

# Selective Sorption of Fe(III) Using Modified Forms of Chitosan Beads

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**ABSTRACT:** Modified chitosan beads (CB) were prepared and used for the removal of Fe(III) ions from aqueous solution. The advantages of modified CB than raw CB have been explored. The sorption capacity (SC) of the modified forms of CB namely, protonated CB, carboxylated CB, and grafted CB were found to be 3533, 3905, and 4203 mg kg<sup>-1</sup>, respectively, while the raw CB showed the SC of 2913 mg kg<sup>-1</sup> only. Batch adsorption studies were conducted to optimize various equilibrating conditions like contact time, pH, and coions. The sorbents were characterized by FTIR, WDXRF, and SEM with EDAX analysis.

The sorption process has been explained with Freundlich and Langmuir isotherms. Thermodynamic parameters such as  $\Delta G^\circ$ ,  $\Delta H^\circ$ , and  $\Delta S^\circ$  were calculated to understand the nature of sorption. Modified CB are more selective for Fe(III) than Cu(II), which in turn higher than Cr(VI). A suitable mechanism for iron sorption onto modified CB was established. © 2011 Wiley Periodicals, Inc. *J Appl Polym Sci* 124: 1858–1865, 2012

**Key words:** chitosan beads; iron removal; sorption; ion exchange; chelation

## INTRODUCTION

Water contamination with heavy metals generates environmental problems because of their high toxicity and nonbiodegradability, which cause a high persistence. Heavy metals have a tendency for bioaccumulation and end up as permanent additions to the environment.<sup>1</sup> Iron is one of the heavy metals and is found in manufacturing industries such as metal polishing and galvanized pipes.<sup>2</sup> The presence of iron in ground and industrial water becomes toxic at high level, which may cause environmental and human health problems.<sup>2–4</sup> There are various technological methods for removing heavy metal ions from water and waste water including supercritical fluid extraction,<sup>5</sup> bioremediation,<sup>6</sup> adsorption, and oxidation with oxidizing agents.<sup>7</sup> Sorption is a cost-effective technique and simple to operate.<sup>8–11</sup> Abundant natural polymers or agriculture waste product can be economically used as potential biosorbents for heavy metals.

Extensive research has evaluated a variety of biosorbents like fungi, yeasts, bacteria, algae, chitin, and chitosan.<sup>12,13</sup> Chitosan is the second most abundant biopolymer in nature, obtained from the shells of shrimp, crabs, and lobsters, which are waste products of seafood processing industries.<sup>14–16</sup> Chitosan,<sup>17</sup> crosslinked chitosan beads,<sup>17</sup> chitin,<sup>18</sup> modified chitin,<sup>18</sup> nanohydroxyapatite,<sup>19</sup> nanohydroxyapatite/chitosan composite,<sup>19</sup> nanohydroxyapatite/chitin composite,<sup>19</sup> *Cicer arietinum* husk,<sup>20</sup> olive cake,<sup>21</sup> natural silica sand,<sup>22</sup> thioglycolic modified oil-palm fiber,<sup>23</sup> etc., were tried for iron removal. Raw CB are soluble in dilute mineral acids, except in sulfuric acid and hence necessary to reinforce chemical stability using crosslinking agents like glutaraldehyde. Chemically modified CB have been used for the removal of Hg(II), Cu(II), Cr(VI), F<sup>-</sup>, and NO<sub>3</sub><sup>-</sup> by the various researchers. But there is no study regarding the removal of Fe(III).

This article aims at the development of crosslinked CB, which are stable, could be regenerated and reused in subsequent operations for iron removal. To use effectively, the amine and hydroxyl groups of chitosan, chemical modifications namely, protonation, carboxylation, and amination were carried out. A comparative evaluation of the sorption capacity (SC) of CB and their modified forms were made. The effect of contact time, pH, coions such as copper and chromium, and temperature were investigated. The best-fit isotherm was identified for the sorption and suitable mechanism was proposed.

Additional Supporting Information may be found in the online version of this article.

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## EXPERIMENTAL

### Materials

Chitosan with its deacetylation degree of 85% was supplied by Pelican Biotech and Chemicals Labs (Kerala, India). The viscosity of the chitosan solution was determined as 700 (mPa s) by Brookfield Dial Reading Viscometer using electronic drive-RVT model (USA made). The chitosan solution was maintained at a constant viscosity for beads preparation to maintain uniform molecular weight. NaOH, HCl, glacial acetic acid, ammonium ferric sulfate, copper sulfate, potassium dichromate, glutaraldehyde, ethylenediamine, and all other chemicals and reagents were of analytical grade.

