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Research Article

Kinetics of Using *Gossypium arboreum* Shell Activated Carbon for Batch Adsorption of Chromium Ions from Aqueous Solution

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ABSTRACT

Aim/Background: *Gossypium arboreum* (Shell), was utilized as an adsorbent to extract the Cr ion from aqueous solution. **Materials and Methods:** The shell had a particle size of 53 to 150 µm. The influence of pH demonstrates that as the pH of the solution rose, so did the amount adsorb. The Langmuir and Freundlich equations help to examine equilibrium adsorption isotherms, which are explained by dual Freundlich and Langmuir models; however, the Langmuir model exhibits superior agreement. Dimer development in the contact zone is suggested by the amount adsorbed increasing as the temperature rose. The surface is heterogeneous, with energetically distinct adsorption sites, as indicated by SEM micrographs and differential molar isosteric heat of Adsorption (ΔH) computed at varying surface coverages. **Results:** According to values of n derived from Freundlich plots, Cr adsorption on the shell of *Gossypium arboreum* occurs spontaneously. The differential heat of adsorption against surface coverage plot reaches its maximum value at high surface coverage, indicating that structural rearrangements in the adsorbate have occurred. **Conclusion:** *Gossypium arboreum* shell activated carbon's high adsorption intensity and affinity for Cr ions can be used to solve a variety of adsorption issues in the industry and water purification processes.

Keywords: Chromium, Activated *Gossypium arboreum* Shell Carbon (AGAS), Adsorption models, Equilibrium.

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INTRODUCTION

Water pollution brought on by advancements in industrial technologies has been decreased through the use of various wastewater treatment techniques.[1] The effectiveness of the removal of the chemistry of the contaminated materials, all influence the selection of appropriate procedures.[2] The contaminants found in sewage, sludge, and fertilizers are widely known. Accordingly, drinking water should have no more than 0.3 mg/L of Chromium. The ion-exchange approach is one of several techniques for eliminating Cr cations from wastewater.[3] Oxidation by oxidizing chemicals like potassium permanganate and chlorine,[4] limestone treatment,[5] bioremediation,[2] and supercritical fluid extraction.[6]

While some of these techniques are straightforward and cost-effective, others are intricate and costly. Cr oxidation is typically treated with oxygen, chlorine, or potassium permanganate ($KMnO_4$). However, typical activated carbon is still a costly heavy metal removal material in developing nations like India. Numerous studies have recently been published in the literature that discuss the creation of activated carbons employing chemical activation with H_3PO_4 and a variety of less expensive and alternative resources, such as biomass and agricultural by-products.[7]

Only a small amount of research has been done on the production of carbons from wood materials, like sawdust, to remove heavy metals like mercury (II) from polluted waters.[8] It has been described that the pH value, in addition to the oxidation state of the removed cations, determines with chemical reaction. However, several writers discovered that the type of affects how well activated carbon removes Chromium and other heavy metals. Following this strategy, this study describes the application of adsorption techniques to investigate the adsorption of Cr ions and establish a particular pH for successful removal. An activated carbon derived from the shell of *Gossypium arboreum* was used for the removal process. The Langmuir and the Freundlich isotherm models examine the adsorption data. The overall goal of

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this work is to ascertain the effectiveness and ideal circumstances for Chromium cation removal by adsorption techniques.

MATERIALS AND METHODS

Adsorbent

The natural plant material used in this study, the shell of *Gossypium Arboreum*, was collected from an agricultural area. The stems were then dried at 110°C in a hot air oven. After that, the *Gossypium arboreum* shell was carbonized in a muffle furnace for 1 hr at 600°C. After being allowed to come to room temperature in a nitrogen-inserted environment, the activated carbon was cleaned with hot distilled water and 0.5 N hydrochloric acid, dried at 110°C in a hot air oven, ground, and sieved to the necessary size (150 µm), and finally put in desiccators for later use.

Chemicals

Every chemical utilized is of commercially accessible, high-purity Analytical grade and was acquired from a scientific equipment firm in Trichy. $FeSO_4.7\ H_2O$ (2.489 g in 500 mL) was used to make the Chromium solution. Cr concentration evaluated using an atomic absorption spectrophotometer (Perkin Elemer 2380).

