

## **BIOSORPTION OF Cr(VI) FROM SYNTHETIC WASTEWATER USING THE FRUIT SHELL OF GULMOHAR (*Delonix regia*): APPLICATION TO ELECTROPLATING WASTEWATER**

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The biosorption of Cr(VI) from synthetic solutions and electroplating wastewater using the fruit shell of gulmohar has been investigated in a batch system. The effects of various parameters such as pH, contact time, adsorbent dosage, and initial concentration of Cr(VI) on the biosorption process were studied. The complete removal of Cr(VI) was observed at  $\text{pH} < 3.0$ . Studies indicated that both biosorption and bioreduction were involved in the removal of Cr(VI). The sorption equilibrium exhibited a better fit to the Langmuir isotherm than the Freundlich isotherm. The maximum biosorption capacity of fruit shell of gulmohar to remove Cr(VI) was 12.28 mg/g. A kinetic model of pseudo-second order provided a good description of the experimental data as compared to a pseudo-first order kinetic model. The sorption rate was found to be dependent on the initial concentration of Cr(VI) and biomaterials dosage. The study showed that the abundant and inexpensive fruit shell of gulmohar biosorbent has a potential application in the removal of Cr(VI) from electroplating wastewater and its conversion into less or non-toxic Cr (III).

*Keywords: Chromium; Gulmohar; Biosorption; Electroplating; Adsorption isotherm; Adsorption kinetics*

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### **INTRODUCTION**

Heavy metals are present in different types of industrial effluents, being responsible for environmental pollution (Lohani et al. 2008). Industrial wastewater often contains considerable amount of heavy metals that are recognized as dangerous contaminants because of their high toxicity, accumulation, and retention in the human body (Ghodbane and Hamdaoui 2008).

Chromium is one of such metals known to be carcinogenic and has an adverse potential to modify the DNA transcription process. It is also reported to cause epigastric pain, nausea, vomiting, severe diarrhoea, and haemorrhage (Dakiky et al. 2002).

Chromium, in particular, is present in mining, metal-finishing and electroplating operations, and is also used in the manufacturing of pigments, leather, print films, and catalysts (Vieira et al. 2008). The chromium electroplating process is one of the largest sources of Cr(VI) released to the environment. In this process a layer of chromium is electro-deposited on a base material to provide a surface with decorative or functional properties such as wear and corrosion resistance, low friction, and hardness (Alvarez-Ayuso et al. 2007).

Hexavalent chromium is much more toxic than trivalent chromium (Lalvani et al. 1998). Therefore, the removal or reduction of Cr(VI) to Cr(III) serve as key processes for removal of Cr(VI)-contaminated water and wastewater (Owlad et al. 2009).

According to Indian standards (1974), the permissible limit of chromium for industrial effluent discharge into inland surface water is 0.10 and into public sewers is 2.00 mg/L. According to USEPA (1990), the tolerance limit to discharge chromium into inland surface water is 0.10 mg/L and in drinking water 0.05 mg/L (Sud et al. 2008).

Conventional methods for removing heavy metals such as activated carbon adsorption, chemical oxidation/ reduction, precipitation, ion exchange, electrochemical processes, membrane filtration, and reverse osmosis from waste streams have a few major disadvantages, such as high energy requirements, incomplete metal removal, and generation of toxic sludge that needs proper disposal, in addition to financial constraints (Kadirvelu et al. 2001; Volesky. 2001; Li et al. 2008).

Compared with these techniques, biosorption has emerged as an attractive alternative to combat heavy metal contamination because of its good selectivity, high efficiency, low cost, broad applicability, and strong ability of precious metal ion recovery (Kiran and Kaushik 2007; Yin et al. 2008).

The present study investigates the biosorption of Cr(VI) by the fruit shell of gulmohar. The effects of different parameters such as the pH of the solution, the initial concentration of the metal, the dose of the adsorbent, and the contact time were examined. The interference of other ions on the biosorption process was investigated. The application of the biosorption process to electroplating wastewater using the gulmohar fruit shell was investigated.

## **EXPERIMENTAL**

### **Adsorbent Preparation**

The fruit shells of gulmohar were collected from the trees on the campus of the University of Mysore, India. The shells were washed several times with 0.1 M HCl and deionized water to remove impurities and other adhered particles on the surface of the adsorbent. The shells were air-dried, crushed, and powdered using a domestic mixer. The powdered materials were stored in airtight plastic bottles for further use as biosorbents without any chemical or physical treatment.

### **Chromium Solution Preparation**

An aqueous solution of hexavalent chromium was prepared by dissolving potassium dichromate ( $K_2Cr_2O_7$ ) salt to obtain a stock solution of 1000 mg/L. This solution was used for further preparation of experimental solutions. The initial pH of each solution was adjusted to the desired values using 0.1 M HCl or 0.1 NaOH.

### **Metal Plating Wastewater**

Wastewater was collected from after the rinsing stage of a nickel/chromium electroplating unit located in Mysore, India. In the plating process, chromium was used

simply to protect and coat a nickel metal surface. The physicochemical characteristics of the wastewater are shown in Table 1.