### Preparation of raw and modified CB

The raw CB have been prepared and crosslinked as reported in the literature by Jeon and Holl, (2003)<sup>24</sup> and Viswanathan et al. (2009).<sup>25</sup> To effectively use both  $-\text{OH}$  and  $-\text{NH}_2$  groups in chitosan for iron removal the modifications namely, protonation, carboxylation, and grafting with amine groups have been made. The modified forms namely, protonated chitosan beads (PCB), carboxylated chitosan beads (CCB), and grafted chitosan beads (GCB) were prepared as reported by Kousalya et al. (2010).<sup>26</sup> The schematic preparation of modified forms of chitosan beads were shown in Figure 1.

### Sorption experiments

The sorption experiments were performed by batch equilibration method. Stock solution of iron containing  $1000 \text{ mg L}^{-1}$  was prepared and this was used for sorption experiments. The batch adsorption experiments in duplicate were carried out by mixing 0.1 g of sorbent with 50 mL of  $10 \text{ mg L}^{-1}$  as initial iron concentration. The contents were shaken thoroughly using a thermostated shaker rotating at a speed of 200 rpm. The solution was then filtered and the residual iron, copper concentration was measured using atomic absorption spectrometer (PerkinElmer-Analyst 100).<sup>27</sup> The concentration of chromium was measured using UV-visible spectrophotometer (Pharo 300 Merck) at 540 nm.<sup>27</sup> The thermodynamic parameters of the adsorption were established by conducting the experiments at 303, 313, and 323 K in a temperature controlled mechanical shaker. The SC of the sorbents were studied at different conditions like contact time of the sorbent for maximum sorption, pH of the medium and the effect of other common ions present in water. All other water quality parameters were analyzed by using standard methods.<sup>27</sup>

### Analysis

The prepared sorbents were characterized by Fourier transform infrared spectrometer (FTIR). FTIR spectra

of the samples as solid by diluting in KBr pellets were recorded with JASCO-460 plus model. The results of FTIR spectrometer was used to confirm the functional groups present, before and after iron sorption onto the sorbents. The surface morphology of the beads before and after iron sorption was studied with scanning electron microscope (SEM) with JOEL JSM 6390 LV model. Elemental spectra were obtained using an energy dispersive X-ray analyzer (EDAX) during SEM observations, which allows a qualitative detection and localization of elements in the sorbents. Presence of iron after sorption is conformed by Wave dispersive X-ray Fluorescence Spectrometer (WDXRF) using WDXRF MagiX PRO 2440 model.

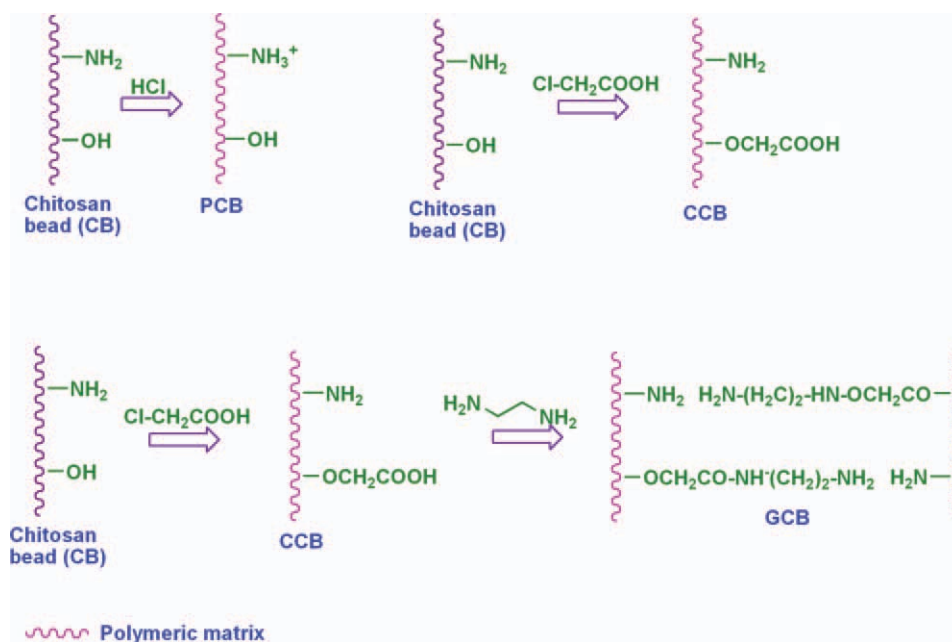
Computations were made using Microcal Origin (Version 6.0) software. The goodness of fit was discussed using regression correlation coefficient ( $r$ ), standard deviation (sd), and chi-square ( $\chi^2$ ) analysis.

