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ORIGINAL PAPER

Removal of hazardous hexavalent chromium from aqueous solution using divinylbenzene copolymer resin

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Abstract This paper presents the removal of hazardous hexavalent chromium from liquid waste streams using divinylbenzene copolymer resin Amberlite IRA 96. Important sorption parameters such as contact time, pH, resin dosage and initial metal concentration were studied at 30 °C. The kinetic study was conducted using pseudo-first and pseudo-second-order kinetics at 30 °C. The sorption process was found to be pH dependent. Maximum removal was obtained at pH 2 under optimized conditions. The sorption process was rapid and 99 % of the removal was achieved in first 30 min. The equilibrium data were fitted to both Langmuir and Freundlich models. The better regression coefficient (R^2) in Freundlich model suggests the multilayer sorption process. The value of Gibbs free energy for sorption process was found to be -12.394 kJmol^{-1}. The negative value indicated the spontaneity of the sorption process. Scanning electron microscope and energy dispersive X-ray spectroscopy studies were conducted to find the role of surface morphology during sorption process. The Fourier transform infrared study was conducted to identify the functional groups responsible for interaction between the resin and chromium. Desorption and regeneration studies were also carried out.

Keywords Adsorption · Environment · Heavy metal · Ion exchange resin · Waste water

Introduction

The tremendous increase in the use of heavy metals due to rapid industrialization in past few decades has resulted into increased metallic substances in the effluent streams. Heavy metal contamination in ground water is an important environmental concern. Chromium is one of the most hazardous metal that find its widespread use in various industries including electroplating, leather processing, mining industry, metal finishing, textile industry and nuclear power plants (Abbasi and Soni 1985). Chromium exists in two stable oxidation states i.e. chromium (III) and chromium (VI). Effluents from industries contain both form of chromium; however, Cr(VI) is more toxic to plants, animals and humans. Hexavalent chromium exists in different forms in aqueous solution depending on the solution pH as acid chromates ($HCrO_4^-$), chromates (CrO_4^{2-}), and dichromates ($Cr_2O_7^{2-}$) (Golonka 1996; Tandon et al. 1984). Central pollution control board in India has set the maximum permissible limit of chromium in waste water to be below 0.01 mg L^{-1} for hexavalent chromium and 5 mg L^{-1} for the trivalent chromium salts (Bajpai et al. 2009). It is therefore important to not only recover/reuse Cr from waste stream prior to disposal for economic reasons but also to conform the stringent laws.

Chromium salts from liquid streams are generally removed by different methods such as chemical precipitation, electrochemical precipitation, membrane separation, ion exchange, solvent extraction, and adsorption by low cost adsorbents. Cr(VI) is usually present in anionic form and its direct precipitation is not the best option. It is first

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reduced to trivalent state, followed with precipitation and redissolution using alkali such as lime or MgO. This process has the disadvantage of high sludge formation, poor quality of recovered chromium and ever increasing cost of land fill. Adsorption from low cost biomaterials are widely studied topic amongst the researchers (Table 1). This promises the cheap alternative, but it lacks in the yield and the control measures are not well defined. The sorption capacity achieved was also very less. Chromium salts can also be removed through pressure driven membrane separation process such as nanofiltration and low pressure reverse osmosis. These methods are suitable for low concentration effluent and have to be integrated with effective pretreatment, else the membranes may be fouled (Hafez et al. 2002).

