Mechanisms of Batch Adsorption of Nickel (II) Ions from Aqueous Solution with *Gossypium arboreum* Shell Activated Carbon

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ABSTRACT

Aim/Background: The effectiveness of an adsorbent made from *Gossypium arboreum* shell through acid treatment was evaluated in terms of nickel ion removal. **Materials and Methods:** Process variables that were investigated included agitation time, initial nickel ion concentration, adsorbent dose, pH, and temperature. The pace is mostly regulated by intra-particle diffusion, and the adsorption follows the second-order reaction equation. Freundlich and Langmuir isotherm models were applied to the equilibrium data. **Results:** The Langmuir isotherm plot's adsorption capacity (Qm) at 30, 40, 50, and 60±0.50ºC, starting at pH 6.5. The elimination of metal ions was significantly impacted by pH, and adsorption increased as temperature rose. Using 0.1M HCl, some of the Ni+ extracted from wasted APSNC. **Conclusion:** This work shows that Gossypium Arboretum Shell carbon may be used to extract Ni (II) ions.

Keywords: *Gossypium arboreum* Shell Carbon (GASC), Ni (II) ion, Isotherm Plot, Equilibrium constant.

INTRODUCTION

One major environmental issue that has an impact on water quality is the contamination of water and water bodies by heavy metals. Reduced aquatic output, eutrophication of water bodies, rising purifying costs, and a shrinking water supply are the results.[1] Several solutions have been implemented to address the threat posed by water contamination by heavy metals. These include membrane separation, ion exchange, Reverse osmosis, adsorption, evaporation, electrolysis, filtering, and electrochemical treatment Singh *et al.*, Adsorption, on the other hand, is among the most effective procedures for the extraction of Ni from aqueous solutions.[2] Given the foregoing, numerous studies have been carried out utilizing a variety of adsorbents. Nevertheless, adsorbents are costly and have a small adsorption surface area; others can include additional toxicants.

Toxic metals can now be removed from aqueous solutions using a variety of technologically advanced physical and chemical techniques.[3] Physical techniques, particularly adsorption on multiple supports, were identified as a viable and successful method for fully removing metal ions.[2] For the removal of Ni (II) ions from aqueous solutions, effective adsorbents must be developed. The most popular adsorbent is activated carbon, which is made via physical activation, which involves carbonating the carbonaceous material at a temperature higher than 900ºC in an inert atmosphere, then thermally activating it.[4]

The current study focuses on the carbonization of *Gossypium arboreum* shells with sulfuric acid to adsorb Ni (II) ions onto activated carbon. The sample was arranged using the kinetic and equilibrium adsorption data that were acquired. Next, the amounts and rates of Ni (II) ion adsorption from aqueous solution employing the activated carbon mentioned above were measured. The literature research indicates that no attempt has been made to improve the *Gossypium arboreum* shell's adsorbent properties.

MATERIALS AND METHODS

The chemicals are highest Analar grade, which is sold commercially. A precisely weighed 4.4786 g. of Ni sulphate was dissolved to create a nickel stock solution with 1000 mg/L. The adsorbent, diluted HCl (or) NaOH was used to raise the pH until the required initial pH value. A Perkin Elmer 2380 atomic absorption spectrophotometer was used to measure the number of remaining nickel ions.

Preparation of adsorbent

The *Gossypium arboretum* Shell used in this study gathered from Manjakkudi. After repeatedly washing the stem with the dust, it was powdered at 110ºC in a hot air oven. The stem was then carbonized by Con.H_2SO_4 to obtain the main carbon. To create activated carbon, the primary carbon was under ideal conditions for 6 hr at >900ºC.

Experimental Procedure of Batch Method

This method was used to examine impacts of effective work on the extraction of Ni (II) ions by regulated *Gossypium arboreum* Shell (GASC), including contact time, activated carbon dose, beginning pH, and other ion concentration.[5,6] This experiment involved agitating a solution of Ni (II) ions at varying temperatures (30-60ºC), adsorbent quantities (0.025 g/L) at 120 rpm, and concentrations (10-50 mg/L) until equilibrium was achieved. The concentration of Ni (II) ions was analyzed at 540 nm using a UV-visible spectrophotometer. Every experiment to remove the Ni (II) ion from aqueous form was conducted at a pH of normal. Over a pH range of 3.0-9.0, the effect of pH on the elimination of Ni (II) ions was investigated. To modify the solution's original pH, dilute. HCl or dil. NaOH was added. Except for employing varied dosages (25-125 mg/50 mL), using the previously described techniques, the effects of activated carbon dose on adsorption rate. The value quantity of adsorption was calculated via time t, qt(mg/g), and the % existing of Ni (II) ion by using the formula.

$$q_t = V \times \frac{(C_0 - C_t)}{w} \qquad (1)$$

$$\% \text{ Removal} = \left(\frac{C_0 - C_t}{C_0}\right) \times 100 \qquad (2)$$

Where w-mass of the adsorbent (g), V-volume of the treated solution (mL), and q (t) is the amount of adsorbed Ni (II) ion per unit mass of adsorbent (mg g^{-1}). The initial and actual concentrations (g dm^{-3}) of Ni (II) ion at time t are denoted by C_0 and Ct, respectively.