**Table 1.** Physicochemical Characteristics of Electroplating Rinse Wastewater

Contents in mg/L									pH	Conductivity ( $\mu\text{S/cm}$ )
Cr (VI)	Ni <sup>2+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Na <sup>+</sup>	K <sup>+</sup>	TDS		
7.70	177.6	126.2	56.1	159.7	26.78	63.8	3.14	790	7.19	1670

### Batch Biosorption Experiments

Batch biosorption experiments were carried out by contacting 0.2 g of adsorbent with 50 mL of chromium solution ( $C_i = 40$  mg/L) in 100 mL Erlenmeyer flasks. The flasks were shaken at 200 rpm on a rotary shaker for a period of 8 hours at  $28 \pm 1$  °C. The suspensions were filtered, and the concentration of Cr(VI) and total chromium ions in the filtrate were analyzed calorimetrically using the 1,5-diphenylcarbazide method (Clesceri et al. 1998). The Cr(III) content in the solutions was calculated by subtracting the concentration of Cr(VI) from that of total chromium.

Preliminary experiments on the effect of pH on the removal of Cr(VI) showed that the maximum removal efficiencies were obtained under strongly acidic conditions, and no significant removal was recorded under alkaline or neutral conditions. Thus, the effect of pH on the biosorption of Cr(VI) was investigated by varying the pH values in the range of 1.0 to 6.0. Adsorption isotherm experiments were conducted by varying the concentration of Cr(VI) solutions from 20 to 120 mg/L. The total chromium uptake was calculated from the mass balance equation as follows,

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

where  $q_e$  is the metal ion adsorbed (mg metal ion/ g biosorbent) at equilibrium,  $V$  is the volume of the solution (L),  $C_i$  and  $C_e$  are the initial and equilibrium concentration of metal ion (mg/L), respectively, and  $m$  is the dry weight of the biosorbent (g). A control experiment was carried out under the same conditions in the absence of biosorbent, and there was no change observed in the chromium concentration in this experiment.

### Adsorption Kinetics

Two sets of experiments were conducted to study the adsorption kinetics of Cr(VI) by the biosorbent. In one set, the biomass concentrations were varied, resulting in the proportions of 4.0, 6.0, and 8.0 g of biomass/L of chromium solution ( $C_i = 40$  mg/L). Another set was made at two different initial concentrations of hexavalent chromium (20 and 60 mg/L), whereas the concentration of biomaterial was kept as 4 g/L. The solution samples were collected at regular time intervals, filtered, and the filtrates were analyzed immediately after separation as mentioned above. All kinetic biosorption experiments

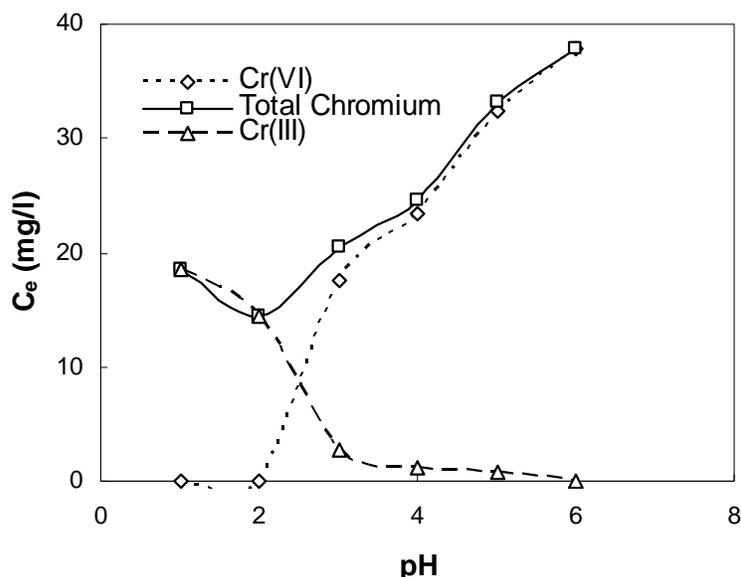
were carried out in 250 ml Erlenmeyer flasks containing 100 ml of Cr(VI) solutions at the optimum pH of 2.0.

## RESULTS AND DISCUSSION

### Effect of pH

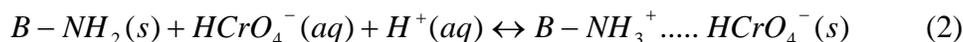
Earlier studies of heavy metal biosorption have shown that solution pH is the single most important parameter affecting the biosorption process (Chen et al. 2004; Li et al. 2009; Wang et al. 2009).

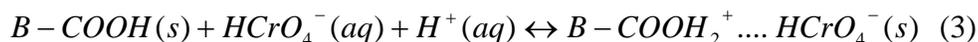
Figure 1 shows the effect of pH on the biosorption of Cr(VI) by the fruit shell of gulmohar. Complete removal of Cr(VI) is shown under strongly acidic conditions (pH<3.0), whereas negligible removal was observed when the pH was increased to 6.0.