## RESULTS AND DISCUSSION

### Characterization of the sorbents

FTIR spectrum of CB and modified CB are shown in Figure S1 of the Supporting Information. The IR spectra of both chitin and chitosan are similar as reported in the literature.<sup>28,29</sup> The chitosan spectrum differs from that of chitin in the band at  $1555 \text{ cm}^{-1}$  corresponding to the  $N-\text{H}$  deformation that is present only in a lower extent in chitosan samples. Although there is a possibility of overlapping between  $-\text{NH}_2$  and  $-\text{OH}$  stretching vibrations, the strong broad band at the wavenumber region of  $3300\text{--}3500 \text{ cm}^{-1}$  is the characteristic of  $-\text{NH}_2$  stretching vibration. The major bands for the chitosan bead can be assigned as follows:  $3440 \text{ cm}^{-1}$  ( $-\text{OH}$  and  $-\text{NH}_2$  stretching vibrations),  $2921 \text{ cm}^{-1}$  ( $-\text{CH}$  stretching vibration in  $-\text{CH}$  and  $-\text{CH}_2$ ),  $1652 \text{ cm}^{-1}$  ( $-\text{NH}_2$  bending vibration),  $1379 \text{ cm}^{-1}$  ( $-\text{CH}$  symmetric bending vibrations in  $-\text{CHOH}-$ ),  $1067$  and  $1028 \text{ cm}^{-1}$  ( $-\text{CO}$  stretching vibration in  $-\text{COH}$ ).<sup>30-32</sup> After crosslinking the CB, the  $-\text{OH}$  and  $-\text{NH}_2$  stretching vibration around the wavenumber of  $3440 \text{ cm}^{-1}$  and the  $-\text{NH}_2$  bending vibration at the wavenumber  $1652 \text{ cm}^{-1}$  were shifted to lower frequencies. Figure 2 explains the FTIR spectra of (a) GCB and (b) iron sorbed GCB. The presence of band at  $570\text{--}590 \text{ cm}^{-1}$  in iron sorbed GCB suggests the bonding between the iron and the chitosan matrix.<sup>33,34</sup> The other bands are the characteristics of GCB.

SEM pictures of GCB and the iron sorbed GCB are shown in Figure 3(a,b), respectively. It is evident that the beads are porous in structure before sorption and after sorption of iron, pores in the GCB are



**Figure 1** Preparation of PCB, CCB, and GCB. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

blocked, which indicates the structural changes in the GCB. The EDAX spectra of iron sorbed GCB shows the presence of iron peaks, which confirm the iron sorption onto the beads [cf. Fig. 3(c)]. This is further supported by WDXRF spectra of iron sorbed GCB which clearly indicates 2.72% of iron and 73% of oxygen confirms the presence of iron in GCB after sorption and are shown in Figures S2(a,b) of the Supporting Information.