Due to the high selectivity of ion exchange process, resins can effectively remove the chromium from the liquid streams (Jeon and Holl 2003; Reddy and Reddy 2003). Ion exchange process involves a reversible chemical reaction wherein an ion from solution is exchanged for a similarly charged ion attached to an immobile solid particle (Bajpai et al. 2009). These solid ion exchanger particles are either naturally occurring inorganic zeolites or synthetically produced organic resins. The synthetic organic resins can be used as their characteristics can be tailored to specific application. Resins are either cationic or anionic in nature. Cationic exchange resin has the mobile ion in form of Na^+ or H^+. Anionic exchange resin has Cl^- or OH^- as mobile ions. Insoluble anion exchange resins contain anions capable of exchanging with chromium ions in solutions passed over them (Petruzelli et al. 1995; Rengaraj et al. 2006). Several studies have been reported in the literature to remove chromium from aqueous solutions using ion exchange resins (Cavaco et al. 2007; Ibrahim and Jimoh 2008; Rafati et al. 2010). Gode and Pehlivan (2003) removed Cr(III) from aqueous streams using Chelax 100 and Lewatit TP 207 cationic exchange resins. In this study, the sorption reached equilibrium in 120 min and the maximum sorption capacity obtained was in the order of 0.28 mmol g^{-1}. In another work (Pehlivan and Cetin 2009), Cr(VI) was removed using two anion exchange resins, i.e. Lewatit MP 64 and Lewatit MP 500. The optimum pH range for maximum removal was reported in the range of pH 3–7. The maximum sorption capacities for these resins were in the order of 0.41 mmol g^{-1}. However, in these studies, the surface morphology and Fourier transform infrared (FTIR) analyses were not conducted.

An attempt has been made to study the removal of chromium from aqueous solutions using weakly anionic resin Amberlite IRA 96. The effect of various operating parameters (pH, contact time, initial Cr concentration and resin dose) and kinetics of sorption were studied. The equilibrium data were fitted to Langmuir and Freundlich adsorption models. The surface morphology and functional groups involved during Cr–resin interaction was analyzed using SEM/EDX and FTIR studies. The research work was

Table 1 Comparison of different adsorbent materials

S. no.	Adsorbent material	Adsorption capacity, Q_{max}	Optimum pH	Kinetics model studied	Isotherms studied	References
1.	Lewatit 64	0.4 mmol g^{-1}	5	–	Langmuir, Freundlich	Pehlivan and Cetin (2009)
2.	Lewatit 500	0.41 mmol g^{-1}	5	–	Langmuir, Freundlich	Pehlivan and Cetin (2009)
3.	Lignocellulosic solid wastes	0.47 mg g^{-1}	2	–	Langmuir, Freundlich	Aliabadi et al. (2006)
4.	Chitosan flakes	22.09 mg g^{-1}	3	Pseudo-second order	Langmuir, Freundlich	Aydin and Aksoy (2009)
5.	Oak wood charcoal	30.1 mg g^{-1}	2	–	Freundlich	Pehlivan and Kahraman (2011)
6.	Zeolite NaX	6.4 mg g^{-1}	4	First order reversible	Langmuir, Freundlich, Temkin	Pandey et al. (2010)
7.	Tea factory waste	54.65 mg g^{-1}	2	Lagergren first order	Langmuir	Malkoc and Nuhoglu (2007)
8.	Quaternary chitosan salt	68.3 mg g^{-1}	4.5	Pseudo-second order	Langmuir	Spinelli et al. (2004)
9.	Wheat Bran	0.943 mg g^{-1}	2	Pseudo-second order	Langmuir	Nameni et al. (2008)
10.	Eucalyptus bark	45 mg g^{-1}	2	First order	Langmuir, Freundlich	Sarin and Pant (2006)
11.	Amberlite IRA96	99.91 mg g^{-1}	2	Pseudo-second order	Langmuir, Freundlich	Present work

carried out during October 2010 to March 2011 at National Institute of Technology, Jalandhar, India.

Materials and methods

Materials

All chemicals used were of analytical grade and procured from Merck, Himedia and Sd-fine chemicals, India. Amberlite IRA 96, a weakly anionic resin, was obtained from Rohm and Haas, USA. The resin beads have matrix containing polystyrene divinylbenzene copolymer with tertiary amine as functional group. Higher porosity makes it suitable for adsorption process. The tan color spherical beads vary between 0.55 and 0.75 mm sizes. The resin shows moisture holding capacity in the range of 57–63 %. It is resistant to decomposition by chemical attack due to vinylbenzene cross-linkage and can be used for a wide range of chemicals especially for mixed effluents (Table 2).