RESULTS

Influence of contact time

The Ni (II) ion adsorption (GASC) *Gossypium Arboreum* Shell was investigated as a function of contact time to analyze the adsorption kinetics process and measure the equilibrium time of maximal removal by the method.[7] Figure 1 presents the findings, while Table 1 presents the equilibrium data. An equilibration interval of 60 min was used for all subsequent trials since figure indicates that the absorption rate was initially quick at first, with the maximal adsorption being completed in half an hour and equilibrium being reached in 50 min.

Influence of Activated Carbon Dosage

By adjusting the adsorbent dosage for a concentration of 50 mg/L of Ni (II) ion, Ni (II) ion on AABC was investigated.[8] Because there are more adsorption sites available and the carbon surface area is growing in Ni (II), the % elimination of Ni (II) ions in Ni (II) alleviated as the GASC dose rose.

Thus, in all investigations, the various adsorbate solutions containing 10, 25, 50, 100, 200, and 250 mg/L were used at a ratio of 0.025 g of adsorbent to 50 mL. The results of this study are shown in Figure 1B. As the dosage of GASC was reduced, so was the amount of Ni (II)/g. This implies that the dosage of activated GASC affects the Ni (II) ion's direct and equilibrium capabilities.

Influence of initial pH

As a result, the adsorption process is highly sensitive to pH. Therefore, the impacts of the initial solution pH were examined in the pH range of 3 to 9. As shown in Figure 2A, the percentage removal of Ni (II) increased from around 60% to 93%, whereas Ni (II) steadily decreased after pH 6.8, or pHzpc (zero-point charge).

Any adsorbent's pHzpc is a critical characteristic, pH at which the surface has net electrical neutrality. The surface charge of GASC may become $^+$ve charged at lower pH values (pH pHzpc) due to the presence of H_3O^+ ions surrounding it. This would boost the electrostatic force of attraction-induced uptake of Ni (II) ions. The initial pH range was set at 6.8 because the pH at neutral of the adsorbent facilitates a higher amount of Ni (II) ion removal in the aqueous solution.

Influence of other ions

At various concentrations, impact of Cl$^+$ ions adsorption was examined. For 60 min at 30ºC, the ions were mixed with 50 mg/L of Ni (II) ion solutions. The findings displayed in Figure 2B demonstrate that a low concentration of Cl has no influence on the % of Ni (II) ion adsorption on GASC because Cl-interaction at accessible adsorbent sites via competitive adsorption is ineffective. These ions interfere at the sorbent's accessible surface sites due to competitive adsorption in Ni (II), raising the concentration of other ions while lowering the adsorption percentage. Ions have better affinity for the sorbent and create less internal swelling pressure.

Adsorption models

The Freundlich and Langmuir models used for analyze the adsorption equilibrium data into two well-known isotherm models.

Freundlich model

The following equation describes the Freundlich model[9] which is a measure of the adsorbent's surface heterogeneity.

$$log q_e = log K_f + \frac{1}{n_f} log C_e \qquad (3)$$

Using the Freundlich and Langmuir models, the adsorption equilibrium data were further analysed into two well-known isotherm models. Figure 3A displays the Freundlich plots between

log qe and log Ce for the adsorption of Ni (II) ion. The Freundlich model proved appropriate for the current study, as indicated by the correlation coefficient (R2) values, which range from 0.946 to 0.965. Table 2 contains these values.

Langmuir model

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

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m} \tag{4}$$

Where KL (L mol-1) is the Langmuir constant associated with the energy of adsorption, qe (mgg⁻¹) is the levels of adsorbed ions at the Ce (mol L⁻¹), and qm (mgg⁻¹) is the Langmuir constant indicating the thicker monolayer adsorption capacity. Figure 3B, the correction coefficient (R2) values are in good agreement with the values of the equilibrium constant (K_L) and monolayer capacity (qm), shown in Table 2. These findings recommended that Ni (II) ions have been adsorbed in a monolayer covering on the surface of the generated adsorbent.

The equation in forms of the dimensionless constant separation factor, or RL, can be used to explain the salient features of the Langmuir isotherm. To ascertain the isotherm's feasibility.

$$R_L = \frac{1}{1 + K_L C_0} \tag{5}$$

Where Co (mg/L) is the maximal initial concentration of Ni (II) ion and K_L (L/mg) is the Langmuir isotherm constant.

Accordingly, the parameter RL indicates the isotherm's shape.

R_L>1-Unfavorable adsorption,

0<R_L<1-Favorable adsorption,

R_L=0-Irreversible adsorption,

R_L=1-Linear adsorption.

For every initial Concentration (C_0) and temperature under study, favourable adsorption is indicated by R_L values in the range of 0 to 1. Figure 4 displays the determined R_L values. As the adsorbent dosage for GASC increased, so did the KL values. High adsorption affinity is indicated by high KL values; for GASC, the monolayer saturation capacity qm was approximately 68.616 mg/L.

Thermodynamic treatment of the adsorption process

The following formulas: Enthalpy change (ΔH0), Entropy change (ΔS0), and standard free energy change (ΔG0).[10]

The free energy of the adsorption process, accounting for the adsorption equilibrium constant K0, is given by the following formula:

$$\Delta G^0 = -RT\ln K_0 \tag{6}$$

Where T is the temperature in Kelvin, R is the universal gas constant (8.314 J mol/K), and G0 is the free energy of adsorption (kJ/mol). The K0 is the adsorption distribution coefficient for the sorption reaction and was determined by calculating the slope of the plot of ln (qe/Ce) against Ce at different temperatures.