Batch experiments

The removal of chromium onto *Gossypium Arboreum* shell. 50 mL of Chromium was a predetermined beginning concentration, and pH was adjusted for every experimental run. The mixture was mixed at a constant agitation speed of 200 rpm after adding 25 mg of adsorbent. Samples were separated by filtration. The content of Chromium (II) was ascertained by analysing the leftover solutions.

By contacting 50 mL of 50 mg/L of Cr ion solution with 25 mg of *Gossypium Arboreum* shell until equilibrium was reached, the impact of adsorbent dose on Cr ion removal was assessed. Using a dosage of 25 mg of *Gossypium Arboreum* shell per 50 mL of Cr ion solution, the adsorption equilibrium isotherm is investigated. The initial concentrations in each set of trials ranged from 25 to 125 mg/L. For 60 min, the plugged conical flask was shaken at 200 rpm. After that, the concentration of Cr ions was measured. The following mass equilibrium equation was used to determine the adsorption capacity:

$$qe = (C0 - Ce)V/M \quad \text{..... (1)}$$

Where M is the adsorbent mass, measured in grams [g], and V is the experimental volume of Chromium (II) solution, measured in Liters [L]. The initial Chromium concentration (mg/L) is denoted by C0, and the equilibrium concentration by Ce. The percentage of Chromium (II). The formula can be used to calculate ions below:

$$\%R = (C0 - Ct)x100/C0 \quad \text{..... (2)}$$

With a constant dosage of *Gossypium arboreum* shell and an Chromium concentration of 25 mg/L, the impact of pH on the rate of adsorption was examined. A solution of diluted HCl and NaOH was used to modify the pH values. The adsorbent-adsorbate combination was shaken for 60 min at 200 rpm while it was at room temperature. After that, the solution's Chromium content was determined.

RESULTS AND DISCUSSION

Characterization

Table 1 lists the various chemical components of activated *Gossypium arboreum* shell in addition to a few other attributes. The amorphous nature of activated *Gossypium arboreum* Shell (AGAS) is not indicated by any peak in the X-ray spectra of either adsorbent.

Adsorption studies

The adsorption process of Cr by the AGAS was examined using batch tests. 50 mL of Cr solution with a known concentration, beginning pH, ionic strength, and AGAS quantity was used for each experimental run. This combination was stirred at specific temperatures and a steady 200 rpm/min. To ensure equilibrium was reached, a specific amount of AGAS was contacted with Cr solutions of varying concentrations for 1 hr under specific circumstances for adsorption equilibrium tests (Table 2).

After measuring the concentration of residual Cr ions, the mass balance was used to determine how much Cr had been adsorbed onto AGAS. The effects of temperature, ionic strength, beginning solution pH, contact time, adsorbent dosage, and initial Cr concentration on AGAS-mediated Cr adsorption were examined. By examining the adsorptive absorption of Cr from aqueous solution at various time intervals, adsorption kinetics were ascertained. The mass balance equation was used to determine the quantity of Cr adsorbed at time t, qt (mg/g).

Impact of Contact Duration on Cr Ions Batch Adsorption in Aqueous Solution

Figure 1 illustrates how contact duration affects the adsorption of a solution of Cr ions using activated carbon derived from *Gossypium arboreum*. Batch adsorption was performed using 25 mg of activated *Gossypium arboreum* shell, and the quantities of Cr ions in solution were varied between 25 mg/L and 125 mg/L. As time passed, the proportion of adsorbed Cr ions rose until each concentration achieved equilibrium. Because there are more reactive sites available, it is clear from Figure 1 that the % adsorption is high at low concentration ranges.

Because there are fewer active surface sites available, the adsorbent's capacity is depleted, the metal ions increase, and more surface sites are covered. As a result, the proportion of metal ions adsorbed at greater concentrations decreases.[9] At a dose of 25 mg/L, found percentage adsorption of Cr ions quickly

achieves equilibrium after ½ hr of contact. At this dose, it rose to 100%, indicating the Cr ions were eliminated from the aqueous solution.

