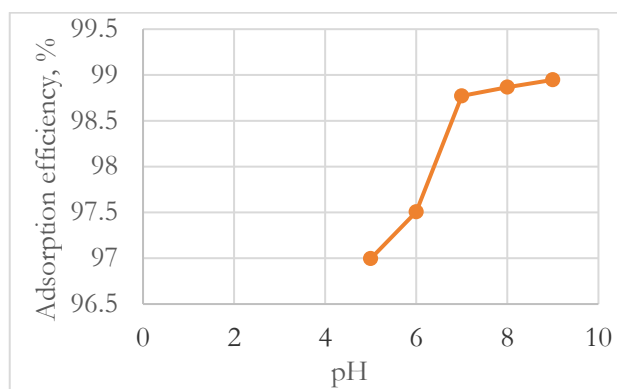


Figure 9. Effect of solution pH on Cr adsorption efficiency

3.5 Effect of Initial Concentration

The results of the effect of initial concentration, shown in Figures 9 and 10, revealed that adsorption efficiency increased slightly with higher initial concentrations (30–50mg/L), with Cd removal rising from 99.25% to 99.82% and Cr from 99.59% to 99.91%. This reflects stronger mass transfer driving forces at elevated concentrations, enhancing ion diffusion toward active sites [25]. At higher concentrations, the adsorption curves revealed plateauing, indicating site saturation. This behavior reflects the finite number of active binding sites on the adsorbent surface, consistent with the microporous structure and functional groups ($-\text{OH}$, $-\text{COOH}$) identified in FTIR analysis. Once these sites are occupied, further increases in concentration do not significantly enhance uptake, confirming Langmuir-type monolayer adsorption [29], [24].

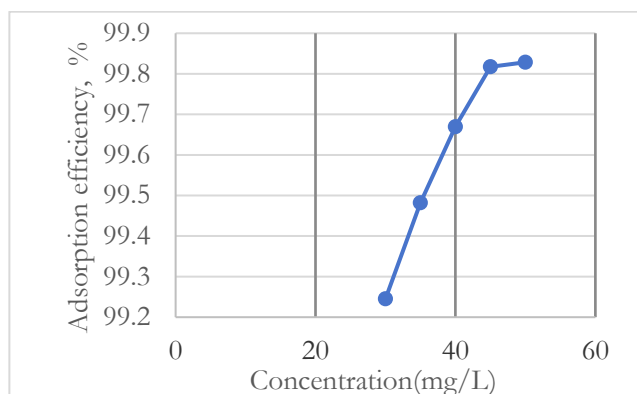


Figure 10. Effect of initial metal ion concentration on Cd removal

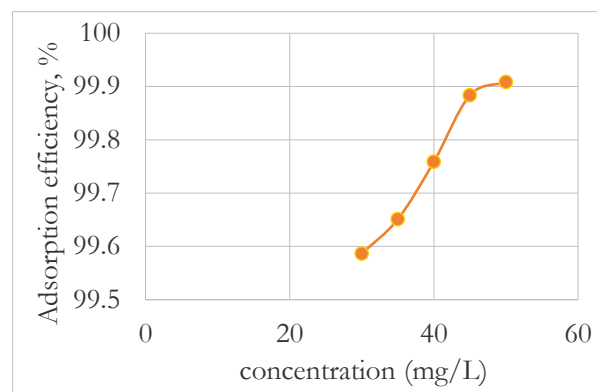


Figure 11. Effect of initial metal ion concentration on Cr removal

3.6 Adsorption Isotherm

The equilibrium adsorption data for Cd and Cr were analyzed using the Langmuir and Freundlich models, with regression parameters summarized in Table 3. The Langmuir plots (Figures 11) yielded excellent fits ($R^2 \approx 0.99999$ for both metals), confirming monolayer adsorption on homogeneous sites [30], [29]. Cd exhibited a higher maximum adsorption capacity ($q_{\text{max}} = 100.80\text{mg/g}$) but a moderate affinity constant ($K_L = 2.21\text{L/mg}$), while Cr showed a lower capacity ($q_{\text{max}} = 10.05\text{mg/g}$) but a very high affinity constant ($K_L = 36.30\text{L/mg}$). This contrast suggests that Cd benefits from abundant adsorption sites, whereas Cr binds more strongly to fewer available sites, consistent with previous reports on heavy metal adsorption using biomass-derived carbons [33], [32]. The Freundlich model plots (Figure 12) (also provided good correlation ($R^2 = 0.96062$ for Cd, 0.91927 for Cr), highlighting the role of heterogeneous surface interactions [24]. Both metals exhibited very high n values (Cd = 83.10, Cr = 144.70), confirming favorable adsorption conditions. The Freundlich constants ($K_F \approx 95\text{--}97$) further indicate strong adsorption intensity across heterogeneous sites, in agreement with studies emphasizing the importance of surface heterogeneity in activated carbons [29], [31].

