



Sorption of Cr(VI) ions on two Lewatit-anion exchange resins and their quantitative determination using UV–visible spectrophotometer

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ABSTRACT

The sorption of Cr(VI) from aqueous solutions with macroporous resins which contain quarternary amine groups (Lewatit MP 64 and Lewatit MP 500) was studied at varying Cr(VI) concentration, adsorbent dose, pH, contact time and temperature. Batch shaking sorption experiments were carried out to evaluate the performance of Lewatit MP 64 and Lewatit MP 500 anion exchange resins in the removal of Cr(VI) from aqueous solutions. The concentration of Cr(VI) in aqueous solution was determined by UV–visible spectrophotometer. The ion exchange process, which is dependent on pH, showed maximum removal of Cr(VI) in the pH range 3–7 for an initial Cr(VI) concentration of 1×10^{-3} M. The optimum pH for Cr(VI) adsorption was found as 5.0 for Lewatit MP 64 and 6.0 for Lewatit MP 500. The maximum Cr(VI) adsorption at pH 5.0 is 0.40 and 0.41 mmol/g resin for Lewatit MP 64 and Lewatit MP 500 anion exchangers, respectively. The maximum chromium sorption occurred at approximately 60 min for Lewatit MP 64 and 75 min for Lewatit MP 500. The suitability of the Freundlich and Langmuir adsorption models was also investigated for each chromium–sorbent system. The uptake of Cr(VI) by the anion exchange resins was reversible and so it has good potential for the removal of Cr(VI) from aqueous solutions. Both ion exchangers had high bonding constants but Lewatit MP 500 showed stronger binding. The rise in the temperature caused a slight decrease in the value of the equilibrium constant (K_c) for the sorption of Cr(VI) ion.

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1. Introduction

The hazardous effects of heavy metals in nature have considerably limited use in industry. As the population increased and the industry grew rapidly, metal discharge from various industries caused environmental pollution. Dissolving chromium ions are the most important pollutants for the environment since they accumulate in living tissues, causing many harmful effects. Many industries are responsible for the environment pollution as they contained heavy metal ions in their wastewaters. Chromium usually exists in the (III) or (VI) oxidation states. Hexavalent chromium compounds are more soluble, mobile and bioavailable compared to sparingly soluble trivalent chromium species. In contrast to Cr(III), which is essential to mammalian systems, Cr(VI) is dangerous for humans due to its toxicity and carcinogenic properties. Since the compounds of chromium, especially Cr(VI) species, are known to be detrimental to human health, the maximum level permitted in wastewater are 5 ppm

for trivalent chromium and 0.05 ppm for hexavalent chromium [1–4].

Chromium is usually analyzed by using accurate and sensitive instrumental methods such as AAS or ICP, but these methods allow determination of only the total content of chromium in a sample. Chromium compounds can be found in the environment due to mainly tanning and electroplating industries. Chromium compounds are widely used by modern industries, resulting in large quantities of this element to be discharged into the environment. Some of the main industrial areas that use chromium compounds are plastic coatings, electroplating of metal for corrosion resistance, leather tanning and finishing, in pigments and for wood preservative. Thus, chromium occurs in wastewater resulting from these operations as both trivalent and hexavalent forms [5–7].

Among the various treatment techniques available, the most commonly used ones are ion exchange, adsorption, reduction and precipitation. However, these techniques except ion exchange have considerable disadvantages, including incomplete metal removal, requirements for expensive equipment and monitoring system, high reagent or energy requirements or generation of toxic sludge or other waste products that require disposal [8]. Synthetic ion exchangers have been widely used in industry for separation of inorganic ions. Styrene polymers are one of the most popular

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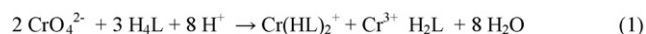
precursor copolymers for obtaining ion exchangers with different functionalities and morphologies. Functional crosslinked polymers, bearing primary amine groups are of great interest because of their high reactivity [9–15].