Batch experiments

A stock solution of hexavalent chromium (1,000 mg L^{-1}) was prepared in double distilled water using potassium dichromate ($K_2Cr_2O_7$). All working solutions of varying concentrations were obtained by successive dilution (Gode and Pehlivan 2003). The concentration of chromium solution is presented in the form of mg of Cr per Litre of solution. The batch experiments were carried out in 250 mL conical flasks by agitating 0.2–10 g L^{-1} amount of the ion exchange resin with 100 mL solution of Cr(VI) of desired concentration 100–500 ppm in the pH range 2–7 for the pre-determined time interval at 30 °C in an incubator cum orbital shaker at 250 rpm. The samples were taken from the shaker at regular time intervals to obtain the sorption data. The adsorbed amount of hexavalent chromium q_t (mg g^{-1}) was calculated as follows:

$$q_t = K(C_0 - C_t) \times \frac{V}{m} \tag{1}$$

where C_0 was the initial metal concentration in mg L^{-1}, C_t was the metal concentration (mg L^{-1}) of solution after time t min, V was volume (L) of sample and m was the amount of resin used in gram. Percentage removal (%R) was calculated as follows:

$$\%R = \frac{\text{initial concentration of Cr} - \text{final concentration of Cr}}{\text{initial concentration of Cr}} \times 100 \tag{2}$$

The concentration of Cr(VI) in the effluent was determined using spectrophotometer (Shimadzu, Japan) by developing a purple–violet color with 1,5-diphenyl carbazide in acidic solution as a complexing agent using standard APHA method (APHA 1992). The absorbance of the purple–violet colored solution was read at 540 nm after 10 min of color development.

Table 2 Constants of different models for adsorption of chromium with Amberlite IRA 96 resin

Pseudo-first-order model		Pseudo-second-order model	
K_{ads} (min^{-1})	R^2	K_1 (g mg^{-1} min^{-1})	R^2
0.0599	0.981	0.0155	0.999

Surface morphology observations

The surface morphology of resin samples before and after chromium adsorption was examined with SEM equipped with EDX analysis (FESEM JEOL, JSM-6700F). Samples were platinum coated by a vacuum electric sputter coater to a finest thickness prior to glue mounted on it.

Fourier transform infrared spectroscopy

The samples were pressed into KBr pellets in Perkin Elmer Hydraulic press and the spectra of different samples were recorded with Perkin Elmer Spectrum RX/FT-IR system in the region 4,000–400 cm^{-1}. The FTIR spectra were recorded with the resolutions of 2 cm^{-1}.

Results and discussion

Effect of contact time on percentage removal of Cr(IV)

Figure 1 shows the effect of contact time on the percentage removal of Cr(VI) using resin. It was evident that the contact time has significant influence on the adsorption process. Sorption seemed to occur in two phases. The first phase involved rapid metal uptake and more than 90 % of the removal occurred in first 20 min. However, complete Cr removal was achieved in 120 min and the curve was flattened. A further increase in contact time has negligible effect on the rate of adsorption of Cr(VI). Hence the equilibrium time for sorption obtained was taken as 120 min. The nature of sorbent and the available active sites determine the rate of adsorption. The mechanism of solute transfer to adsorbent particles includes diffusion of solute from bulk to the surface of solid particles and then to the internal pore of the adsorbent. In the initial stage of sorption, the concentration difference between solid surface and the bulk is large and therefore the sorption is fast and rapid in the initial stages and once the resin is saturated

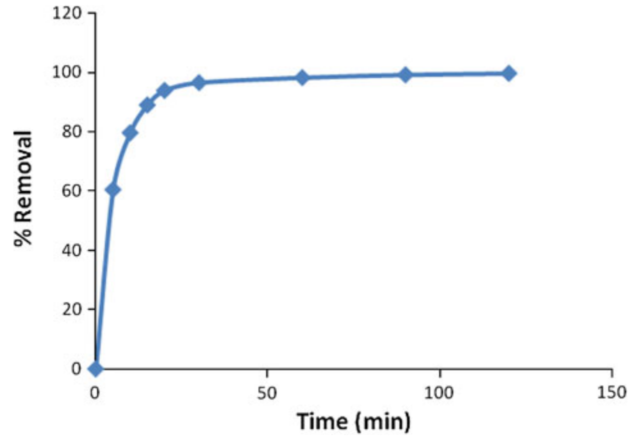

Fig. 1 Effect of contact time on adsorption of chromium (VI) with Amberlite IRA 96 at pH 2, initial Cr conc. of 100 mg L^{-1}, resin dose 5 g L^{-1}, and sample volume of 100 mL at 30 °C

with the Cr(VI), the removal increases slowly with time (Gupta and Babu 2009).