These findings align closely with the physicochemical characterization results. The higher carbon purity and well-developed microporosity of coconut husk activated carbon (Section 2.2) explain the large q_{max} observed for Cd, as micropores enhance intraparticle diffusion and provide abundant binding sites [27]. The strong binding affinity of Cr, reflected in its high K_L , can be attributed to the presence of polar functional groups (hydroxyl, carboxyl) identified in FTIR analysis, which favor chemisorption and ion exchange [11]. The amorphous structure observed in XRD further supports heterogeneous adsorption, consistent with the Freundlich model fit [24].

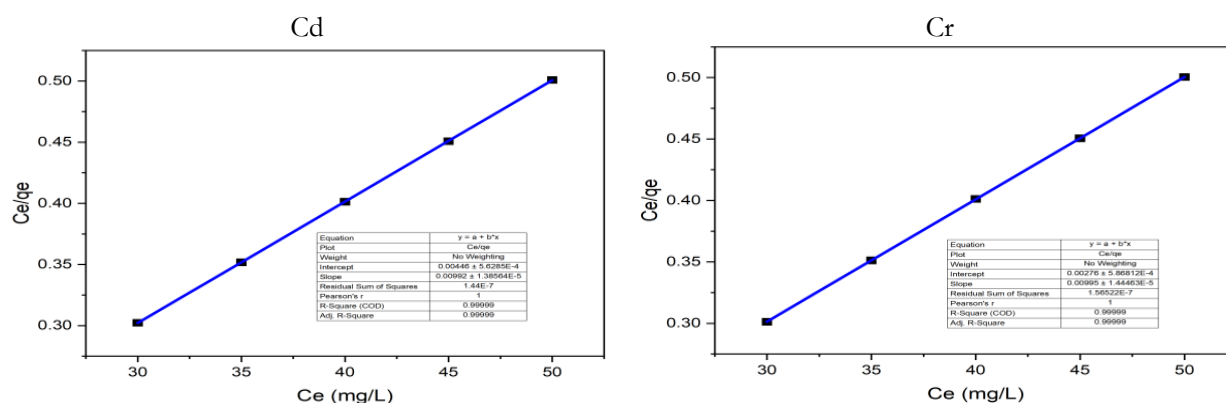


Figure 12. Langmuir isotherm plot for Cadmium and Chromium adsorption

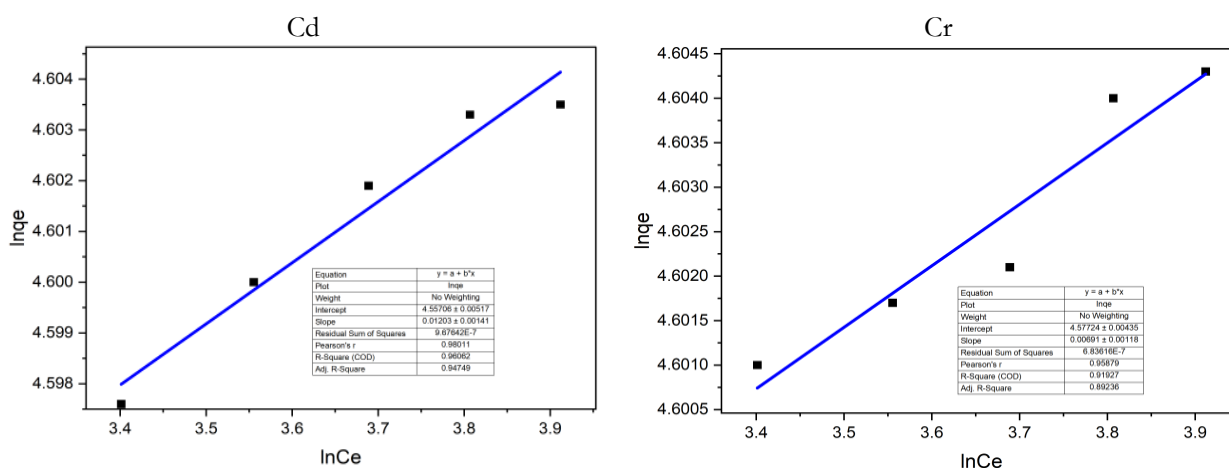


Figure 13. Freundlich isotherm plot for Cadmium and Chromium adsorption

Table 3. Langmuir and Freundlich Isotherm Parameters for Cd and Cr Adsorption

Model	Parameter	Cd	Cr
Langmuir	$q_{\max}$ (mg/g)	100.80	10.05
	K_L (L/mg)	2.21	36.30
	R^2	0.99999	0.99999
Freundlich	K_F	95.20	97.20
	n	83.10	144.70
	R^2	0.96062	0.91927

3.7 Kinetics of Adsorption

The adsorption kinetics of Cd and Cr onto coconut husk-derived activated carbon were evaluated using pseudo-first-order (PFO), pseudo-second-order (PSO), intraparticle diffusion (IPD), and Elovich models, with the parameters summarized in Table 4. Among the tested models, the PSO model provided the best fit for both Cd and Cr adsorption, with correlation coefficients ($R^2 = 0.9999$) approaching unity and calculated adsorption capacities ($q_{e,cal}$) closely matching the experimental values ($q_{e,exp}$). The Akaike Information Criterion (AIC) values were also lowest for PSO, confirming its superior predictive ability. These results indicate that chemisorption is the dominant mechanism, involving valence forces or electron sharing/exchange between the adsorbent surface and the metal ions [24], [29], facilitated by surface functional groups ($-OH$, $-COOH$) identified in FTIR analysis.