Initial Concentration's Impact on Cr Ion Adsorption in Aqueous Solution

Cr ion concentration on Cr ion adsorption using shell activated carbon from *Gossypium arboreum*. As the initial dose of Cr ions decreases, the total number of Cr ions that adsorb into the solution increases dramatically. The adsorbate's initial concentration ranged from 25 mg/L to 125 mg/L. Within 30 min of adsorption, the concentration of Cr ions rose from 25 mg/L to 125 mg/L, causing the amount of adsorption to drop from 92% to 70%. This was anticipated and indicates that the *Gossypium arboreum* shell activated carbon pore has more reactive sites.

Impact of Carbon Dosage on the Batch Adsorption of Cr Ions in Aqueous Solution

Different carbon dosages of activated *Gossypium arboreum* shell, 25-125 mg in 50 mL of Cr ions, were used to adsorb chromium ions in an aqueous solution of known concentration. Figure 2 shows that carbon dosage affects the adsorption of Cr ions by activated carbon made from leftover *Gossypium arboreum* shells. As the carbon dose increased over the 30-min adsorption period, there was a noticeable rise in the adsorption of Cr ions in solution.[10] Documented comparable results when using modified oak sawdust to remove heavy metal adsorption. This is because there are more active adsorption sites and an increase in effective surface area brought on by higher adsorbent doses. After further increasing the adsorbent dosage, it was shown that around 250 mg of activated carbon from *Gossypium arboreum* shell is needed to adsorb 100% of the Cr ions in an aqueous stock Cr ions solution for the best uptake of Cr ions (Table 3).

Impact of Particle Size on the Batch Adsorption of Cr Ions in Aqueous Solution

The batch adsorption of Cr ions is impacted by the size of the activated carbon particles made from leftover *Gossypium arboreum* shells. As the particle size decreased, the adsorption of Cr ions increased.[10] The shape reduction also showed that the adsorption of Cr ions in aqueous solution for batch processes is significantly influenced by the particle size of activated *Gossypium arboreum* shell carbon. Within 30 min of adsorption, the greatest amount of Cr ions was adsorbed by particles smaller than 150 µm; hence, *Gossypium arboreum* shells are an excellent way to adsorb Cr ions in aqueous solution.

pH's Impact on Cr Ion Batch Adsorption in Aqueous Solution

Adsorption of metal ions is affected by pH. Under certain settings (at an ideal contact duration of 60 min, a shaking speed of 200 rpm, with 25 mg of the adsorbents utilized, at 30°C), the impact of pH was examined from a range of 2 to 6. Figure 3 illustrates how the % removal of Chromium (II) ions rose as the wastewater's pH climbed from 2 to 6.5 when activated carbon got *Gossypium arboreum* shell was used as an adsorbent. The greatest elimination of metal ions was achieved at pH 6.5, where 92.72% of Cr was removed.

Adsorption Models

The adsorption equilibrium data were further examined into two well-known isotherm models two models following the given in Table 3.

Freundlich model

The following equation describes the Freundlich model, which is a measure of the adsorbent's surface heterogeneity.

$$Logqe = logkf + 1/n + logCe \text{ ---------- (3)}$$

For the adsorption of Cr, Freundlich graphs between logqe and logCe were produced, with Kf and 1/n representing the Freundlich constants associated with the intensity and capacity of adsorption, respectively. At both of the temperatures examined, correlation efficiency values were less than 0.99, suggesting that the Freundlich model was not appropriate for the current investigation.

Langmuir model

The Langmuir model to the adsorption isotherm. The following is the Langmuir equation that applies to monolayer adsorption onto a surface.

$$1/qe = 1/qm + 1/qmbCe \text{ ---------- (4)}$$

Where b (L mol-1) is the Langmuir constant linked to the energy of adsorption, qm (mgg-1) is the Langmuir constant representing the maximum monolayer adsorption capacity, and qe (mgg-1) is the amount adsorbed at the equilibrium concentration Ce (mol L-1). Plots of 1/qe as a function of 1/Ce were found to be linear for the adsorption of Cr, suggesting that the existing adsorption system be subjected to the Langmuir model. The correction coefficient (R^2=0.9926 and 0.9932 at 30 and 60°C, respectively) validates the monolayer capacity (qm) and equilibrium constant (b) statistics that were computed by graph and displayed in Table 3.

Table 1: Characteristics of the Adsorbent.