**Fig. 1.** Effect of pH on the final concentration of total chromium, Cr(VI) and Cr(III) during the biosorption of Cr(VI) by gulmohar's fruit shell ( $C_i = 40$  mg/L; adsorbent dose = 4 g/L; 200 rpm; time = 480 minutes)

Hexavalent chromium exists as  $\text{CrO}_4^{2-}$ ,  $\text{HCrO}_4^-$ ,  $\text{H}_2\text{CrO}_4$ , and  $\text{Cr}_2\text{O}_7^{2-}$  in solution. In low pH solutions,  $\text{HCrO}_4^-$  is the prevalent form hexavalent chromium, which subsequently shifts to other forms such as  $\text{CrO}_4^{2-}$  and  $\text{Cr}_2\text{O}_7^{2-}$  as the pH increases (Prabhakaran et al. 2009). At lower pH, the carboxyl and amino groups on the surface of biomass are protonated, which results in a strong electrostatic attraction between Cr(VI) anions and positively charged biosorbent. With the aid of protons in aqueous solution, amino and carboxyl groups present on the surface of biomaterial ( $B$ ) can bind Cr(VI) anions as follows (Park et al. 2008);





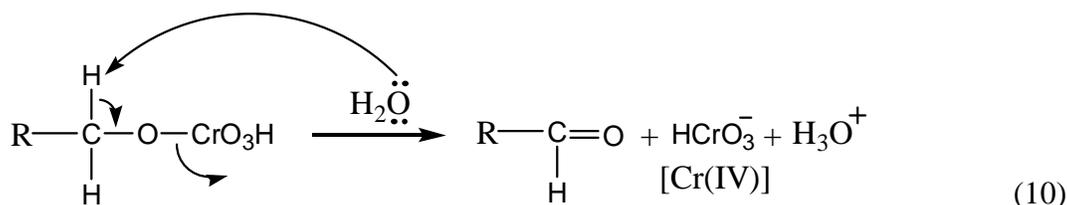
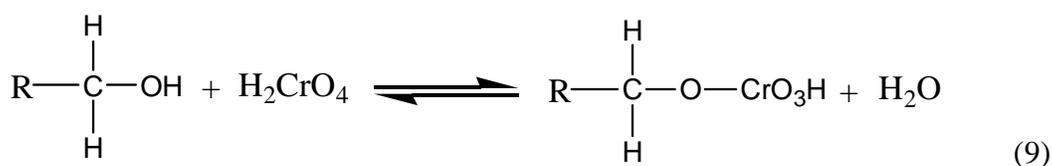
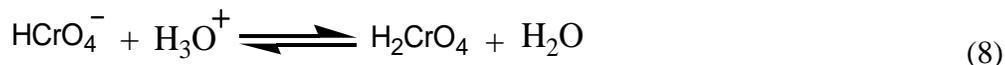
In alkaline and neutral solutions the efficiency of negatively charged biosorbent to bind negatively charged Cr(VI) anions will be low due to repulsive force. However, in acidic solutions, the protonated biosorbent will be available for the biosorption of chromium anions.

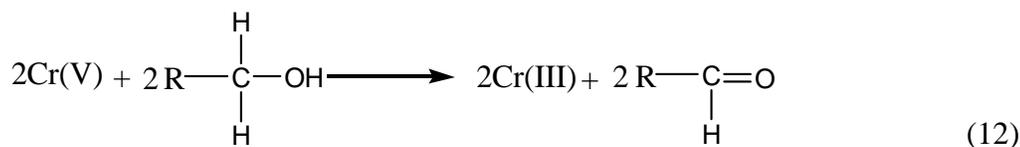
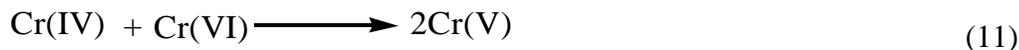
Figure 1 also shows the existence of Cr(III), which had not initially been present in the solution. The presence of Cr(III) in the solution indicates the reduction of Cr(VI) to Cr(III) when it contacted with biosorbent. The acidic pH accelerates the redox reaction in the aqueous and solid phases, as a result of proton participate in this reaction (Park et al. 2008). The chromium reduction can take place as follows (Cabatingan et al. 2001):



It can be stated that the mechanism of Cr(VI) removal by biomaterials in acidic medium is not only an anionic adsorption but an adsorption-coupled reduction process. A similar trend was reported by Sharma and Forster (1993), Zhao and Duncan (1997), Cabatingan et al. (2001), Park et al. (2007), Namasivayam and Sureshkumar (2008), Blazquez et al. (2009), Chand et al. 2009, and Prabhakaran et al. (2009).

It is well known that the plants cell wall mainly consists of cellulose, with has primary alcohol groups. The alcoholic group has been reported as the electron-donor group of the biosorbent (Park et al. 2008). This group in the acidic condition can be oxidized by Cr(VI), which will be reduced to Cr(III). The mechanisms of these processes are given as in the following sequences,





The maximum removal efficiency of the biosorbent for the removal of total chromium was observed within the pH range 2.0 to 3.0 (Fig.1). The low removal efficiency of total chromium at pH less than 2.0 can be due to the fact that the Cr(VI) will be reduced to Cr(III) under this acidic condition. The resulting Cr(III) cations can't adsorb on the protonated surface of the biomass due to the repulsive force, leading to low total chromium removal.