The PFO model showed relatively poor fits, with lower R^2 values (Cd = 0.94, Cr = 0.82) and significant deviations between $q_{e,cal}$ and $q_{e,exp}$, suggesting that physisorption does not adequately describe the adsorption process. The IPD model yielded moderate correlation coefficients (Cd = 0.927, Cr = 0.917) and non-zero intercepts, indicating that intraparticle diffusion contributes to the overall adsorption but is not the sole rate-

controlling step. This is consistent with the microporous structure of the adsorbent, which facilitates diffusion but also requires surface binding interactions. The Elovich model provided reasonable fits ($R^2 \approx 0.93\text{--}0.94$), supporting the role of heterogeneous surface adsorption, in line with the amorphous carbon structure observed in XRD analysis [27], [31].

Table 4. Kinetic Model Parameters and Goodness-of-Fit for Cd and Cr Adsorption onto Coconut Husk Activated Carbon

Model	Parameter	Cd	Cr
PFO	R^2	0.9411	0.82115
	AIC	22.18	16.74
	k_1 (min^{-1})	0.02719	0.08451
	$Q_{e, \text{exp}}$ (mg/g)	3.3832	0.02086
	$Q_{e, \text{cal}}$ (mg/g)	0.00367	0.02086
PSO	R^2	0.99999	0.99999
	AIC	-71.15	-68.69
	$Q_{e, \text{exp}}$ (mg/g)	3.3832	1.98696
	$Q_{e, \text{cal}}$ (mg/g)	3.3834	1.98696
	k_2 (g/mg·min)	17.07322	13.78977
IPD	R^2	0.9269	0.91705
	AIC	-56.29	-58.37
	k_d (mg/g·min ^{0.5})	0.00048	0.00263
	C (mg/g)	3.37744	1.96663
Elovich	R^2	0.94215	0.92771
	AIC	-67.32	-53.55
	β (g/mg)	812.40585	190.39267
	α	1.68×10^{1192}	6.72×10^{162}

3.8 Adsorption Thermodynamics

Thermodynamic analysis was carried out to evaluate the feasibility and nature of Cd and Cr adsorption onto coconut husk-derived activated carbon. The Van't Hoff plots (Figure 13) provided estimates of enthalpy (ΔH°) and entropy (ΔS°), as shown in Table 5. Cd adsorption displayed near-zero enthalpy change, indicating minimal energy requirement, whereas Cr adsorption showed positive enthalpy values, confirming endothermic behavior where higher temperatures enhance uptake [27]. Positive entropy values for both metals suggest increased randomness at the solid–solution interface, likely due to ion exchange and structural rearrangements on heterogeneous carbon surfaces [24], [29].