Properties	AGAS
Particle size (mm)	0.015
Density (g/cc)	0.2005
Moisture content (%)	0.2527
Loss in ignition (%)	0.021
pH of aqueous solution	5.2

Kinetics study

Rate of Cr adsorption by *Gossypium arboreum* shell as detailed in the adsorption isotherms section at pH 6.5. To examine the behavior of the Cr adsorption process onto the adsorbents, three kinetic models were applied to the adsorption kinetic data (Table 4). These models consist of intra-particle diffusion, pseudo-second-order, and pseudo-first-order kinetics (reversible or irreversible). The reversible pseudo-first-order model's linear form can be expressed as follows:

$$\ln \quad (\quad q_e - q_t) \quad = \quad \ln q_e - k_1 x \quad t \qquad (5)$$

The amount of Cr deletion by *Gossypium arboreum* shell, according to the adsorption isotherms section, was examined in batch experiments at pH 6.5. The kinetic adsorption data were assessed in order to comprehend the dynamics of the adsorption response in terms of the order of the rate constant. Three kinetic models were applied to the adsorption kinetic data in order to analyze the behavior of the Cr adsorption process onto the adsorbents. These models include pseudo-first-order (irreversible or reversible) kinetics, intra-particle diffusion, and pseudo-second-order kinetics. The reversible pseudo-first-order model's linear variant looks like this:

$$\ln \quad (C_o/C_t) \quad = \quad K \quad \times \quad t \quad (6)$$

Where Co (mg/L) represents the starting concentration of Cr, Ct (mg/L) represents the equilibrium concentration of Cr at time "t," and Kg 1 min represents the rate constant. The results are shown as a ln (Co/Ct) against time linear plot. It is possible to express the pseudo-second-order equation in linear form.

$$t/q_t = \quad 1/K_2 q_e^2 + \quad t/q_e \qquad (7)$$

Where K2 (g/mg/min) is the second-order rate constant and qe and qt stand for the surface loading of Cr at equilibrium and time "t," respectively. The rate constant K2 and an independent evaluation of qe were obtained from the linear plot of t/qt as a function of. The calculated correlation coefficients (R^2) almost matched, suggesting that the pseudo-second-order equations fit the experimental data quite well.

The Elovich equation and intra-particle diffusion model

The Elovich model equation

$$dqt/dt = exp(-qt) \cdots\cdots\cdots (8)$$

Where α is the initial adsorption rate (mg g^{-1} min-1) and β is the desorption constant (g/mg) for any particular experiment. To simplify the Elovich equation.[11] Using the boundary constraints qt = 0 at t=0 and qt = qt at t=t, and assuming that t>>t Equation (10) becomes:

$$qt = 1/\ln() + 1/\ln t \ldots\ldots\ldots\ldots (9)$$

If the adsorption of Cr ions is by the Elovich model, a plot of qt vs. ln(t) should display a linear relationship with a slope of (1/β) and an intercept of (1/β)ln (αβ). Table 5 provides a summary of the Elovich model parameters α, β, and the correlation coefficient. The initial adsorption rate (α) rises with temperature like that of the initial adsorption rate (h) in pseudo-second-order kinetics models, according to experimental data such as the initial adsorption rate (f_0), adsorption constant (β), and correlation coefficient (γ) computed from this model. This could be because the AGAS adsorbent has more pores or active sites.

Table 2: Equilibrium parameters for the adsorption of Chromium ion onto *Gossypium arboreum* shell.

Cr_0	Ce (Mg / L)				Qe (Mg / g)				Removed (%)			
	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
10	2.013	1.632	1.090	1.034	15.973	16.735	17.821	17.932	79.867	83.676	89.104	89.661
20	5.985	5.444	4.920	3.810	28.029	29.112	30.160	32.380	70.073	72.781	75.400	80.949
30	12.444	11.864	10.338	9.579	35.112	36.272	39.323	40.842	58.520	60.453	65.538	68.070
40	19.090	17.458	16.560	15.533	41.820	45.084	46.880	48.933	52.275	56.355	58.600	61.166
50	28.295	27.313	26.710	25.124	43.411	45.374	46.579	49.752	43.411	45.374	46.579	49.752

Table 3: Langmuir and Freundlich isotherm parameters for the adsorption of chromium ions onto *Gossypium arboreum* shell.