The decrease in the biosorption with the increase of pH is due to deprotonation of the biosorbent surface, which leads to a decrease in electrostatic force of attraction between the sorbent and sorbate ions.

### Adsorption Isotherm

Due to difficulties in the determination of Cr(VI) and Cr(III) on the surface of the biosorbent, the isotherms are drawn based on total chromium disappearance from the solutions. In this study, two important sorption isotherm models were selected to fit experimental data, namely the Langmuir and Freundlich isotherm models.

The Langmuir isotherm model (Langmuir 1918) is based on the assumption that a maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, that the energy of adsorption is constant, and that there is no transmigration of adsorbate in the plane of the surface. The Langmuir isotherm is given by the following equation,

$$\frac{C_e}{q_e} = \frac{1}{K_L \cdot q_{\max}} + \frac{C_e}{q_{\max}} \quad (13)$$

where  $q_{\max}$  is the maximum biosorption capacity of adsorbent (mg/g) and  $K_L$  is the Langmuir biosorption constant (L/mg), which are determined from the slope and intercept, respectively, of the linear plot of  $C_e/q_e$  versus  $C_e$ . The values of the Langmuir parameters  $q_{\max}$  and  $K_L$  were calculated to be 12.28 mg/g and 0.068 L/g.

The essential feature of the Langmuir isotherm model can be expressed by means of a separation factor or equilibrium parameter  $R_L$ , which is calculated according to the following equation:

$$R_L = \frac{1}{1 + K_L C_i} \quad (14)$$

The value of  $R_L$  indicates the type of biosorption isotherm to be linear ( $R_L = 1$ ), favorable ( $0 < R_L < 1$ ), unfavorable ( $R_L > 1$ ), or irreversible ( $R_L = 0$ ). The  $R_L$  value for the adsorption of Cr(VI) onto the biosorbent was 0.423 at an initial concentration of 20 mg/L, and 0.109 at an initial concentration of 120 mg/L, indicating favorable adsorption of Cr(VI) onto the surface of gulmohar's fruit shell. A comparison of the maximum adsorption capacity of various biosorbents, including gulmohar's fruit shell, is summarized in Table 2.

**Table 2** Comparison of Biosorption Capacity of Gulmohar's Fruit Shell for Cr(VI) Removal with that of Different Biosorbents

Adsorbent	pH	$q_{\max}$ (mg/g)	References
Pine needles	2.0	21.5	Dakiky <i>et al.</i> 2002
Biogas residual slurry	2.0	40.0	Namasivayam and Yamuna 1995
<i>Chlorella vulgaris</i>	2.0	24.0	Veglio and Beolcini 1997
Spirogyra	2.0	14.7	Kratochvil and Volesky 1998
Sugar cane bagasse	2.0	13.4	Sharma and Forster 1994b
Hazelnut shell	2.0	17.7	Cimino <i>et al.</i> 2000
Leaf mould	1.5	27.6	Sharma and Forster 1994a
<i>Rhizopus arrhizus</i>	2.0	8.8	Loukidou <i>et al.</i> 2004
Eucalyptus bark	2.0	45.0	Sarin and Pant 2006
<i>Ceramium virgatum</i>	1.5	26.5	Sari and Tuzen 2008
Waste pomace of olive oil factory	2.0	13.9	Malkoc <i>et al.</i> 2006
Gulmohar's fruit shell	2.0	12.28	Present study

The Freundlich isotherm model (Freundlich 1907) was applied to study the biosorption behavior, assuming a heterogeneous adsorption surface and active sites with different energy, and its linearized equation can be given as:

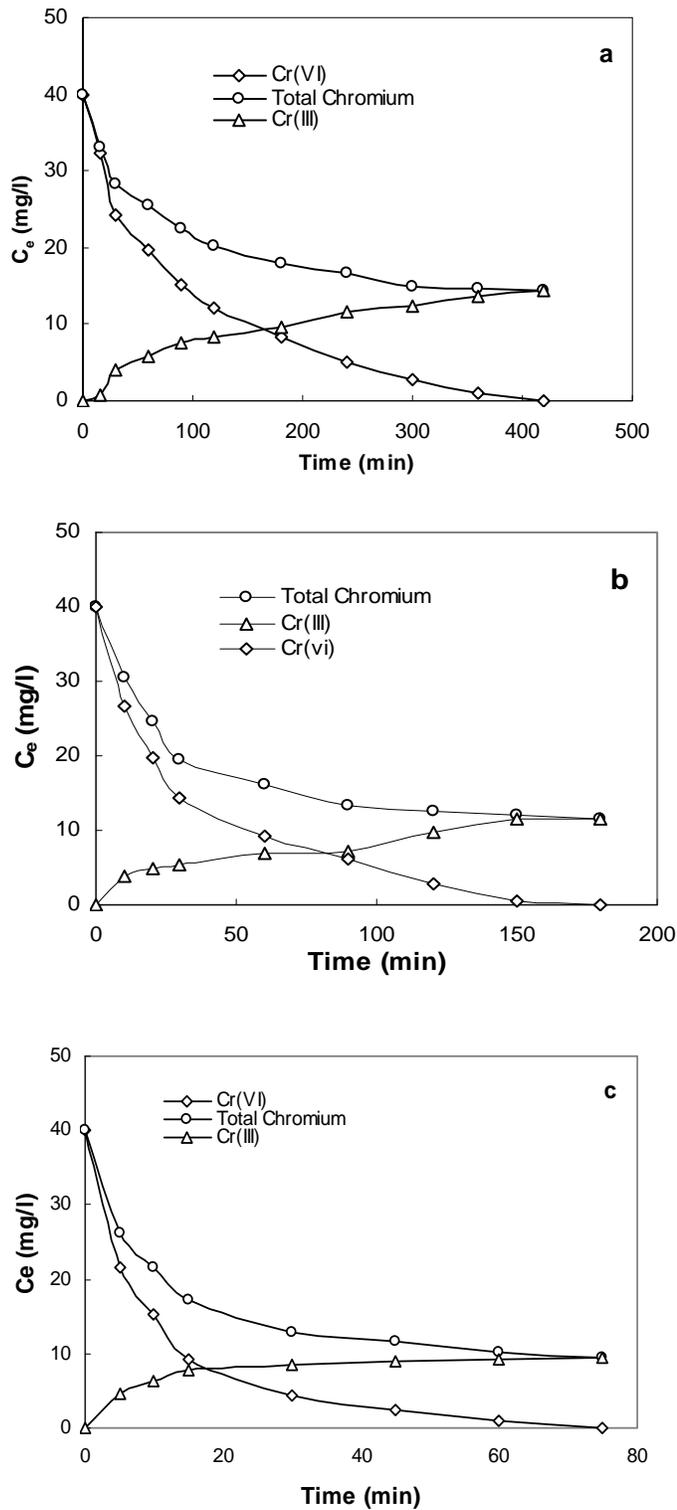
$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (15)$$

where  $K_f$  is a constant is related to the biosorption capacity and  $n$  is an empirical parameter related to the biosorption intensity of the adsorbent. The Freundlich isotherm constants  $n$  and  $K_f$  were calculated from the slope and intercepts of the linear plot of  $\log q_e$  versus  $\log C_e$  and found to be 2.50 and 1.95, respectively.

The values of coefficient of determination ( $R^2$ ) of both models indicated that the Langmuir adsorption isotherm model ( $R^2 = 0.996$ ) exhibited a better fit to the equilibrium data than the Freundlich isotherm model ( $R^2 = 0.964$ ). Therefore, the biosorption process of Cr(VI) by gulmohar's fruit shell can be interpreted as monolayer adsorption.

### Adsorption Kinetics

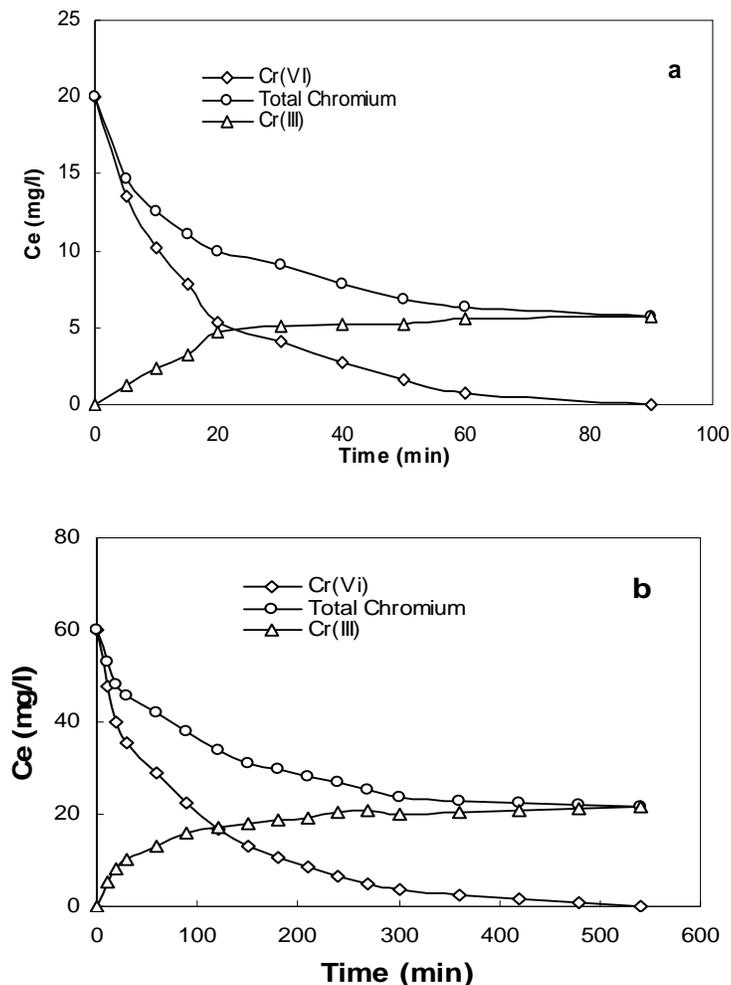
Kinetic studies were conducted for different biosorbent dosages and different initial concentrations of Cr(VI). Figures 2 (a), (b), and (c) present the concentration decay of Cr(VI) as a function of time at different adsorbent dosages.