In addition to the conventional Van't Hoff analysis, ΔG vs $1/T$ plots (Figure 14) were presented as a novel visualization of spontaneity trends. These plots clearly illustrate how Gibbs free energy changes with temperature. The consistently negative Gibbs free energy (ΔG°) values across the studied temperatures confirm that both adsorption processes are spontaneous. Cd exhibited more negative ΔG° values than Cr, reflecting stronger affinity and energetically favorable adsorption, while Cr showed less negative values, consistent with its endothermic nature [32], [33].

The thermodynamic analysis confirms that Cd adsorption is spontaneous and energetically favorable without external energy input, while Cr adsorption is endothermic and benefits from elevated temperatures. These findings are consistent with the physicochemical characterization: the microporous structure and high surface area of coconut husk activated carbon explain the low energy requirement for Cd adsorption, while the functional groups ($-\text{OH}$, $-\text{COOH}$) identified in FTIR analysis contribute to spontaneity by providing strong binding sites. Cr's endothermic behavior reflects the need for thermal activation to overcome steric hindrance, consistent with the presence of heterogeneous binding sites. Furthermore, the amorphous carbon structure observed in XRD supports the positive entropy values, as surface heterogeneity allows multiple binding configurations and ion

exchange pathways. Together, these structural features validate the thermodynamic results and highlight the versatility of coconut husk activated carbon as a low-cost, effective adsorbent [27], [29], [32], [33], [24].

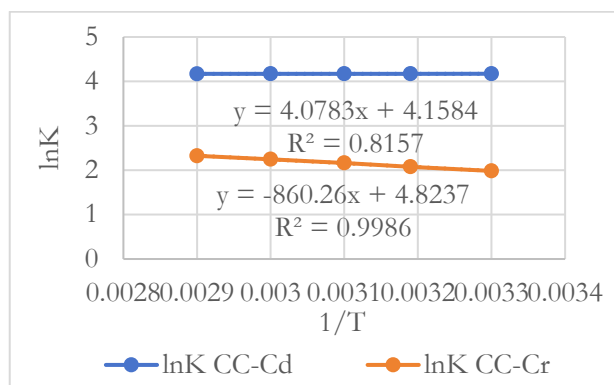


Figure 14. Equilibrium constant vs reciprocal of temperature plots

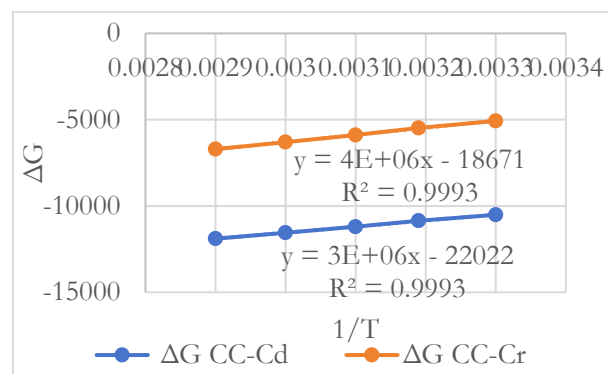


Figure 15. Free energy change vs reciprocal of temperature plots

Table 5. Thermodynamic insight from Van't Hoff analysis

System	ΔH° (J/mol)	ΔH° (J/mol.K)	R^2
CC-Cd	-27.95	34.59	0.8157
CC-Cr	7358.03	40.77	0.9986

* CC stands for Coconut Husk-Derived Activated Carbon

4.0 Conclusion

This study demonstrated that coconut husk-derived activated carbon is an effective, low-cost adsorbent for the removal of Cd and Cr from aqueous solutions. The physicochemical characterization confirmed the presence of microporosity, functional groups, and amorphous carbon structure, which collectively contributed to high adsorption efficiency. Adsorption experiments revealed that removal performance was strongly influenced by adsorbent dosage, pH, and initial concentration, with near-complete removal achieved under optimal conditions. Kinetic modeling identified the pseudo-second-order model as the best fit, confirming chemisorption as the dominant mechanism, while thermodynamic analysis showed that Cd adsorption is spontaneous and energetically favorable, and Cr adsorption is endothermic but enhanced at higher temperatures. Overall, the findings highlight the potential of coconut husk activated carbon as a sustainable adsorbent for heavy metal remediation. Future work should focus on scaling up the process, testing performance in real wastewater systems, and exploring regeneration and reuse of the adsorbent to enhance practical applicability.

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