Model	Constant	Temperature (°C)			
		30	40	50	60
Freundlich	K_f (mg/g) $(L/mg)^{1/n}$	12.960	14.647	17.862	19.018
	N	2.594	2.719	3.125	3.052
	R^2	0.972	0.972	0.976	0.964
Langmuir	Q_m (mg/g)	50.825	52.410	51.814	54.882
	K_L (L/mg)	0.210	0.248	0.367	0.398
	R^2	0.997	0.992	0.994	0.997

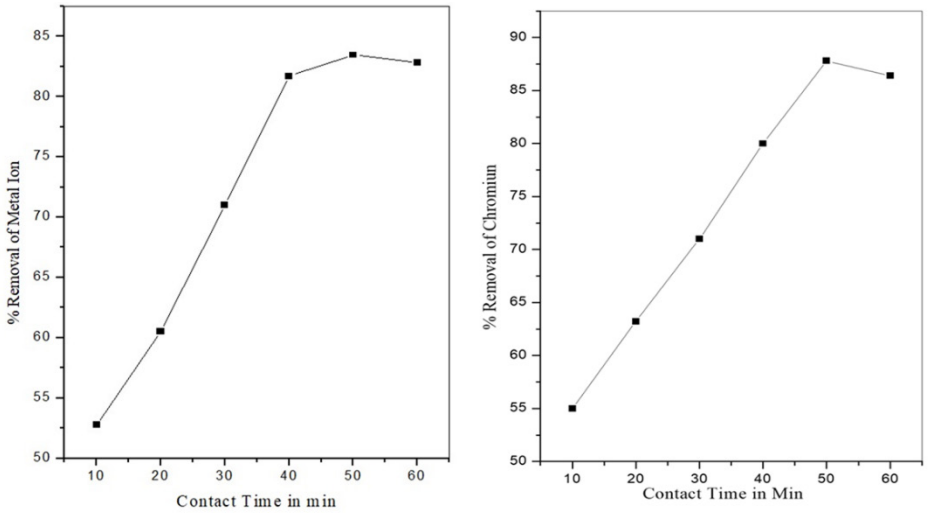

Figure 1: A) Effect of Contact Time on the Removal of metal ion [M]=50 mg/L: adsorbent dose=25 mg/50 mL; Temp=30°C. B) Effect of Contact Time on the Removal of Cr Ion [Cr]=50 mg/L; Temperature 30°C; adsorbent dose=25 mg/50 mL.

The initial adsorption rate K2qe2 for the *Gossypium arboreum* shell and the acquired results for the adsorption of Cr onto it are more in line with the pseudo-second order model (R^2=0.95). The intra-particle diffusion model was used to assess the kinetic data for the adsorption of Cr, and the results can be expressed as follows.[12]

$$Qt = k_{pt} 0.5 \quad (10)$$

Where kp (mg/g min0.5) is the intra-particle diffusion rate constant and qt is the quantity of Cr adsorbed (mg/g) at time t. The results are shown in Table 4. The adsorption process can usually be broken down into two or more stages, as shown by the plot of qt versus t0.5.

Adsorption Thermodynamics

The following formulas were used to calculate the adsorption of Cr ions by the shell of Activated *Gossypium arboreum*:

$$KD = qe/Ce \quad (11)$$

$$\Delta Go = - RT \ln KD \quad (12)$$

$$\ln KD = (\Delta So/R) - (\Delta Ho/RT) \quad (13)$$

Where ΔHo is the enthalpy change in kJ/mol, ΔSo is the entropy change in J/mol K, and T is the absolute temperature in K. ΔGo is the Gibbs free energy in J/mol, and KD is the distribution coefficient for the adsorption in g/L.[13]

The values of Gibbs free energy (ΔGo) for various temperatures were calculated using the experimental data. The values of entropy change (ΔSo) and enthalpy change (ΔHo) were estimated using the slope and intercept of the plot of ln KD Vs 1/T.

Table 6 displays the estimated thermodynamic parameters that were tabulated. However, the spontaneous character of the adsorption process was demonstrated by the negative values of Gibbs free energy change (ΔGo) observed for the adsorption of Cr ions by Activated *Gossypium arboreum* shell at different temperatures.

The positive values of enthalpy change (ΔH°) observed for the adsorption of Cr ions by Activated *Gossypium arboreum* shell at different temperatures revealed the endothermic character of the adsorption reactions.