The adsorption of the distribution coefficient can be written as enthalpy change (H0) and entropy change (S0) as a function of T.

$$\ln K_o = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \tag{7}$$

Where H° is the standard heat variation of sorption (kJ/mol) and S° is the standard entropy change (kJ/mol). The amount of ∕H° and ∕S° found using graph curve and intercept of the graph of ln K0 against 1/T. Equations 6 and 7 were used to obtain the value of the thermodynamic parameter, which is shown in Table 3. ⁺values of H° indicate the endothermic nature of adsorption, which dictates the likelihood of physical adsorption.

The sorption data's thermodynamic analysis showed that every G° value was negative. The findings demonstrate that physisorption is far more advantageous for Ni (II) ion adsorption, a character of adsorption, which is shown by positive values of H°.

As the extent of Ni (II) ion adsorption rises, the possibility of chemisorption's is reduced, even while physical adsorption causes Ni (II) to lower the system's temperature. The low H° value indicates that the adsorbent GASC has physiosorbed Ni (II) ions. The negative Δvalues verified that the Ni (II) ion adsorption onto GASC was spontaneous. It is implied that adsorption is a physical process by the lower ΔG° values. The positive value of ΔH° provides more evidence for the endothermic nature of the adsorption process. ⁺values of ΔS° in Table 3 show that the solid solution interface became more random when Ni (II) ions were adsorbed onto GASC.

Kinetic models

Pseudo-second-order

Usually, experimental data is tested using kinetic models to investigate the adsorption mechanism.[11] If the surface concentrations and the observed concentrations are same, pseudo-second-order equations can be applied. The pseudo-second-order equation is produced in a linearized form.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right) t \tag{9}$$

Where qt (mgg⁻¹) is the quantity of adsorbed Ni (II) ion on the adsorbent at time t, qe is the equilibrium sorption uptake and k2 (min⁻¹) is the pseudo-second-order adsorption rate constant. A straight line is produced when plotting t/qt against t, suggesting that the second-order kinetic model is suitable. The plot's slope and intercept are then used to compute Qe and k2 respectively. The high regression value in Table 5 indicates the pseudo-second-order adsorption process.
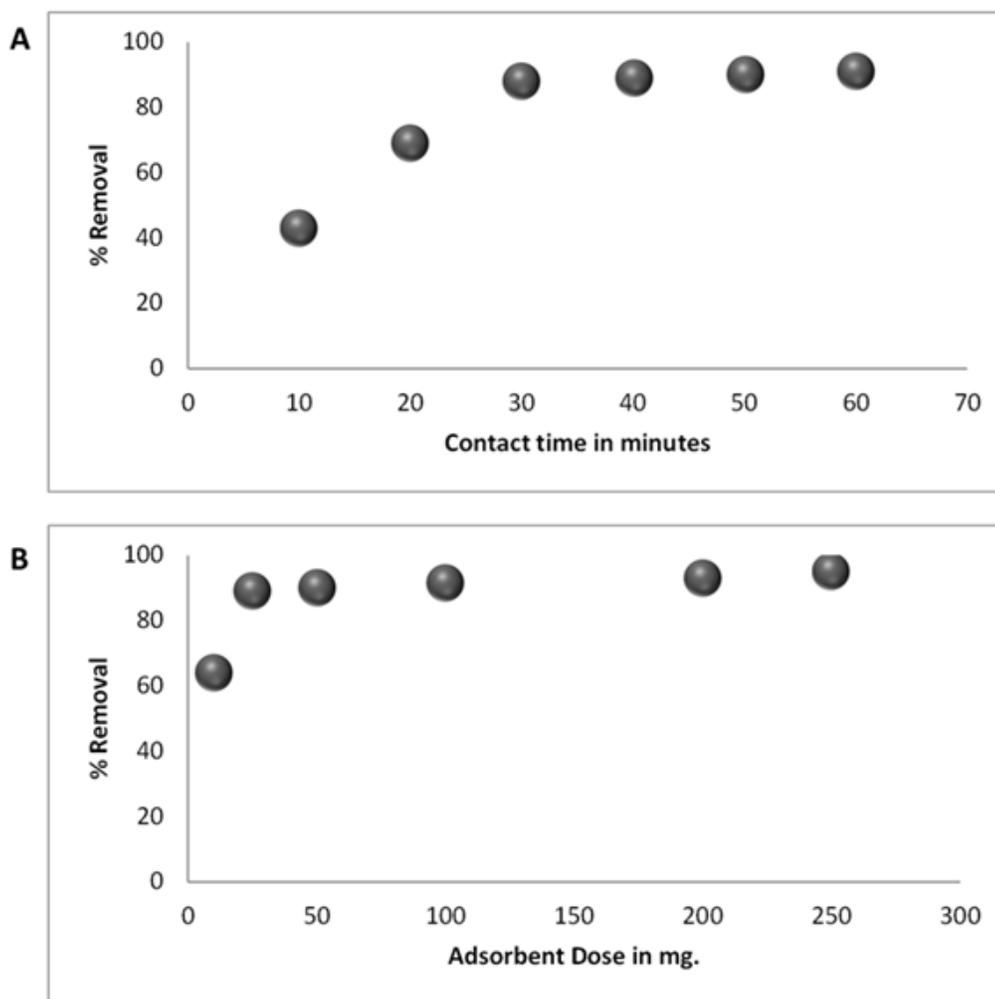
Figure 1: A) Contact Time's Impact on Ni (II) Removal. [Ni (II)]=10 mg/L; Adsorbent dosage=0.025 g/50 mL; Temperature: 300ºC. B) Adsorbent dose's effect on Ni (II) removal; [Ni (II)]=10 mg/L; 100ºC; 60-min contact time.