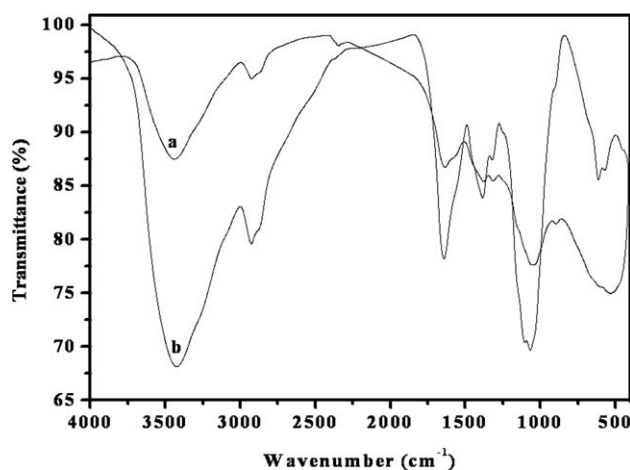
#### Effect of contact time

The diameter of chitosan bead and modified chitosan bead was in the range of 0.5–0.7 mm. The SC of CB, PCB, CCB, and GCB was determined by varying the contact time in the range of 5–60 min. For this purpose, about 0.1 g of the sorbent was placed into 50 mL of the  $10 \text{ mg L}^{-1}$  initial iron solution. The contents were shaken thoroughly using a mechanical shaker at 200 rpm, then filtered and analyzed for  $\text{Fe(III)}$  ion. Figure 4 shows that the SC of all the sorbents reached saturation at 10 min. Consequently, for further studies, 10 min is fixed as the contact time for the sorbents. The maximum SC of CB, PCB, CCB, and GCB were found to be 2913, 3533, 3905, and  $4203 \text{ mg kg}^{-1}$ , respectively. Among the sorbents, GCB experienced higher SC than CB, PCB, and CCB.

#### Effect of pH

The removal of ion from the aqueous solution was very much dependent on the solution pH and consequently the SC of all the sorbents was deter-

mined at pH 1–4. Figure 5 clearly point out that the pH influences on the SC of the sorbents for iron sorption. A maximum SC was observed at pH 4. In acidic medium where  $\text{H}^+$  concentration is higher, the protonation of amine groups take place, which restricts the number of binding sites for the sorption of  $\text{Fe}^{3+}$ . However, at  $\text{pH} > 4$  precipitation of  $\text{Fe}^{3+}$  as  $\text{Fe(OH)}_3$  have occurred and hence at pH values higher than 4, sorption studies could not be carried out for  $\text{Fe}^{3+}$ . Therefore, throughout the study, the pH of the medium was maintained at 4. Further studies were limited to the modified forms of CB namely, PCB, CCB, and GCB, as the modified forms of CB possessed a higher SC than raw CB at all pH ranges studied.



**Figure 2** FTIR spectra of (a) GCB and (b) iron sorbed GCB.

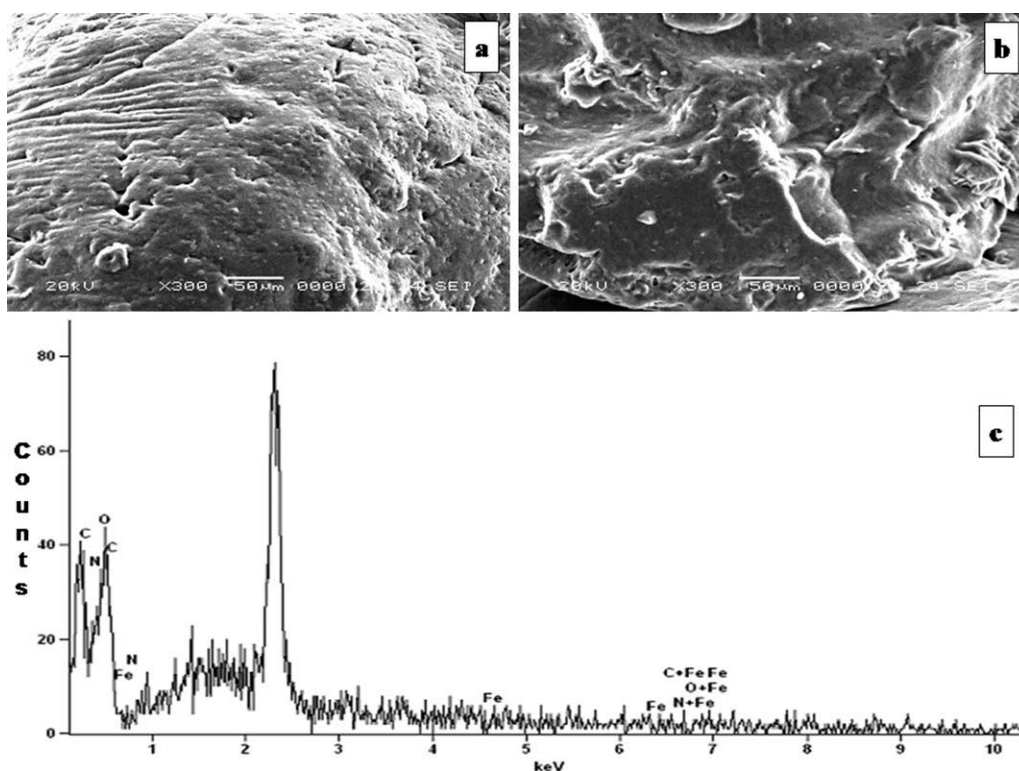


Figure 3 SEM micrographs of (a) GCB and (b) iron sorbed GCB, EDAX spectra of (c) iron-treated GCB.