The increased randomness in the solid-liquid interphase during the sorption processes of Cr ions on the adsorbent AGAS was demonstrated by the positive values of entropy change (ΔS°) for the adsorption of Cr ions by Activated *Gossypium arboreum* shell at different temperatures. This is a direct result of (i) the adsorbent beads' structure opening up, (ii) increasing the mobility and penetration depth inside the adsorbent beads, and (iii) breaking through the activation energy barrier and speeding up intra-particle diffusion.[14]

The activated *Gossypium arboreum* shell's ability to adsorb Cr ions increased somewhat when the temperature was elevated to 60°C. Both the enhanced rate of pore diffusion and the development of fresh active sites on the surface of the adsorbent may be the reason. However, adsorption activities significantly diminished as the temperature was raised further. It is shown that the physical and exothermic adsorption processes of Cr ions by the activated *Gossypium arboreum* shell.

SEM Images of APSNC

The AGAS sample's SEM micrographs before and after dye adsorption are displayed in Figures 3A and 3B. AGAS contains a sizable number of heterogeneous pore layers where Cr ions have a

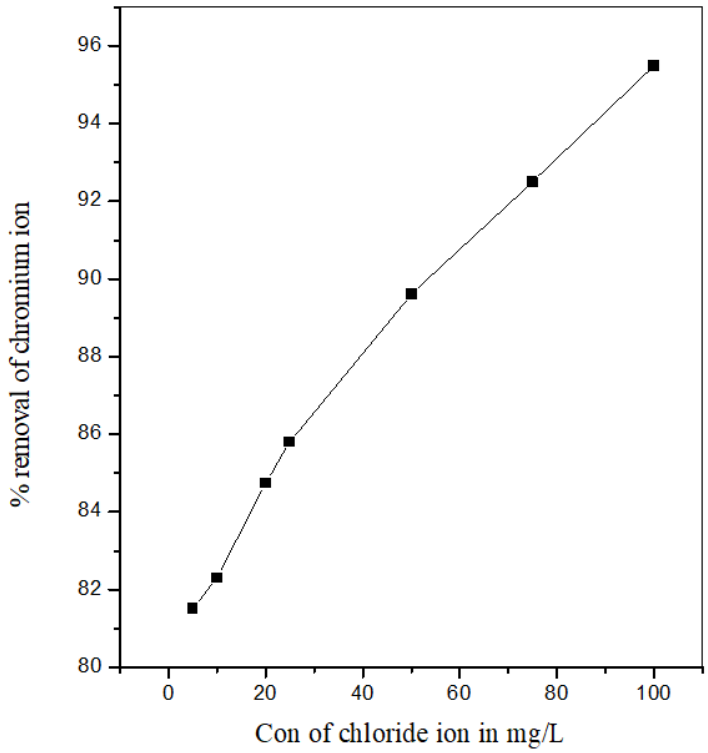

Figure 2: Effect of ionic strength on the adsorption of chromium ion onto POP[Cr]=50mg/L; Contact Time 60 min: Adsorbent Dose=25 mg/50 mL.

Table 4: Kinetic parameters for the Adsorption of Chromium ions onto *Gossypium arboreum* Shell.