There are different natural and synthetic products that show ion exchange properties. The organic resins are by far the most important ion exchangers. Anion exchange resins are used to remove Cr(VI) from synthetic wastewater. The main advantages of using these resins are due to their high chemical and mechanical stability, high ion exchange capacity, and ion exchange rate. Another advantage is the possibility of selecting the fixed ligand groups and the degree of cross-linking. Anion exchange resins are generally prepared from synthetic polymers such as styrene–divinylbenzene copolymers, which are aminated and methylated to form strongly base anion exchangers. Removal of Cr(VI) from cooling water and ground water by an ion exchanger has been investigated by some researchers [16,17]. Weak-base anion exchange resins are generally used for removing chromates from water at acidic pH values. Ion exchange resins are suitable for metal-ion complexation because of their hydrophobicity and high selectivity.

The effects of competing ion concentrations, pH, and ionic strength on chromate selectivity have been studied in relation to chromate ion exchange [18]. Another report by Sule and Ingle [19] describes the adsorption of Cr(III) species by Chelex-100 chelating resin and Cr(VI) species by the anion exchange resin. In the study of Korngold et al. [20], strong-base anion exchange resins (Amberlite 416, Purolite A420) were used for selective removal of Cr(VI) from tap water. Zhao et al. [21] reported in their study that a new anion exchanger, called polymeric ligand exchanger, which shows very high chromate selectivity at neutral to alkaline pH would be very effective. Batch shaking adsorption experiments were carried out by Rengaraj et al. [22] to evaluate the performance of IRN77 and SKN1 cation exchange resins in the removal of chromium from aqueous solutions. In another study reported by Rengaraj et al. [23], the removal of chromium from aqueous solution by ion exchange resins such as 1200H, 1500H and IRN97H was described. In the review reported by Dabrowski et al. [24], removal of Cr(III) and Cr(VI) with various commercial resins was explained. The work by Saha et al. [25] investigated the removal of Cr(VI) from aqueous solution using solvent impregnated resins, which was formed by impregnating Amberlite XAD-7 with Aliquat 336.

Lewatit® is seen as an innovator and a key driver in the development of new and efficient high-performance ion exchange resins. These products have paved the way for completely new fields of application by opening up new dimensions in terms of performance. Lewatit® comes wrapped in a convincing package: it is an all-embracing solution concept consisting of the product itself plus full technical support. The problems may involve the treatment of potable water, the separation of individual components in the food industry, or the extraction of valuable materials in hydrometallurgy. Utilization of Lewatit® is gaining attention as a simple, effective and economic means of treating wastewater containing heavy metals. Lewatit® are abundant, inexpensive and readily available. They also possess several characteristics that make them effective media for the removal of dissolved metal pollutants [7].

This paper describes sorption of Cr(VI) on two types of anion exchangers and sensitive determination of Cr(VI) in aqueous solutions with UV detector. Parameters that influence adsorption, such as initial Cr(VI) concentration, agitation time, pH, resin amount, isotherm and kinetic studies were investigated at 25 °C. In addition to this, the equilibrium and kinetic parameters of Cr(VI) at pH 5 were investigated at 20, 35 and 45 °C.



H₄L: 1,5-Diphenylcarbazine
H₂L: Diphenylcarbazone

Scheme 1. Reaction between Cr(VI) ion and diphenylcarbazine.

2. Experimental

2.1. Materials and methods

Double distilled water free from interference at the minimum detection limit of each constituent was filtered through a membrane filter and used throughout all experiments. Lewatit MP 64 and Lewatit MP 500 resins were received from Bayer AG. Their physical properties were shown in Table 1.

Solutions of 0.01 M NaOH and HCl (from Aldrich) were used for pH adjustment. Cr(VI) stock solution (from Merck) was prepared from potassium salts of dichromate (K₂Cr₂O₇), which is analytical grade. Solutions were stored in plastic sealed beaker. A series of standard metal solution were prepared by appropriate dilution of the stock metal solution. Dissolved Cr(VI) ions in the samples at least three concentrations of each were determined from linear graph of calibration curve.