#### Effect of common ions in the medium

The initial concentration of common ions was maintained as  $200 \text{ mg L}^{-1}$  by keeping sorbent dose as  $0.1 \text{ g}$  and  $10 \text{ mg L}^{-1}$  as initial iron concentration at room temperature. Under this condition, the SC of the sorbents in the presence of other common ions, which are normally present in water namely,  $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{HCO}_3^-$  was investigated to know the SC of GCB and shown in Figure S3 of the Supporting Information. This figure confirms that these ions do not have much significant effect on SC

of GCB. This is because of the fact that the GCB selectively removes iron even in the presence of other coions. Similar results were obtained for PCB and CCB.

#### Selectivity of the metal ions

The selectivity of a specific metal ion by the sorbents from the mixture of the cations namely,  $\text{Cu(II)}$ ,  $\text{Fe(III)}$ , and  $\text{Cr(VI)}$  were studied. Table I provides the

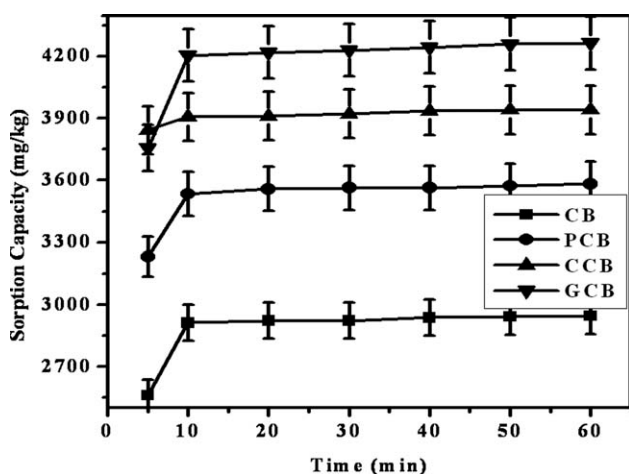


Figure 4 Effect of contact time on the SC of the sorbents at 303 K.

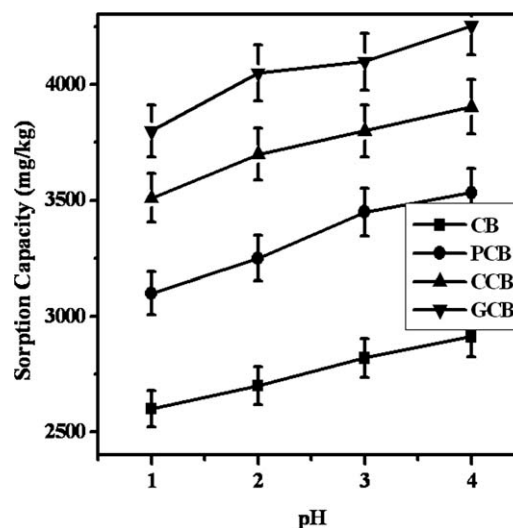


Figure 5 Influence of pH on the SC of the sorbents at 303 K.

TABLE I  
Selectivity of the Metal Ions on PCB, CCB, and GCB

S. No	Sorbents	Sorption capacity (mg kg <sup>-1</sup> )		
		Cu (II)	Fe(III)	Cr (VI)
1	PCB	2065	4920	1260
2	CCB	3280	4885	1183
3	GCB	2460	4885	1845

SC of Cu(II), Fe(III), and Cr(VI), taken for the investigation, when they were in the form of coions. The results of the analysis of the adsorption of the individual metal ions from an aqueous solution containing all the three metal ions together in equal concentrations reveals that the presence of foreign ions diminished the sorption of each of the ions. Although the degree of SC varies with respect to a particular sorbent, the selectivity of adsorption of specified metal ion on the influence of other coions is found to be in the order Fe(III) > Cu(II) > Cr(VI).

Jha et al. reported similar cocations effect in the removal of specific metal ions in their studies using chitosan.<sup>35</sup> The tendency of Fe(III) to get adsorbed preferentially is explained by ionic potential, which is higher than Cu(II) [ionic potential of Fe(III) = 4.7; copper (II) = 2.8]. The higher adsorption of Fe(III) is thus attributed to the higher ionic potential.