Metal ion Con.	Temp °C	Pseudo Second Order				Elovich Model			Intraparticle Diffusion		
		q_e	K_2		H				K_{id}		C
10	30	24.2198	1.20E-03	0.9572	0.7027	1.4E+00	1.78E-01	0.9592	10.1074	0.4974	0.9905
	40	21.2877	2.50E-03	0.9779	1.1308	2.6E+00	2.20E-01	0.9592	19.4855	0.3490	0.9836
	50	19.9681	5.77E-03	0.9927	2.3015	1.6E+01	3.30E-01	0.9592	39.0108	0.1969	0.9744
	60	19.9135	6.29E-03	0.9936	2.4941	2.1E+01	3.47E-01	0.9592	5.0393	0.1839	0.9735
20	30	50.3860	3.58E-04	0.8334	0.9082	1.9E+00	9.20E-02	0.9058	5.7901	0.5917	0.9673
	40	45.5230	5.62E-04	0.9143	1.1647	2.4E+00	9.64E-02	0.9288	8.3530	0.5158	0.9759
	50	43.0623	8.25E-04	0.9666	1.5303	3.1E+00	1.01E-01	0.9601	11.8719	0.4460	0.9858
	60	41.4895	1.19E-03	0.9668	2.0546	4.7E+00	1.12E-01	0.9431	3.4852	0.3614	0.9748
30	30	52.4231	5.02E-04	0.8056	1.3783	2.9E+00	8.60E-02	0.8280	7.6084	0.4729	0.8955
	40	51.4580	7.61E-04	0.9590	2.0146	4.1E+00	8.44E-02	0.9402	10.4719	0.4293	0.9591
	50	58.5412	5.79E-04	0.9730	1.9827	3.9E+00	7.24E-02	0.9677	9.4393	0.4765	0.9826
	60	52.0479	1.21E-03	0.9991	3.2727	6.8E+00	8.53E-02	0.9889	3.3239	0.3640	0.9750
40	30	64.2897	5.29E-04	0.9763	2.1861	4.1E+00	6.26E-02	0.9734	6.4375	0.5298	0.9541
	40	66.4701	5.52E-04	0.9940	2.4410	4.6E+00	6.14E-02	0.9905	7.6766	0.4993	0.9693
	50	65.3263	6.86E-04	0.9936	2.9275	5.5E+00	6.29E-02	0.9820	9.5976	0.4548	0.9600
	60	66.3199	7.47E-04	0.9958	3.2872	6.3E+00	6.29E-02	0.9835	2.8510	0.4275	0.9647
50	30	110.4746	8.23E-05	0.5251	1.0039	2.4E+00	5.34E-02	0.8589	1.8848	0.7401	0.9527
	40	102.2885	1.09E-04	0.6122	1.1380	2.6E+00	5.26E-02	0.8635	2.3491	0.6979	0.9530
	50	84.1462	1.98E-04	0.7187	1.4054	3.0E+00	5.57E-02	0.8563	3.5271	0.6050	0.9397
	60	90.0790	1.81E-04	0.6802	1.4718	3.2E+00	5.21E-02	0.8425	1.7519	0.6119	0.9300

Table 5: Dimensionless Separation Factor (R_l) for the Adsorption of Chromium Ion onto *Gossypium arboreum* Shell.

(C_i)	Temperature °C			
	30°C	40°C	50°C	60°C
10	0.3222	0.2876	0.2143	0.2006
20	0.1921	0.1680	0.1200	0.1115
30	0.1368	0.1186	0.0833	0.0772
40	0.1062	0.0917	0.0638	0.0590
50	0.0868	0.0747	0.0517	0.0478

Table 6: Thermodynamic Parameters for the Adsorption of Chromium Ion onto *Gossypium arboreum* Shell.

C_0	G				H	S
	30°C	40°C	50°C	60°C		
10	-3471.443	-4252.998	-5643.291	-5980.268	-23.687	89.697
20	-2143.242	-2559.478	-3007.852	-4005.285	-16.031	59.623
30	-866.933	-1104.303	-1726.162	-2095.815	-12.196	42.907
40	-229.380	-665.088	-933.058	-1257.785	-9.937	33.675
50	667.829	482.886	367.996	27.487	-6.800	20.169