Table 1: Parameters of equilibrium for Ni (ii) adsorption upon GASC.

C_0	Ce (Mg/L)				q_e (Mg/L)				Removal %			
	30ºC	40ºC	50ºC	60ºC	30ºC	40ºC	50ºC	60ºC	30ºC	40ºC	50ºC	60ºC
10	1.82	1.47	0.98	0.93	16.36	17.04	18.03	18.13	81.80	85.24	90.15	90.65
20	5.41	4.92	4.44	3.44	29.17	30.15	31.10	33.11	72.94	75.39	77.76	82.77
30	11.24	10.72	9.34	8.65	37.50	38.55	41.31	42.68	62.50	64.25	68.84	71.13
40	17.25	15.78	14.96	14.04	45.48	48.43	50.06	51.91	56.86	60.54	62.57	64.89
50	25.57	24.68	24.14	22.71	48.84	50.62	51.71	54.57	48.84	50.62	51.71	54.57

Table 2: Ni (II) adsorption onto GASC is measured using the Langmuir and Freundlich isotherm parameters.

Model	Constant	Temperature (ºC)			
		30	40	50	60
Freundlich	K_f (mg/g) $(L/mg)^{1/n}$	13.39	15.16	18.48	19.71
	n_f	2.38	2.51	2.88	2.84
	R^2	0.98	0.98	0.98	0.97
Langmuir	q_m (mg/g)	58.60	59.62	58.34	60.91
	K_L (L/mg)	0.18	0.22	0.32	0.36
	R^2	0.99	0.99	0.99	0.99

The Elovich equation

The Elovich model equation is commonly expressed as:

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

Where β is the desorption constant (g/mg) for every trial and α is the starting adsorption rate (mg g^{-1} min^{-1}). A plot of qt Vs ln (t) shows a linear connection with a slope of (1/β) and an intercept of (1/β) ln ($\alpha\beta$) if Ni (II)ion adsorption is caused by the Elovich model. Table 4 provides a summary of the Elovich model parameters α, β, and correlation coefficient (R2). Similar to the initial adsorption rate (h) in pseudo-second-order kinetics models, this model shows that the initial adsorption (α) rises with temperature. This could be because Ni (II) facilitates the GASC adsorbent's pore or active site.

Intra-particle diffusion model

The intra-particle diffusion model was used to further examine kinetic data.

$$log \, R = log \, K_{id} + \alpha \, log \, t \quad (9)$$

Where the thickness of the boundary layer is connected with kid, the intra-particle diffusion rate constant. The adsorption mechanism follows the intra-particle diffusion process, and correlation coefficient values are close to unity, as indicated by the straight-line plot of log R vs log t, which is displayed by the equation above.

DISCUSSION

An appealing and promising method for cleaning industrial and municipal wastewater is adsorption.[12] For particular adsorption systems, adsorption efficiency is associated with both the
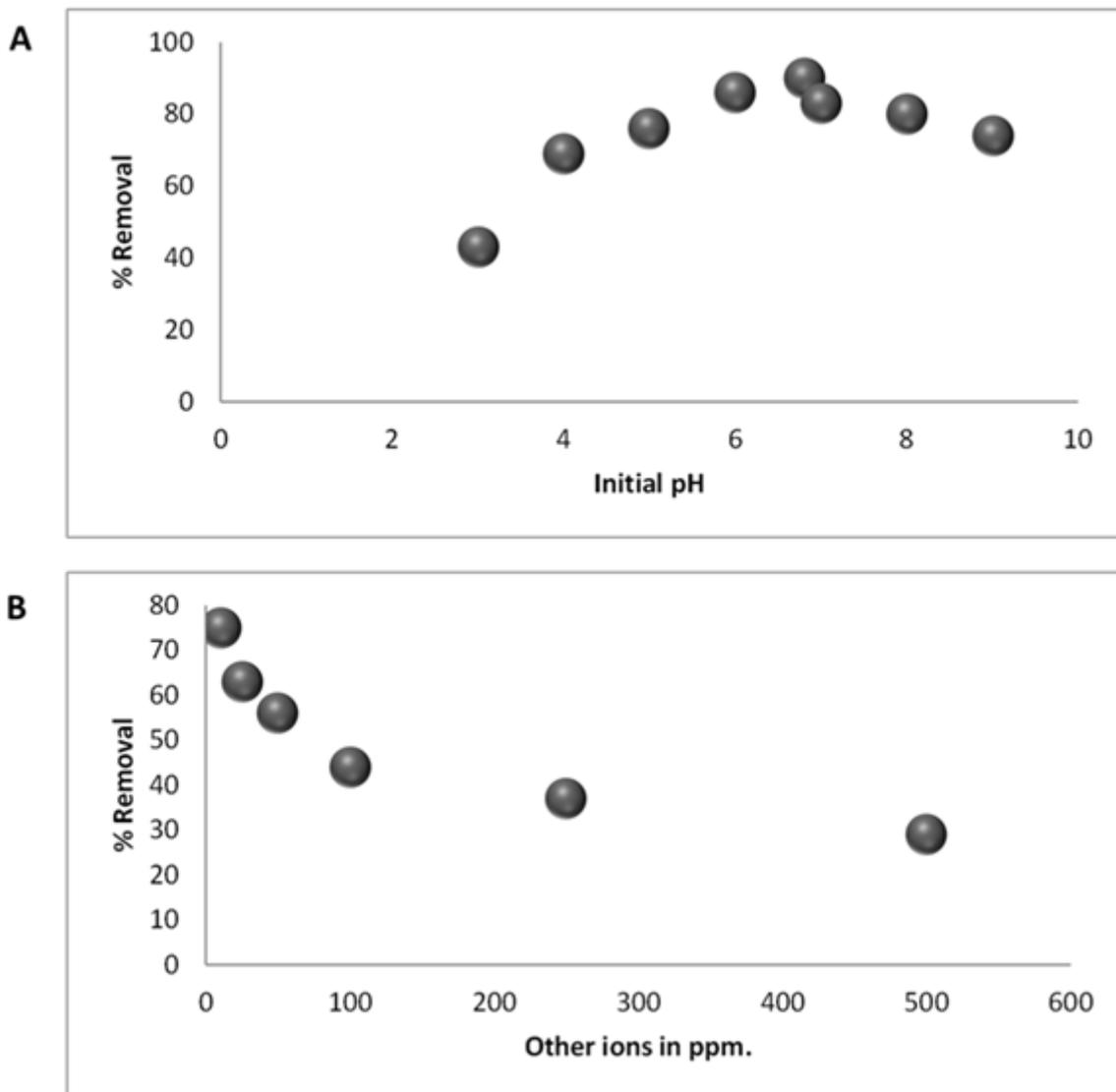