Kinetics study of sorption process

Kinetics of sorption process describes the metal uptake rate of resin and it also provides the desired residence time of sorption reaction. The kinetic of sorption process were studied for the agitation times ranging from 5 to 120 min by monitoring the removal percentage of the Cr(VI) at same experimental conditions, i.e. at pH 2, 5 g L^{-1} resin dose, 100 ppm concentration and at 30 °C. Experimental data were fitted into pseudo-first-order and pseudo-second-order kinetic models. The pseudo-first-order kinetic model of Lagergren is expressed as (Sarin and Pant 2006):

$$\log(q_e - q_t) = \log q_e - (K_{ads} * t/2.303) \qquad (3)$$

where q_e and q_t are the amounts of chromium adsorbed on resin (mg g^{-1}) at equilibrium and at time t, respectively, and K_{ads} is the rate constant of pseudo-first-order adsorption (min^{-1}). The slope and intercept of the plot of log ($q_e - q_t$) versus t are used to determine the pseudo-first-order rate constant K_{ads} and q_e, respectively.

Pseudo-second-order rate equation (Nameni et al. 2008) can be expressed in the following form:

$$\frac{t}{q_t} = \frac{1}{k_1 \times q_e^2} + \frac{t}{q_e} \qquad (4)$$

where K_1 (g mg^{-1} min^{-1}) is the rate constant of pseudo-second-order adsorption. The slope and intercept of plots of t/q_t versus t are used to calculate K_1 and q_e, respectively.

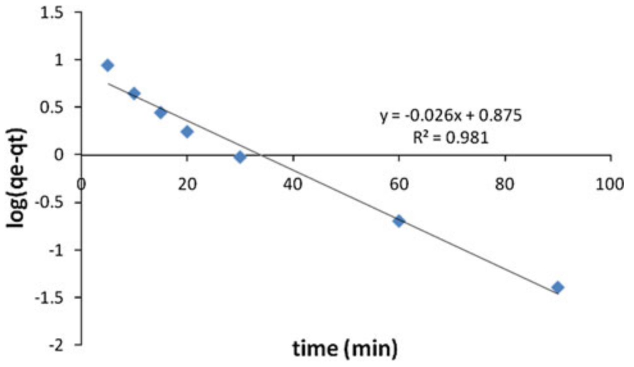

Fig. 2 Pseudo-first-order model for adsorption of chromium with Amberlite IRA 96 at pH 2, initial Cr conc. 100 ppm, resin dose 5 g L^{-1}, shaking time 120 min at 30 °C

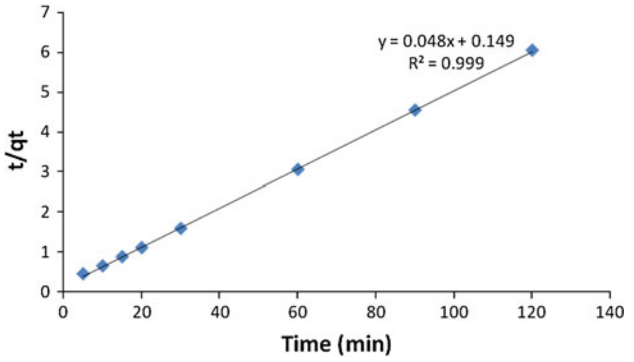

Fig. 3 Pseudo-second-order model for adsorption of chromium with Amberlite IRA 96 at pH 2, initial Cr conc. 100 mg Lm^{-1}, resin dose 5 g L^{-1}, shaking time 120 min at 30 °C

Table 3 Isotherm constants for adsorption of chromium with Amberlite IRA 96 resins

Langmuir isotherm				Freundlich isotherm		
q_{max} (mg g^{-1})	B (L mg^{-1})	R_L	R^2	K_F (L g^{-1})	n	R^2
99.91	0.0283	0.066–0.2612	0.967	21.846	3.268	0.974

In this study, the plot of first and second order kinetic for sorption of Cr(VI) on resin is presented in Figs. 2 and 3. The various kinetic parameters of different models were calculated and presented in Table 3. The correlation coefficient (R^2) of plot t/q_t versus t was found to be 0.999, which shows the applicability of pseudo-second-order kinetic model for the removal of Cr(VI) from liquid stream using resin IRA 96.