**Fig. 2.** Effect of time on chromium concentrations during biosorption of Cr(VI) by gulmohar's fruit shell at (a) 4 g/L, (b) 6 g/L and (c) 8 g/L (pH = 2.0; initial concentration of Cr(VI) = 40 mg/L; agitation speed = 200 rpm)

The results showed that the Cr(VI) was completely removed from the aqueous solution within the contact times of 240, 180, and 75 minutes for 4, 6, and 8 g/L of biosorbent dosage, respectively. A high dosage of biosorbent shortened the equilibrium time and increased the removal efficiency of total chromium. The Cr(III) ions, which were not initially present in the solution, were found to increase with time, indicating the simultaneous biosorption and bioreduction of Cr(VI) by gulmohar fruit shell. It can be observed from the Figs. 2 (a), (b), and (c) that the total chromium in the solutions was in the form of Cr(III) at equilibrium for all biosorbent dosages. There were no significant differences in the amount of Cr(III) resulting from the reduction of Cr(VI) with increase in the biosorbent concentration. Irrespective of the concentrations of biosorbent, the low removal efficiency of total chromium at lower pH values is due to the fact that the resulting Cr(III) cations can't be adsorbed on the protonated surface of biomass, due to the repulsion force, leading to low total chromium removal as mentioned above.

Figures 3 (a) and (b) show the remaining concentration of chromates in the solution as a function of time at the initial concentrations of Cr(VI).



**Fig. 3.** Effect of time on chromium concentrations during biosorption of Cr(VI) by gulmohar's fruit shell at (a) 20 mg/L and (b) 60 mg/L (pH = 2.0; adsorbent dosage = 4 g/L; agitation speed = 200 rpm)

The results showed that the removal of Cr(VI) versus equilibrium time was dependent on the initial chromium concentration. The equilibrium time was found to be 90 and 540 minutes for 20 and 60 mg/L of chromium concentration, respectively. An increase in the initial Cr(VI) concentration decreased the removal efficiency of total chromium. This may be attributed to lack of sufficient surface area to accommodate much more metal available in the solution (King et al. 2008).

The results obtained from kinetic experiments were analyzed using pseudo-first-order and pseudo-second-order kinetic models. The linear form of pseudo-first order kinetic model (Lagergren 1898) is generally expressed as,

$$\log(q_e - q_t) = \log q_e - \frac{K_{1,ads}}{2.303} t \quad (16)$$

where  $q_t$  (mg/g) is the amount of metal ion adsorbed at time  $t$ , (min),  $q_e$  is the amount of metal ion adsorbed at equilibrium (mg/g), and  $K_{1,ads}$  is the constant of the pseudo first-order kinetic model ( $\text{min}^{-1}$ ). The values of  $K_{1,ads}$  and  $q_e$  can be obtained from the slope and intercept of the plot of  $\log(q_e - q_t)$  versus  $t$ , respectively.

The linear form of the pseudo-second-order kinetic model (Ho and McKay 2000) is given as,

$$\frac{t}{q_t} = \frac{1}{K_{2,ads} \cdot q_e^2} + \frac{1}{q_e} \cdot t \quad (17)$$

where  $K_{2,ads}$  is the constant of pseudo second-order kinetics ( $\text{g mg}^{-1} \text{min}^{-1}$ ). The values of  $K_{2,ads}$  and  $q_e$  can be calculated from the slope and intercept of the plot of  $(t/q_t)$  versus  $t$  (Figs. 4 (a) and (b)).