Chromium ions in aqueous solution behave as  $\text{HCrO}_4^-$  and  $\text{Cr}_2\text{O}_7^{2-}$  and hence the possibility of chelation of chromium is comparatively less than the other two ions namely, Cu(II) and Fe(III). Further, higher solvation property of chromium results in higher hydration, which retards itself from being trapped by sorbent and hence possesses low SC. The studies of sorption of Cu(II) and Cr(VI) on chitosan Schmuhl et al.<sup>36</sup> indicate the adsorption rate constant for Cr(VI) is lower than that of Cu(II). Based on the above discussions, it has been concluded that the order of preferential sorption of the three metal ions onto modified CB is Fe(III) > Cu(II) > Cr(VI).

### Sorption isotherms

To quantify the SC of the sorbents studied for the iron removal, the two most commonly used isotherms, namely Freundlich and Langmuir isotherms have been adopted.

#### Freundlich isotherm

The Freundlich isotherm<sup>37</sup> in its linear form is represented by

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

where  $q_e$  is the amount of iron adsorbed per unit weight of the sorbent (mg g<sup>-1</sup>),  $C_e$  is the equilibrium concentration of iron in solution (mg L<sup>-1</sup>),  $k_F$  is a measure of adsorption capacity, and  $1/n$  is the adsorption intensity. The calculated values of Freundlich isotherm constants for PCB, CCB, and GCB obtained from the linear plot of  $\log q_e$  versus  $\log C_e$  are presented in Table II. It is confirmed that there are favorable conditions for adsorption as the values of  $1/n$  lie between 0 and 1. The  $k_F$  values of all the sorbents increase with increase in temperature and this confirm the endothermic nature of sorption. The higher  $r$ -values obtained for all the sorbents indicate the applicability of Freundlich isotherm.

#### Langmuir isotherm

The Langmuir isotherm<sup>38</sup> in its linear form is represented by

$$\frac{C_e}{q_e} = \frac{1}{Q^0 b} + \frac{C_e}{Q^0} \quad (2)$$

where  $q_e$  is the amount of iron adsorbed per unit weight of the sorbent (mg g<sup>-1</sup>),  $C_e$  is the equilibrium concentration of iron in solution (mg L<sup>-1</sup>),  $Q^0$  is the

TABLE II  
Isotherm Parameters of PCB, CCB, and GCB

Sorbents	Temp. (K)	Freundlich isotherm					Langmuir isotherm				
		$1/n$	$n$	$k_F$ (mg g <sup>-1</sup> ) (L mg <sup>-1</sup> ) <sup>1/n</sup>	$r$	$\chi^2$	$Q^0$ (mg g <sup>-1</sup> )	$b$ (L g <sup>-1</sup> )	$R_L$	$r$	$\chi^2$
PCB	303	0.658	1.520	1.932	0.991	4.54 E-4	7.042	0.128	0.128	0.994	2.99 E-4
	313	0.678	1.475	1.816	0.979	1.07 E-3	8.264	0.114	0.114	0.984	7.97 E-4
	323	0.734	1.362	1.614	0.994	2.98 E-4	9.901	0.084	0.084	0.996	1.99 E-4
CCB	303	0.457	2.188	3.228	0.946	2.66 E-3	9.346	0.396	0.048	0.958	1.91 E-3
	313	0.348	2.874	3.581	0.998	5.98 E-5	10.000	0.593	0.033	0.999	2.14 E-5
	323	0.238	4.202	4.009	0.974	6.36 E-4	12.049	0.966	0.020	0.951	1.36 E-3
GCB	303	0.394	2.538	3.864	0.999	2.77 E-5	14.286	0.588	0.028	0.994	3.08 E-4
	313	0.430	2.326	3.846	0.970	1.61 E-3	14.925	0.543	0.030	0.982	9.08 E-4
	323	0.524	1.908	3.664	0.985	8.97 E-4	17.857	0.390	0.041	0.992	4.84 E-4

amount of adsorbate at complete monolayer coverage ( $\text{mg g}^{-1}$ ) and gives the maximum SC of sorbent, and  $b$  ( $\text{L mg}^{-1}$ ) is Langmuir isotherm constant that relates to the energy of adsorption. The calculated values of Langmuir isotherm constants  $Q^\circ$  and  $b$  for PCB, CCB, and GCB obtained from the respective slope and intercept of the linear plot of  $C_e/q_e$  versus  $C_e$  are presented in Table II. The higher values of  $r$  reveal the applicability of Langmuir isotherm. The values of  $Q^\circ$  for all the sorbents were found to increase with the increase in temperature. This confirms the endothermic nature and temperature dependence of the sorption process, yet again.