Effect of pH on sorption process

In the present work, effect of solution pH on Cr removal using ion exchange resin has been studied by varying the pH in the range of 1–7 (Fig. 4). It was found that the sorption process was pH dependent (Fig. 3). The maximum

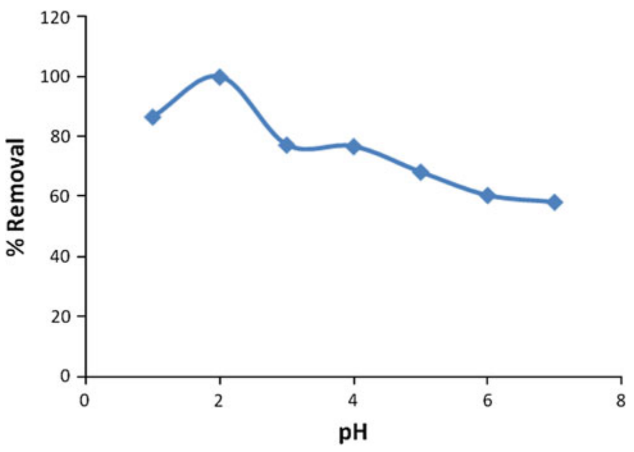

Fig. 4 Effect of pH on adsorption of chromium with Amberlite IRA 96 at initial Cr conc. of 100 mg L^{-1}, shaking time 120 min, resin dose 5 g L^{-1} and sample volume of 100 mL at 30 °C

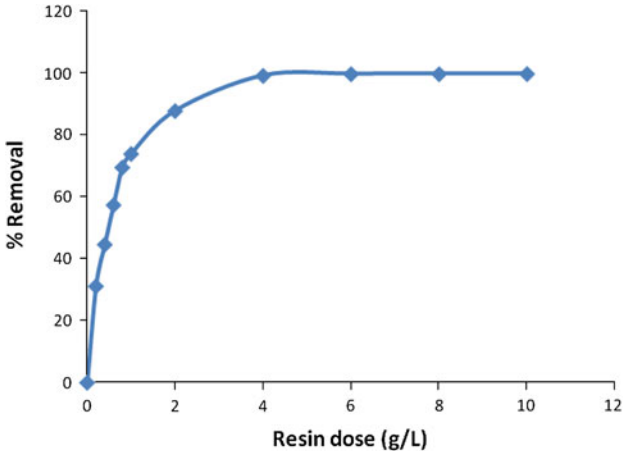

Fig. 5 Effect of resin dose on adsorption of chromium with Amberlite IRA 96 at pH 2, initial Cr conc. of 100 mg L^{-1}, shaking time 120 min and sample volume of 100 mL at 30 °C

removal was obtained at pH 2 at optimized conditions. The percentage removal of Cr(VI) decreased from 99.8 to 57.8 % by increasing the solution pH from 2 to 7. The reason for this decrease can be explained by the fact that the dominant form of Cr(VI) at initial pH 2 was $HCrO_4^-$ (Tandon et al. 1984) and increase in pH shifts concentration of $HCrO_4^-$ to other forms, i.e. CrO_4^- and $Cr_2O_7^{-2}$. The increase in Cr sorption at acidic pH could be attributed to strong electrostatic attraction between positively charged amine groups of resin and negatively charged $HCrO_4^-$ ions. However, the decrease in removal due to increase in pH may be due to result of decrease of electrostatic attraction, and competitiveness between Cr anionic species (CrO_4^-, $Cr_2O_7^{-2}$) and the OH^- ions in the bulk for sorption on active sites of resin. It can be concluded that the active form of Cr(VI) that can be adsorbed by Amberlite IRA96 at pH 2 was largely $HCrO_4^-$ ions (Sarin and Pant 2006). The slight decrease in removal from 99.8 to 96 % by changing pH from 2 to 1 can be attributed to neutral form of chromium (Kumar et al. 2008).