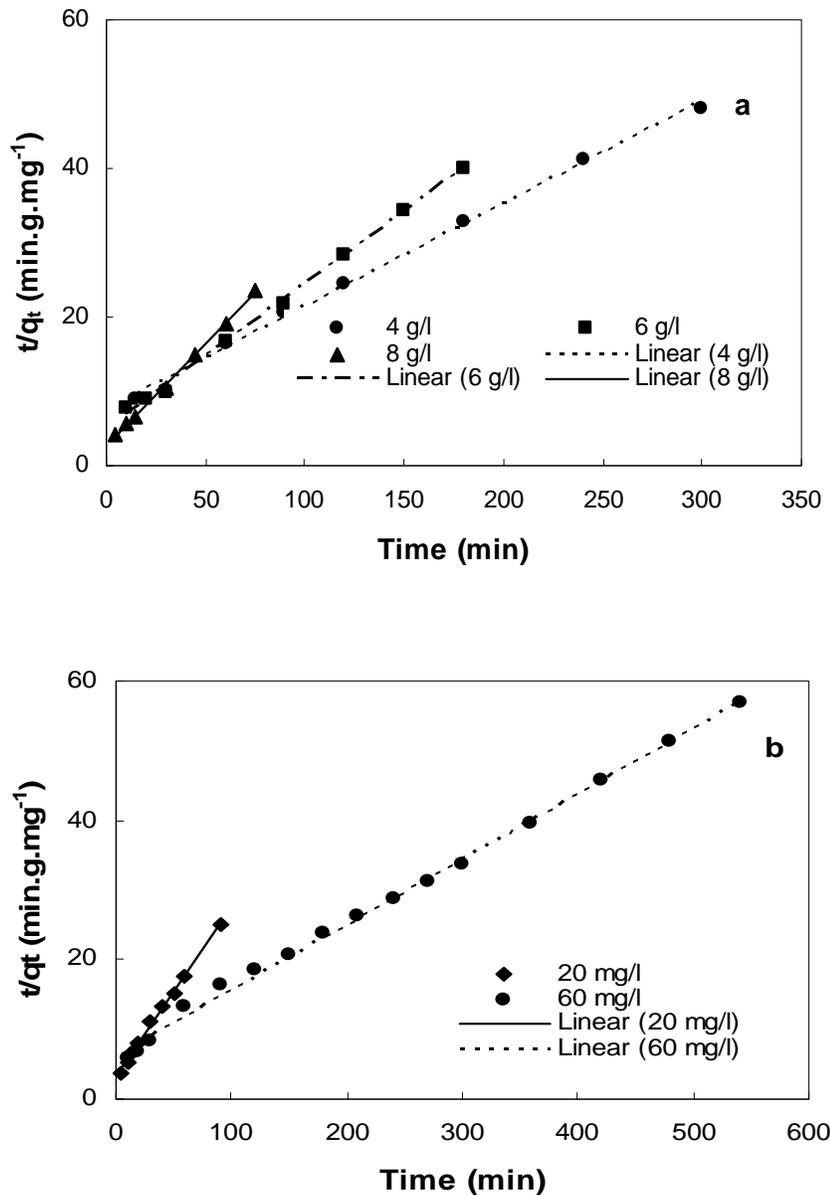
The values of the parameters along with coefficient of determination for each kinetic model are tabulated in Table 3.

**Table 3.** Parameter Values Calculated Using the Pseudo First-order and Pseudo Second-order Kinetic Models for the Biosorption of Cr(VI) by Gulmohar's Fruit Shell

Parameters	Pseudo first-order kinetic model			Pseudo second-order kinetic model		
	$K_{1,ads}$ ( $\text{min}^{-1}$ )	$q_e$ ( $\text{mg.g}^{-1}$ )	$R^2$	$K_{2,ads}$ ( $\text{g.mg}^{-1}.\text{min}^{-1}$ )	$q_e$ ( $\text{mg.g}^{-1}$ )	$R^2$
Adsorbent dosage ( $\text{g.l}^{-1}$ )*						
4	0.014	7.384	0.918	0.003	7.220	0.998
6	0.015	3.181	0.957	0.007	5.151	0.996
8	0.063	2.434	0.990	0.031	3.602	0.999
Initial Cr(VI) concentration ( $\text{mg.l}^{-1}$ )**						
20	0.046	2.894	0.982	0.020	4.050	0.998
60	0.008	8.169	0.995	0.001	10.67	0.997

\* Conditions:  $C_i = 40$  mg/L; pH = 2; rpm = 200, temperature =  $28 \pm 2$ .

\*\* Conditions: biosorbent dose = 4 g/L; pH = 2; rpm = 200, temperature =  $28 \pm 2$ .



**Fig. 4.** Pseudo second-order kinetic plot for the sorption of chromium by gulmohar's fruit shell at pH =2.0 for: (a) different biosorbent concentrations, and (b) different Cr(VI) concentrations