Figure 2: A) Initial pH Impact on Ni (II) Removal; [Ni(II)]=10 mg/L; Temperature: 300ºC; Adsorbent dosage: 0.025 g/50 mL. B) Ionic strength effects on Ni (II) removal; [Ni]=10 mg/L; contact period=60 min; adsorbent dose=0.025 g/50 mL.
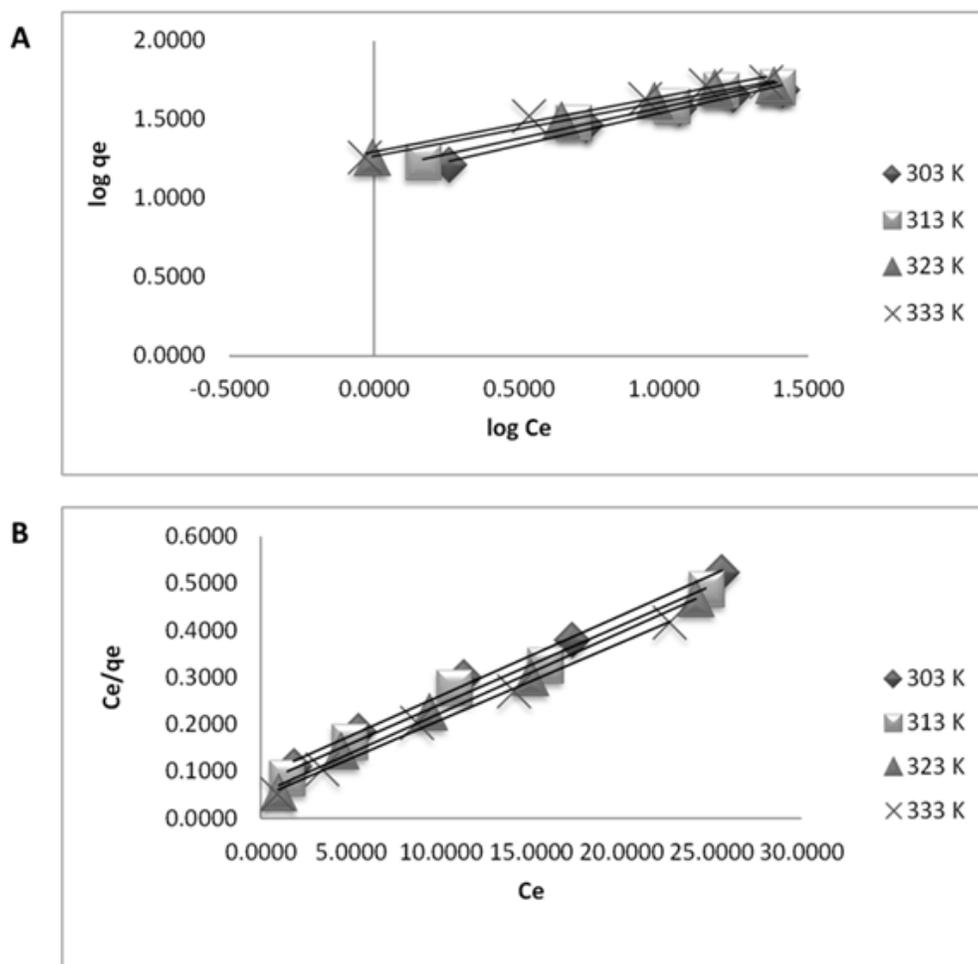
Figure 3: Ni (II) removal using the Freundlich adsorption isotherm (A) and the Langmuir adsorption isotherm (B).