To find the feasibility of the isotherm, the essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter,  $R_L$

$$R_L = \frac{1}{1 + bC_0} \quad (3)$$

where  $b$  is the Langmuir isotherm constant and  $C_0$  is the initial concentration of iron ( $\text{mg L}^{-1}$ ).

The  $R_L$  values at different temperatures studied were calculated and listed in Table II. The  $R_L$  values lying between 0 and 1 indicate that the conditions were favorable for adsorption.<sup>39</sup>

### Chi-square ( $\chi^2$ ) analysis

To identify a suitable isotherm model for the sorption of iron on modified forms of CB, this analysis has been carried out. The equivalent mathematical statement is<sup>40</sup>

$$\chi^2 = \sum \frac{(q_e - q_{e,m})^2}{q_{e,m}} \quad (4)$$

where  $q_{e,m}$  is equilibrium capacity obtained by calculating from the model ( $\text{mg g}^{-1}$ ) and  $q_e$  is experimental data of the equilibrium capacity ( $\text{mg g}^{-1}$ ). If data from the model are similar to the experimental data,  $\chi^2$  will be a small number, while if they differ,  $\chi^2$  will be a bigger number. The results of chi-square analysis are presented in Table II. The lower  $\chi^2$  values of Freundlich isotherm than the Langmuir isotherm suggest the applicability of best fitting model for the sorption of iron on modified CB.

### Thermodynamic treatment of the sorption process

Thermodynamic parameters associated with the adsorption, namely, standard free energy change ( $\Delta G^\circ$ ), standard enthalpy change ( $\Delta H^\circ$ ), and standard entropy change ( $\Delta S^\circ$ ) were calculated as follows

**TABLE III**  
Thermodynamic Parameters of PCB, CCB, and GCB

Thermodynamic parameters		PCB	CCB	GCB
$\Delta G^\circ$ ( $\text{kJ mol}^{-1}$ )	303 K	-6.27	-4.43	-3.69
	313 K	-6.70	-4.15	-3.89
	323 K	-7.51	-3.87	-4.35
$\Delta H^\circ$ ( $\text{kJ mol}^{-1}$ )		12.47	13.04	6.23
$\Delta S^\circ$ ( $\text{kJ mol}^{-1}\text{K}^{-1}$ )		0.06	0.03	0.07

The free energy of sorption process, considering the sorption equilibrium coefficient  $K_o$ , is given by the equation

$$\Delta G^\circ = -RT \ln K_o \quad (5)$$

where  $\Delta G^\circ$  is the standard free energy of sorption ( $\text{kJ mol}^{-1}$ ),  $T$  is the temperature in Kelvin, and  $R$  is the universal gas constant ( $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ ). The sorption distribution coefficient  $K_o$ , was determined from the slope of the plot  $\ln(q_e/C_e)$  against  $C_e$  at different temperatures and extrapolating to zero  $C_e$  according to the method suggested by Khan and Singh<sup>41</sup>

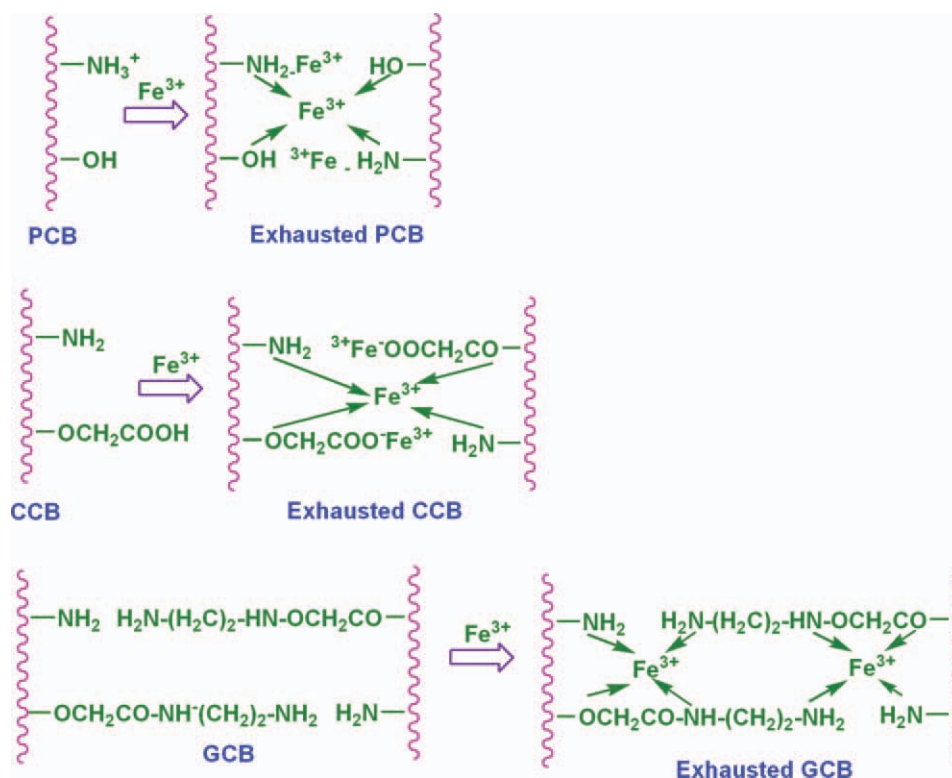
The sorption distribution coefficient may be expressed in terms of  $\Delta H^\circ$  and  $\Delta S^\circ$  as a function of temperature:

$$\ln K_o = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad (6)$$

where  $\Delta H^\circ$  is the standard enthalpy change ( $\text{kJ mol}^{-1}$ ) and  $\Delta S^\circ$  is the standard entropy change ( $\text{kJ mol}^{-1} \text{ K}$ ). The values of  $\Delta H^\circ$  and  $\Delta S^\circ$  can be obtained from the slope and intercept of a plot of  $\ln K_o$  against  $1/T$ . Table III shows the calculated values of the thermodynamic parameters of PCB, CCB, and GCB. The thermodynamic treatment of the sorption data indicates that  $\Delta G^\circ$  values were negative at all temperatures taken for investigation. The negative values of  $\Delta G^\circ$  confirm the spontaneous nature of iron sorption by the sorbents. The positive value of  $\Delta S^\circ$  indicates that the freedom of Fe(III) ions is not too restricted in the sorbents. The positive value of  $\Delta H^\circ$  for iron removal confirms the endothermic nature of sorption process by all the modified CB.

### Mechanism of iron sorption

The removal of iron by the modified CB was controlled by adsorption, ion-exchange, and chelation mechanism. The possible mechanism of iron removal by PCB, CCB, and GCB are given in Figure 6. The lone pair of electrons present in O and N of the respective hydroxyl and aminogroups in the chitosan chelates Fe(III).<sup>17-19</sup> PCB removes iron by ion exchange mechanism while CCB removes by means



**Figure 6** Mechanism of iron sorption by the modified CB. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

of ion-exchange as well as chelation as it contains both exchangeable  $H^+$  ions and metal chelating amino groups. In the case of GCB, the number of chelating amino groups has been increased through grafting, which provides more active sites for chelating iron and hence showed higher SC than CCB, which in turn is higher than PCB.

### Field applications

The suitability of PCB, CCB, and GCB is tested with a field sample taken in a nearby industrial area. About 0.1 g of sorbent was added to 50 mL of water sample and the contents were shaken with constant time at room temperature. The results are presented in Table IV. There is a significant reduction in the levels

**TABLE IV**  
Field Trial Results of PCB, CCB, and GCB

Water quality parameters	Before treatment	After treatment		
		PCB	CCB	GCB
Iron ( $mg L^{-1}$ )	0.8	Nil	Nil	Nil
pH	7.65	7.07	7.14	7.10
$Cl^-$ ( $mg L^{-1}$ )	1704	951	923	937
Total hardness ( $mg L^{-1}$ )	1160	1060	1000	900
Total dissolved solids ( $mg L^{-1}$ )	4650	2350	2250	2000

of other water quality parameters in addition to iron. It is evident from the result that all the sorbents can be effectively employed for removing the iron from water.

### CONCLUSIONS

The SCs of the modified CB namely, PCB, CCB, and GCB are found to be 3533, 3905, and 4203  $mg kg^{-1}$ , respectively, while the raw CB showed only 2913  $mg kg^{-1}$ . The pH of the medium influences the sorption of iron on modified CB. All the sorbents remove iron selectively in the presence of coions. Modified CB are more selective for Fe(III) than Cu(II), which in turn is higher than Cr(VI). Iron sorption follows Freundlich isotherm. The nature of sorption process is spontaneous and endothermic. The mechanism of iron sorption on all the modified forms of CB is governed by adsorption, ion exchange, and chelation. These modified CB are stable, selective for iron sorption and could be used for field applications.

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