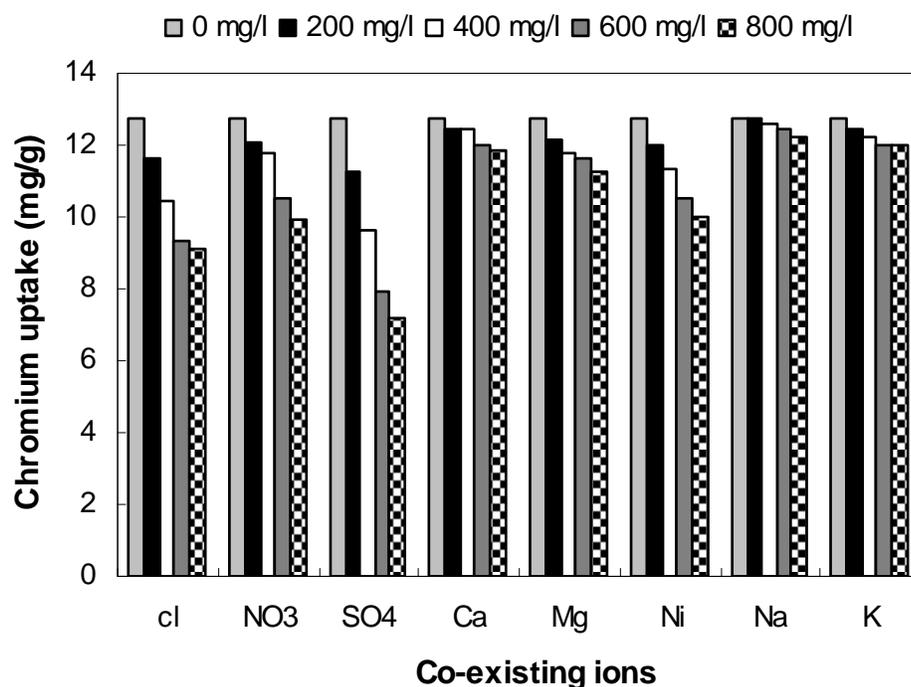
It is clear from the table that the coefficient of determination of the pseudo-second-order model was higher in comparison to that of the pseudo-first-order model. This suggests that the pseudo-second-order kinetic model fitted the biosorption kinetic data of Cr(VI) onto gulmohar's fruit shell better than the pseudo-first-order kinetic model. The adsorption rate increases with an increase of biosorbent dosage and decreases with an increase in initial concentration of Cr(VI).

### Interference of Competitive Ions on the Binding of Cr(VI)

Wastewaters generated by industries often contain other ions along with heavy metals. The sorption of metal ions in the presence of other common ions may be affected due to competition for the sorption sites (Malik et al. 2005).

For the determination of any interference caused by other ions on the biosorption of chromium by gulmohar's fruit shell, experiments were conducted under optimized biosorption conditions in the presence of cations ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Ni}^{2+}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ ) and anions ( $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , and  $\text{Cl}^-$ ). The sodium salt of anions and nitrates of cations were added with Cr(VI) in the solutions. The concentrations of different ions were varied from 200 to 800 mg/L. A control experiment was carried out under the same conditions without addition of other ions.

The effects of ions on the chromium uptake by gulmohar fruit shell are demonstrated in Fig. 5. The results showed insignificant effects of cations on the biosorption of total chromium by gulmohar fruit shell. This can be explained by the fact that the overall surface charge on the biosorbent become positively charged at pH 2.0, which will inhibit the approach of positively charged metal cations as a result of repulsive force (Arshad et al. 2008). Anions reduced the removal efficiency under the given experimental conditions. The inhibition by divalent  $\text{SO}_4^{2-}$  was more than that of monovalent  $\text{Cl}^-$  and  $\text{NO}_3^-$ . This inhibition is due to competition of the anions with Cr(VI) for the available binding sites on the surface of gulmohar's fruit shell.



**Fig.5.** Effect of co-ions on the chromium uptake by gulmohar's fruit shell (pH=2.0, concentration of Cr(VI) = 40 mg/L, concentration of biosorbent = 4 g/L, agitation speed = 200 rpm).

### **Application to Electroplating Wastewater**

In order to assess the practical performance of gulmohar's fruit shell for the removal of Cr(VI) from electroplating wastewater, an experiment was carried out after adjusting the pH of wastewater to pH 2.0, at which the maximum adsorption of hexavalent and total chromium can be achieved. 4 g/L of gulmohar's fruit shell was contacted with the wastewater sample for the time of two hours. The result showed a total absence of Cr(VI) from electroplating rinse wastewater, which indicated that gulmohar's fruit shell was very efficient for removal of hexavalent chromium from rinsing wastewater of the plating factory. The biosorption efficiency was the same as in the synthetic solutions, indicating less competition of other ions present in the wastewater for the binding sites.

### **CONCLUSIONS**

1. Gulmohar's fruit shell was found to be an effective biosorbent for the removal of chromium from aqueous solution and electroplating wastewater.
2. The results obtained from the present study revealed that the sorption efficiency was dependent on operating conditions, such as pH, contact time, biosorbent dosage, and initial metal concentration.
3. The process was strongly pH-dependent. The complete removal of Cr(VI) was found at a  $\text{pH} < 3.0$ . The mechanism that governs the complete removal of Cr(VI) by gulmohar's fruit shell was sorption-coupled reduction.
4. The adsorption isotherm could be adequately described by the Langmuir isotherm.
5. The kinetic data were well described by pseudo second order kinetics.
6. The adsorption rate increases with an increase of biosorbent dosage and decreases with an increase in initial concentration of Cr(VI).
7. The presence of cations does not significantly interfere with binding of Cr(VI) by gulmohar's fruit shell, whereas anions decreased the biosorption efficiency.
8. The application of the gulmohar's fruit shell for the removal of Cr(VI) from electroplating wastewater was found to be technically feasible, economically viable, and eco-friendly, compared to the existing treatment processes.

### **ACKNOWLEDGMENTS**

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