Table 3: Thermodynamic parameter for Ni (ii) adsorption onto GASC.

(C_0)	ΔG°				H	S
	30°C	40°C	50°C	60°C		
10	-3786.16	-4564.16	-5945.89	-6290.41	-23.30	89.46
20	-2498.98	-2914.17	-3361.97	-4346.82	-15.54	59.20
30	-1287.34	-1525.76	-2129.77	-2497.48	-11.55	42.17
40	-695.62	-1114.68	-1380.64	-1701.34	-9.25	32.95
50	116.14	-64.76	-183.93	-508.54	-6.12	19.75

equilibrium characteristics and the kinetics of the adsorption process. To construct industrial reactors, lower operating costs, and learn more about adsorption processes, it is crucial to research adsorption equilibrium and kinetics.[13] Similar attention was paid to our current study of the equilibrium time for maximal removal and to comprehend the removal process kinetics. The Ni (II) ion adsorption in the *Gossypium arboreum* Shell adsorbent (GASC) was examined as a function of contact time.

In recent years, the scientific community has been more interested in the utilization of natural materials for the adsorption of heavy metal ions from aqueous solutions. This is explained by the

fact that nickel compounds are regarded as some of the most hazardous to the environment because of their serious health effects.[14]

It is not always feasible to precisely regulate amounts, concentrations, duration, or pH during the process in an industrial setting. Researchers frequently choose laboratory testing utilizing actual wastewater because of the notable distinctions between sorption processes carried out in laboratory settings and those carried out in industrial settings. Because all tests for choosing the best parameters are conducted in tiny quantities without affecting production, this kind of testing enables cost savings.[14]

This approach yields outcomes that are satisfactory in industrial settings, which is a step in the right direction. Studies on the treatment of actual wastewaters with high concentrations of nickel and other metals, such as post-coalvanic and steel processing wastewaters are especially crucial in the context of real-world applications. Our present data showed that the Ni (II) ion comes into contact with the adsorbent due to several functional groups on its surface. We determined at different pH levels, the ion can be protonated or deprotonated to give distinct charge of surface in the solution. The adsorption mechanism is, therefore, extremely sensitive to pH.

One important property of the pH at which the surface has net electrical neutrality is its pHzpc. It is commonly recognized that negatively charged groups on the adsorbent surface are necessary for cationic Ni (II) ion adsorption. Because GASC is surrounded by H_3O+ ions, it leads to the positively charged at lower pH values (pH pHzpc). Due to the electrostatic force of attraction, this increases the uptake of Ni (II) ions. Finally, the adsorbent's neutral surface allows for the greatest amount of Ni (II) ion removal from the aqueous solution, the starting pH value was chosen at 6.8 for further work. Although anion exchange resin AER was able to quickly adsorb the chloride ions from the solution, its performance declined as the pH of its surroundings rose. The chloride content of the AER was higher than that of the

surrounding cement matrix when it was mixed with the cement mortar, confirming the AER's ability to adsorb chloride ions.

The same effect of chlorine ions on the adsorption was investigated at different concentrations in our study, showed that ions were combined with 50 m/L of Ni (II) ion solutions and left at 30ºC for 60 min, due to Cl-interaction at accessible adsorbent sites via competitive adsorption is in efficient, finally suggested that a low conc of Cl not affect the % of Ni (II) ion adsorption on GASC. The correlation coefficient (R2) values, which vary from 0.946 to 0.965, show that the Freundlich model worked well for the current investigation. The Langmuir adsorption isotherm equation for monolayer adsorption onto a surface. The findings displayed the linear graphs for the adsorption of Ni (II) ions between Ce/qe and Ce. The equilibrium constant (KL) and monolayer capacity (qm), which were calculated from the slope and intercept of these plots and are displayed in Table 2, are in good agreement with the correction coefficient (R2) values.

Even while physical adsorption causes Ni (II) to lower the system's temperature, chemisorptions become less likely as the Ni (II) ion adsorption has developed. The adsorbent GASC contains physiosorbed Ni (II) ions, as shown by the low Hº value. Kinetic models are typically used to examine the adsorption mechanism.[11] If the surface concentrations and the observed concentrations are the same, pseudo-second-order equations

Table 4: The kinetic characteristics of Ni (II) adsorption onto GASC.