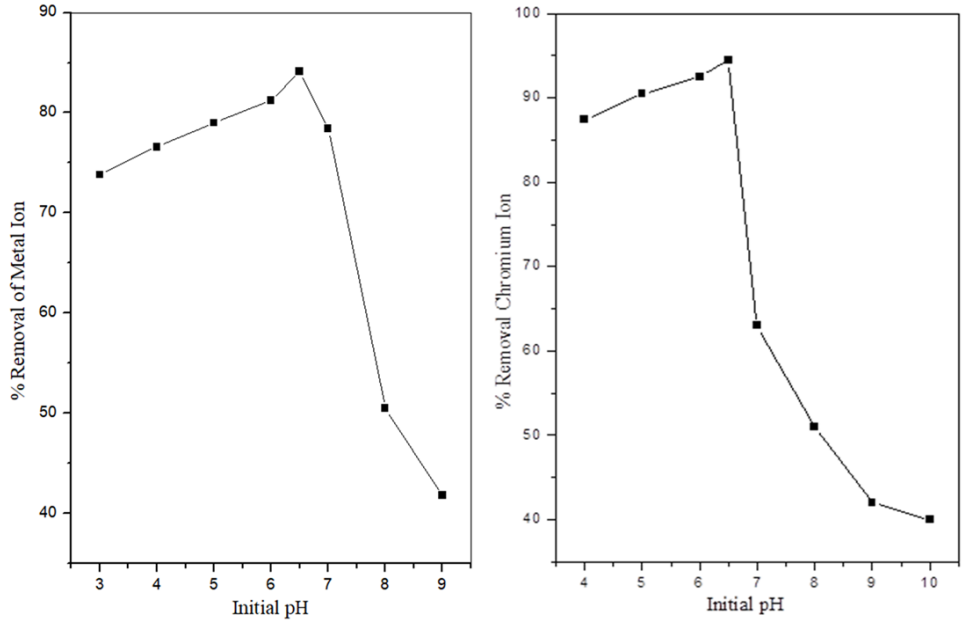

Figure 3: Effect of Initial pH on the removal of Metal ion [M]=50mg/L: Contact time=60 min: dose=25 mg/50 mL.

strong chance of being adsorbed. However, it is evident from the metal-loaded adsorbent's surface that metal ions fill the AGAS surface.

Desorption studies

The nature of adsorption and recycling of the metal ions and spent adsorbent is clarified by desorption investigations. Weak bonds hold the adsorbent's metal ions in place, allowing the adsorbed metal ions to be desorbed using water with a neutral pH. Because we were able to remove almost 92% of the deposited metal ions, the data show that for desorption, hydrochloric acid is a more effective reagent. The discovered pH-dependent results support the reversibility of adsorbed metal ions in mineral acid or base. Both physisorption and chemisorption methods may have been used to adsorb the metal ion onto the AGAS, as evidenced by its desorption by alkaline and mineral acids.

CONCLUSION

Activated carbon made from leftover *Gossypium arboreum* shells was applied to study the kinetics of batch adsorption of Cr ions. Process variables such as particle size, carbon dose, starting adsorbate concentration, and contact time greatly affected the

amount of Chromium (II) ions adsorbed. The Langmuir and Freundlich isotherms are followed in the adsorption process; however, the Langmuir isotherm model produced a better sorption fit, suggesting the creation of a monolayer across the material's surface. 166.7 mg of Cr ions adsorbed per g of *Gossypium arboreum* shell activated carbon is higher than that of other adsorbents used for Cr ion adsorption. Intra-particle diffusion models, Adsorption dynamics were modelled using pseudo-first-order and pseudo-second-order kinetic equations. According to sorption kinetics, which showed the experimental results, the pseudo-second-order kinetic reaction is the rate-controlling step, with some intra-particle diffusion taking place. Numerous adsorption problems in the industry and water purification procedures can be resolved with the use of the *Gossypium arboreum* shell activated carbon's high adsorption intensity and affinity for Cr ions.

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CONFLICT OF INTEREST

The author declares that there is no conflict of Interest.

AUTHOR CONTRIBUTIONS

SG, HMA. Designed experiments, supervised SG. Wrote the initial draft and edited the manuscript, HMA. Carried out an investigation, MM. Validation, characterization, and editing of the manuscript, HMA. Wrote the initial draft and edited the manuscript, MM. Funding acquisition, and HMA: characterization and software analysis.

SUMMARY

The kinetics of batch adsorption of Cr ions were investigated using activated carbon derived from residual *Gossypium arboreum* shells. The amount of Chromium (II) ions adsorbed was significantly impacted by process variables like particle size, carbon dosage, beginning adsorbate concentration, and contact time. Although the adsorption process adheres to both the Freundlich and Langmuir isotherms, the Langmuir isotherm model yielded a better sorption fit, indicating the formation of a monolayer across the material's surface. Compared to other adsorbents utilized for Cr ion adsorption, *Gossypium arboreum* shell activated carbon absorbed 166.7 mg of Cr ions per g. Pseudo-first- and pseudo-second-order kinetic equations were used to model the kinetics of adsorption and intraparticle diffusion. The pseudo-second-order kinetic reaction is the rate-controlling step, with some intra-particle diffusion occurring, according to sorption kinetics, which is demonstrated by the experimental results. *Gossypium arboreum* shell activated carbon's high adsorption intensity and affinity for Cr ions can be used to solve a variety of adsorption issues in the industry and water purification processes.

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