Effect of adsorbent dosage on sorption process

Figure 5 shows the effect of adsorbent dose on percentage removal of chromium (VI) using resin. The removal increased with the increase of adsorbent dosage. It increased from 31.1 to 99.5 % with increasing the adsorbent dosage from 0.2 to 5 g L^{-1} at same experimental conditions, i.e. at pH 2, 120 min contact time, 100 mg L^{-1} concentration at 30 °C. This result is in line with the fact that increasing adsorbent dose increases the active sites and overall surface area of the adsorbent particles that removes Cr anions from liquid streams (Garg et al. 2007).

Effect of initial metal concentration on removal

In the present work, effect of initial metal concentration on percentage removal of toxic metal was studied in the concentration range 100–500 ppm at same experimental conditions (Fig. 6). It was found that the percentage removal decreases from 99.8 to 80 % as initial concentration of the Cr(VI) increased from 100 to 500 mg L^{-1}. This could be explained as the resin beads have limited active sites and it would have saturated above a certain concentration. Moreover, at low initial Cr(VI) concentration, the ratio of surface area of resin to the initial Cr(VI) concentration was large. However, as initial Cr(VI) concentration increases, the ratio of surface area of resin to the initial Cr(VI) concentration decreases and therefore percentage removal also decreases, which is in line as reported in literature (Zakaria et al. 2009).

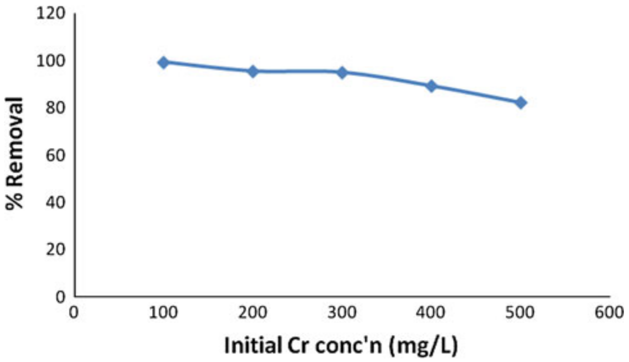

Fig. 6 Effect of initial Cr conc. on adsorption of chromium with Amberlite IRA 96 at pH 2, shaking time 120 min, resin dose 5 g L^{-1} and sample volume of 100 mL at 30 °C

Isotherm modeling for sorption process

Adsorption isotherms represent the amount of solute adsorbed per unit of adsorbent as a function of equilibrium concentration of metal in bulk solution at constant temperature. The quantity of metal adsorbed at equilibrium was calculated by the following equation:

$$q_e = (C_0 - C_e) \times \frac{V}{m} \tag{5}$$

where m is the mass of adsorbent (g), V is the volume of the solution (L), C_0 is the initial concentration of metal (mg L^{-1}), C_e is the equilibrium metal concentration (mg L^{-1}) and q_e is the metal quantity adsorbed at equilibrium (mg of Cr(VI)/g of adsorbent). During adsorption, a rapid equilibrium was established between the quantity of metal sorbed on the adsorbent (q_e) and metal remaining in the solution (C_e). The isotherm data were analyzed by Langmuir and Freundlich models. The linear form of Langmuir model equation is:

$$\frac{1}{q_e} = \frac{1}{q_{\max} \times b} \times \frac{1}{C_e} + \frac{1}{q_{\max}} \tag{6}$$

where $q_{\max}$ is the maximum quantity of metal ions per unit weight of adsorbent to form a complete monolayer on the surface (mg g^{-1}) and b is a constant related to the affinity of binding sites with the metal ions (L mg^{-1}). The essential feature of the Langmuir isotherm equation can be given in term of dimensionless separation factor R_L, i.e. defined as:

$$R_L = 1/(1 + bC_0) \tag{7}$$

where C_0 is the initial solute concentration and the value of R_L indicates the shape of the isotherm to be unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), or irreversible ($R_L = 0$) (Mohan et al. 2001).