| C_0	TempC	Pseudo second order				Elovich model			Intra particle diffusion		
		q_e	k_2	R^2	h			R^2	K_{id}	α	R^2
10	30	22.35	1.79E-03	0.96	0.89	1.9E+00	1.97E-01	0.95	14.43	0.41	0.98
	40	20.70	3.21E-03	0.98	1.37	3.8E+00	2.43E-01	0.95	24.37	0.29	0.98
	50	19.87	6.79E-03	0.99	2.68	2.9E+01	3.65E-01	0.95	43.61	0.17	0.97
	60	19.83	7.36E-03	0.99	2.89	4.0E+01	3.84E-01	0.95	5.27	0.16	0.97
20	30	43.28	6.66E-04	0.90	1.24	2.6E+00	1.02E-01	0.90	9.72	0.47	0.95
	40	41.60	8.91E-04	0.94	1.54	3.2E+00	1.07E-01	0.92	12.68	0.42	0.96
	50	40.80	1.18E-03	0.97	1.95	4.3E+00	1.12E-01	0.96	16.53	0.37	0.98
	60	40.34	1.56E-03	0.97	2.53	6.8E+00	1.23E-01	0.94	3.87	0.30	0.97
30	30	49.27	8.13E-04	0.88	1.97	4.6E+00	9.52E-02	0.82	12.42	0.37	0.88
	40	49.85	1.11E-03	0.97	2.75	6.4E+00	9.34E-02	0.94	15.51	0.34	0.95
	50	55.31	8.72E-04	0.98	2.66	5.6E+00	8.01E-02	0.96	14.12	0.38	0.98
	60	51.57	1.59E-03	0.99	4.23	1.1E+01	9.43E-02	0.98	3.76	0.30	0.97
40	30	60.75	8.87E-04	0.99	3.27	6.3E+00	6.92E-02	0.97	11.19	0.41	0.95
	40	63.43	8.74E-04	0.99	3.51	7.0E+00	6.79E-02	0.99	12.53	0.39	0.97
	50	63.60	1.01E-03	0.99	4.09	8.5E+00	6.96E-02	0.98	14.67	0.36	0.96
	60	65.03	1.06E-03	0.99	4.4884	9.7E+00	6.96E-02	0.98	3.36	0.34	0.96
50	30	74.41	3.35E-04	0.81	1.85	3.8E+00	5.91E-02	0.85	5.49	0.51	0.93
	40	75.59	3.51E-04	0.83	2.00	4.2E+00	5.82E-02	0.86	6.13	0.49	0.93
	50	71.96	4.53E-04	0.86	2.34	5.0E+00	6.16E-02	0.85	7.82	0.43	0.92
	60	76.48	4.08E-04	0.84	2.38	5.0E+00	5.76E-02	0.84	2.44	0.451	0.91
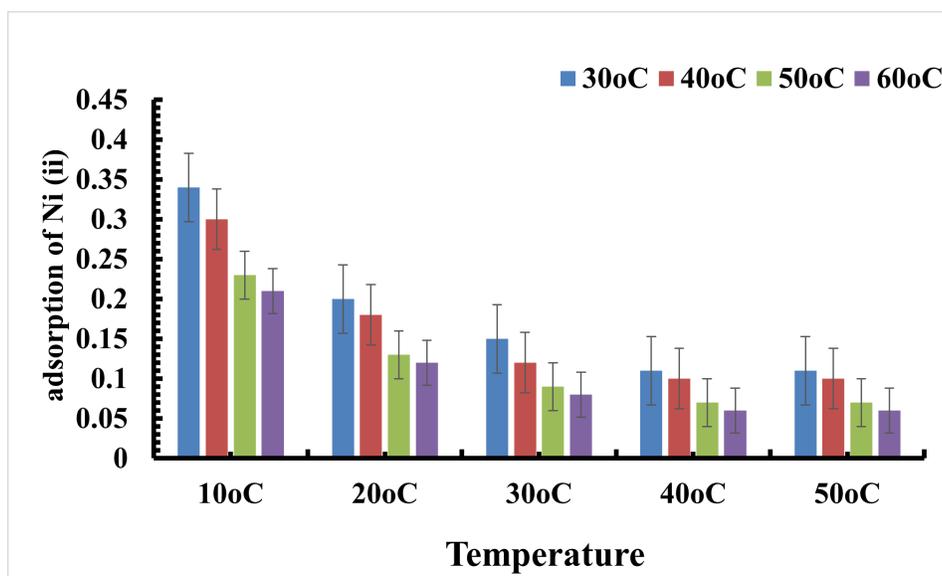
Figure 4: Dimensionless separation factor (r_l) for the adsorption of Ni (ii) onto GASC.

can be applied. The pseudo-second-order equation is produced in a linearized form. Then, Qe and k2 are calculated using the plot's slope and intercept, respectively. The pseudo-second-order adsorption process is indicated by Table 5's high regression value.

The general expression for the Elovich model equation followed Ni (II) ion adsorption is caused by the Elovich model. Reports provided a summary of the Elovich model parameters α, β, and correlation coefficient (R2). This could be because Ni (II) facilitates the GASC adsorbent's pore or active site. Our findings showed the Kinetic data analyzed using the intra-particle diffusion model, with equations of thickness of the boundary layer. Intra particle diffusion process and correlation coefficient values that followed the mechanism of adsorption were close to unity, as indicated by the straight-line plot of log R vs log t, which is displayed by the equation above.

CONCLUSION

Because Ni (II) ions can be effectively removed from aqueous solutions, this work shows that innovative alternative adsorbents are effective in removing heavy metal ions from industrial effluent. Ni (II) ion adsorption onto GASC was expected to be strongly influenced by adsorbent dose, pH, contact time, and other ionic strengths. The Elovich model, intra-particle diffusion models, and pseudo-second-order model Sall fit the adsorption data well, suggesting that a chemical reaction role in the adsorption process. Three stages of diffusion processes were revealed to regulate the adsorption process. The results show that for Ni (II) ion adsorption, physisorption is much more beneficial.

CONFLICT OF INTEREST

The authors declare that there is no conflict of Interest.

ABBREVIATIONS

APSLNC: Activated Pistia stratiotes Leaves Nano Carbon; **GASC:** *Gossypium arboreum* Shell carbon; **pHzpc:** pH zero-point charge; **KL:** Equilibrium constant.

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AUTHOR CONTRIBUTIONS

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

SUMMARY

Novel alternative adsorbents are efficient in removing heavy metal ions from industrial effluent since Ni (II) ions can be successfully extracted from aqueous solutions in our work. Adsorbent dosage, pH, contact time, and other ionic strengths were predicted to have a significant impact on Ni (II) ion adsorption onto GASC. The adsorption data was well-fitted by the Elovich model, intra-particle diffusion models, and pseudo-second-order models, indicating that the adsorption process involved a chemical reaction. The adsorption process was found to be regulated by three stages of diffusion processes. The monolayer adsorption capacity was determined to be 68.616 mg/g, and the isotherm equilibrium data fit the Langmuir isotherm model fairly well. While the positive values of ΔH0 and ΔS0 indicated the endothermic nature, the negative values of ΔG0 for the

thermodynamic parameters showed the spontaneity of the Ni (II) ion adsorption process. This study demonstrates that Ni (II) ions may be extracted from aqueous solutions using Gossypium Arboretum Shell carbon.

REFERENCES

1. Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., *et al.* Water Quality Degradation Due to Heavy Metal Contamination: Health Impacts and Eco-Friendly Approaches for Heavy Metal Remediation. Toxics, 2023;11(10), 828. doi: 10.3390/toxics11100828.

2. Qasem, N.A.A., Mohammed, R.H., Lawal, D.U. Removal of heavy metal ions from wastewater: a comprehensive and critical review. npj Clean Water, 2021;4:36). https://doi.org/10.1038/s41545-021-00127-0.

3. Bazrafshan, E., Mohammadi, L., Ansari-Moghaddam, A., *Amir H.M.* Heavy metals removal from aqueous environments by electrocoagulation process- a systematic review. *J* Journal of Environmental Health Science and Engineering, 2015;13(74). https://doi.org/10.1186/s40201-015-0233-8.

4. Ahmed, A., Huo, A., Ibrahim, M. Progressive Approaches in Ni (II) Contaminated Water Treatment: A Review of Adsorbent Strategies. Water, Air, and Soil Pollution, 2025;236(5). https://doi.org/10.1007/s11270-024-07635-y.

5. Wang, X.S., Huang, J., Hu, H.Q., Wang, J., Qin, Y. Determination of kinetic and equilibrium parameters of the batch adsorption of Ni (II) from aqueous solutions by Na-mordenite. Journal of Hazardous Materials, 2007;142(1-2):468-76, DOI: 10.1016/j.jhazmat.2006.08.047. PMID: 17010513.

6. Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., *et al.* Water Quality Degradation Due to Heavy Metal Contamination: Health Impacts and Eco-Friendly Approaches for Heavy Metal Remediation. Toxics, 2023;11(10), 828. doi: 10.3390/toxics11100828.

7. Charazińska, S., Burszta-Adamiak, E., Lochyński, P. Recent trends in Ni (II) sorption from aqueous solutions using natural materials. Reviews in Environmental Science and Biotechnology, 2022;21:105-38. https://doi.org/10.1007/s11157-021-09599-5.

8. Wang, X.S., Huang, J., Hu, H.Q., Wang, J., Qin, Y. Determination of kinetic and equilibrium parameters of the batch adsorption of Ni (II) from aqueous solutions by Na-mordenite. Journal of Hazardous Materials, 2007;142(1-2):468-76, DOI: 10.1016/j.jhazmat.2006.08.047. PMID: 17010513.

9. Omo-Okoro, P.N., Curtis, C.J., Karásková, P. Lisa, P.K, Opeyemi A.O., Jonathan O.O. Kinetics, Isotherm, and Thermodynamic Studies of the Adsorption Mechanism of PFOS and PFOA Using Inactivated and Chemically Activated Maize Tassel. Water, Air, and Soil Pollution, 2020;231(485), https://doi.org/10.1007/s11270-020-04852-z.

10. Tran, H, N., Bonilla-Petriciolet, A. Improper Estimation of Thermodynamic Parameters in Adsorption Studies with Distribution Coefficient KD (qe/Ce) or Freundlich Constant (KF): Considerations from the Derivation of Dimensionless Thermodynamic Equilibrium Constant and Suggestions. *Adsorption Science and Technology*. 2022; 2022, doi:10.1155/2022/5553212.

11. Asanu, M., Beyene, D., Befekadu, A., Oueslati, W. Removal of Hexavalent Chromium from Aqueous Solutions Using Natural Zeolite Coated with Magnetic Nanoparticles: Optimization, Kinetics, and Equilibrium Studies. Adsorption Science and Technology, 2022; 2022. doi:10.1155/2022/8625489.

12. Kato, S., Kansha, Y. Comprehensive review of industrial wastewater treatment techniques, Environ Sci Pollut Res Int, 2024;31(39):51064-97. doi: 10.1007/s11356-024-34584-0.

13. Lima, É.C., Adebayo, M.A., Machado, F.M. Kinetic and Equilibrium Models of Adsorption. In: Bergmann, C., Machado, F. (eds) Carbon Nanomaterials as Adsorbents for Environmental and Biological Applications, Carbon Nanostructures. Springer, Cham. 2015https://doi.org/10.1007/978-3-319-18875-1_3

14. Charazińska, S., Burszta-Adamiak, E. and Lochyński, P. Recent trends in Ni (II) sorption from aqueous solutions using natural materials, Rev Environ Sci Biotechnol, 2022;21;105-38. https://doi.org/10.1007/s11157-021-09599-5.