The equation of Freundlich model is based on an adsorption on heterogeneous surfaces. The linear form of Freundlich model equation can be expressed as:

$$\ln q_e = \ln K_F + \left(\frac{1}{n}\right) \times \ln C_e \tag{8}$$

where K_F is an indicator of adsorption capacity (L g^{-1}) and n is dimensionless constant.

Gibbs free energy change ΔG° (J mol^{-1}) of sorption process (Pandey et al. 2010) can be calculated from the following equation:

$$\Delta G^\circ = -RT \ln K_c \tag{9}$$

where R is the universal gas constant (J mol^{-1} K^{-1}), K_c is the thermodynamic equilibrium constant, and T is temperature of the system in Kelvin and K_c can be calculated from the equation:

Table 4 Characteristics of resin used in the experiment

Resin	Amberlite IRA 96
Matrix	Polystyrene divinylbenzene copolymer
Functional groups	Tertiary amine
Physical form	Tan color opaque spherical beads
Moisture holding capacity	57–63 %
Mean size	0.55–0.75 mm
Uniformity coefficient	1.8 maximum
Screen grading (wet)	16–50 mesh

$$K_c = \frac{C_a}{C_e} \tag{10}$$

where C_a is the concentration of Cr(VI) on the adsorbent at equilibrium in mg L^{-1} and C_e is the concentration of Cr(VI) in solution at equilibrium in mg L^{-1}.

In the present study, the adsorption data of Cr(VI) were fitted to Freundlich and Langmuir isotherm models. The various coefficients related to above models are calculated and presented in the Table 4. Better regression coefficient (R^2) in Freundlich model suggests the multilayer sorption process. Moreover, the value of n obtained was 3.2 (i.e. >1), which suggests the favorability of multilayered sorption process (Nameni et al. 2008). The value of K_F was found to be 26.17 L g^{-1}, which indicated that resin has a high adsorption capacity for Cr(VI) solution. The value of Gibbs free energy for sorption process was found to be −12.394 kJ mol^{-1}. The negative value indicated the spontaneity of the sorption process (Sarin and Pant 2006).

SEM studies and EDX analysis

Scanning electron micrograph was used to study the morphology and surface characteristics of resin used. From Fig. 7a, it could be observed that prior to chromium adsorption, resin beads are having very fine pores on it. Figure 7b clearly shows the filling up of the fine pores of resin with the Cr metal after chromium adsorption on resin. EDX analysis of resin before and after Cr adsorption studied and concluded that resin IRA 96 was having the carbon, nitrogen and chlorine elements on its surface before interacting with Cr(VI) ions. After interaction with chromium, new chromium peaks were observed with surface having groups of carbon, nitrogen and chlorine, which confirmed the chromium adsorption on resin Amberlite IRA96.

Fourier transform infrared analysis

FTIR analysis helps in understanding the sorption mechanism as it identifies the functional groups involved during

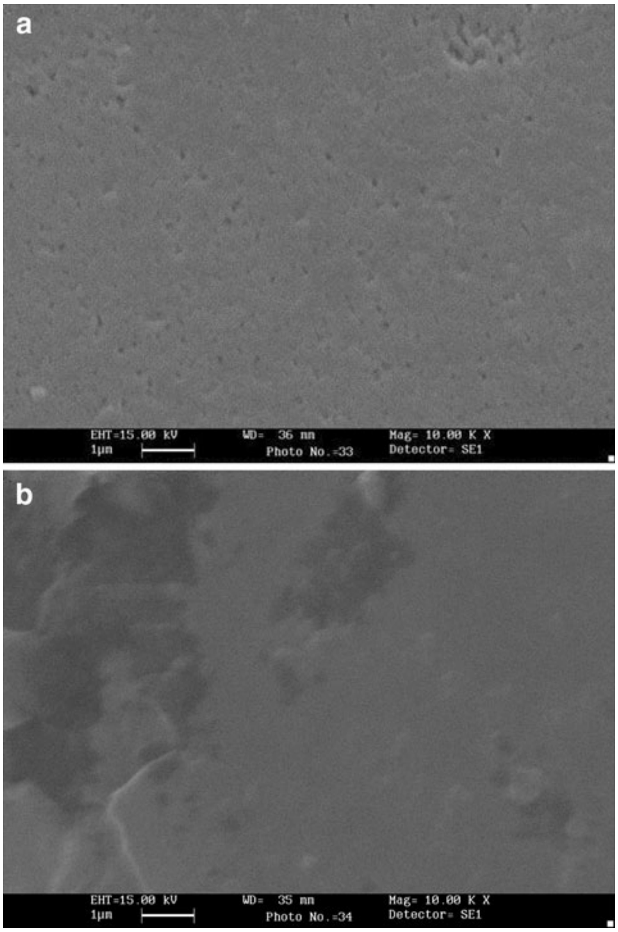

Fig. 7 **a** Scanning electron micrograph of resin IRA 96 before chromium (VI) adsorption. **b** Scanning electron micrograph of resin IRA 96 after chromium (VI) adsorption

interaction between the resin and chromium. The FTIR spectra of resin prior to chromium adsorption showed broad and distinct peak at 3,405 cm^{-1}, indicating the presence of O–H and N–H stretching vibrations (Majumadar et al. 2010). A sharp peak at 2,923 cm^{-1} is attributed to C–H group of alkyl chain (Bajpai et al. 2011). The peaks at 1,609 and 1,648 cm^{-1} are due to the presence of carbonyl groups that are in conjugation with double bond (Pavia et al. 2006). The sharp peak at 1,218 cm^{-1} shows the presence of C–N (s) vibration. The multiple bands in the range 1,166, 1,016, and 942 cm^{-1} show the in plane C–H bending vibration of halogenated aromatic compound (Pavia et al. 2006). The medium and sharp bands at 854 and 811 cm^{-1} are characteristic of C–Cl (s) vibrations (Das and Guha 2007). The peaks at 764 and 705 cm^{-1} are due to the presence of N–H wag vibrations due to secondary amines. The FTIR spectra of resin, before and after the chromium (Figures not provided), showed the distinct shift of band from 3,405 to 3,458 cm^{-1} indicating the involvement of O–H and N–H groups (Bajpai et al. 2011) in Cr–resin interaction. It is further confirmed by observing a clear reduction in the transmittance level at all peaks in the resin spectra after chromium adsorption. This shows the involvement of above mentioned functional groups during the sorption process.

Desorption study

Desorption study was conducted by batch experiment. 5 g L^{-1} of saturated resin at initial pH 2 and at 30 °C with hexavalent chromium was treated with different concentrations of NaOH (0.5–3 %). Results indicated that approximately 80 % of desorption was achieved. This indicates that resin can be reused for the Cr(VI) adsorption.

The resin cost for treating 1,000 L of effluent containing 50 mg L^{-1} Cr(VI) was calculated to show the economical feasibility of this process. The resin cost (considering its maximum sorption capacity) comes around approximately $15 per 1,000 L of effluent, assuming 100 % regeneration of resin per pass for five cycles. The slightly higher cost of resin is compensated with the high sorption capacity (99.91 mg g^{-1}) and good quality of recovered chromium.

Conclusion

This work shows that Amberlite IRA96 has a good potential to remove hexavalent chromium from liquid waste stream. The maximum sorption capacity for this resin was found to be 99.91 mg g^{-1} under optimized conditions, which is very good in comparison with other low cost adsorbents (Table 1). The study found that pseudo-second-order kinetics was followed in the sorption process. The process was found to be pH dependent. Maximum removal was obtained at pH 2 under optimized conditions. However, removal reduced by increasing pH in the range of 2–7. The sorption process was rapid and 99 % of the removal was achieved in first 30 min. The sorption also increased with increasing the resin dose and decreased with increasing initial metal concentration of solution. The isotherm study was conducted using Langmuir and Freundlich models. The equilibrium data better fitted with Freundlich model suggesting the multilayered adherence process. SEM and EDX studies further confirmed the sorption of chromium on resin. The FTIR study identified the functional groups responsible for interaction between resin and chromium. Desorption study reveals that resin can reuse for the chromium removal. This study concludes the applicability of weakly anionic Amberlite IRA 96 resin for the removal of toxic chromium ions from liquid streams.

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