The United States Environmental Protection Agency (US EPA) recognizes four methods for determination of Cr(VI): co-precipitation [26], colorimetric with diphenylcarbazine [27], chelation/extraction [28] and differential pulse polarography [29]. Balasubramanian and Pugalenti [30] proposed the comparative study of the three analytical techniques, namely ICP-AES, FAAS and UV–visible spectrophotometer for the determination of the total chromium in tannery wastewater after complete conversion of trivalent chromium to hexavalent chromium. The analysis of Cr(VI) in our experiments was carried out colorimetrically with the 1,5 diphenyl carbazine method [31] by using a UV–visible spectrophotometer (Shimadzu UV-1700) (λ : 540 nm). When we compare the application of classic UV detector with other instrumental techniques such as AAS or ICP, this method is relatively cheap and readily available in laboratories. Diphenylcarbazine gives reaction with Cr(VI) in acid medium and Cr(III)–diphenylcarbazone complex occurs (Eq. (1) of Scheme 1) [32].

Total unadsorbed Cr(VI) was calculated by taking the difference between initial concentration and total hexavalent chromium concentration in the filtrate.

$$\text{Cr(VI) sorbed} = (\text{Initial chromium concentration}) \\ - (\text{Chromium concentration in the filtrate})$$

Mass balance was confirmed in all cases. All experiments were conducted in duplicate and average values were considered.

3. Results and discussion

3.1. Effect of shaking time on the removal of Cr(VI)

Fig. 1 shows the effect of shaking time on the removal of Cr(VI) by resins. High adsorption rates of chromium for Lewatit MP 64 and Lewatit MP 500 anion exchange resin were observed at the onset; and then plateau values are gradually reached within 50 min. The metal uptake versus time figure showed a single, smooth curve that was continuously leading to saturation, suggesting the possible monolayer coverage of metal ions on the surface of the sorbent. For an initial Cr(VI) concentration of 1×10^{-3} M, the increasing contact time increased the Cr(VI) sorption and it remained constant after equilibrium was reached in 75 min and 60 min for Lewatit MP 64

Table 1
Properties and speciations of Lewatit MP 64 and Lewatit MP 500 anion exchange resins

Resin	Lewatit® MonoPlus MP 64	Lewatit® MonoPlus MP 500
Type	Anion exchange resins, weakly basic	Anion exchange resins, strongly basic
Matrix	Styrene–polystyrene	Styrene–polystyrene
Functional group	Quarternary amine	Quarternary amine
Ionic form as shipped	Free base/Cl ⁻	Cl ⁻
Total exchange capacity	1.3 min eq/l	1.1 min eq/l
Moisture holding capacity	61–66%	62%
Stability (at pH range)	0–14	0–14
Specific gravity	1.04 g/ml	1.06 g/ml
Uniformity coefficient	1.1 (max.)	1.1 (max.)
Mean bead size	0.59 (±0.05)	0.63 (±0.05)

and Lewatit MP 500, respectively. In each case, the decreasing concentration of Cr(VI) remaining in the solution indicated that Cr(VI) ion was adsorbed strongly by both resins.

3.2. Sorption at various pH levels

It is necessary to understand the solution chemistry of hexavalent chromium in order to explain the binding mechanism of chromate by ion exchange materials. The sorption of Cr(VI) species is dependent on both the total concentration of Cr(VI) and pH of the equilibrium solution. The hexavalent species of chromium exist primarily as chromic acid (H₂CrO₄) and its salts, hydrogen chromate (HCrO₄⁻) and chromate (CrO₄²⁻) ions depending on sample pH [33,34]. The dichromate ion (Cr₂O₇²⁻) is a dimer of HCrO₄⁻, which is formed when the concentration of chromium exceeds approximately 1 g l⁻¹. In neutral solutions, Cr(VI) will be present in the form of HCrO₄⁻ and CrO₄²⁻ at low concentrations. A strong-base anion exchange resin will adsorb chromates from aqueous solution according to the reactions shown in the following equations:



The explanation for this finding lies in the influence of the functional group of the quaternary ammonium moiety of the resin, which has a significant influence on the uptake of Cr(VI).

The interactions between Cr(VI) and both type of resins were investigated at different pH values. There are two principal means by which anion exchanger and ions can interact with each other in aqueous solutions. The most common way involves ion exchange or chelation of metal ions. These interactions are characterized by the resin structure in terms of present functional groups. Amine groups bound to carbon are considered to be the reaction partner

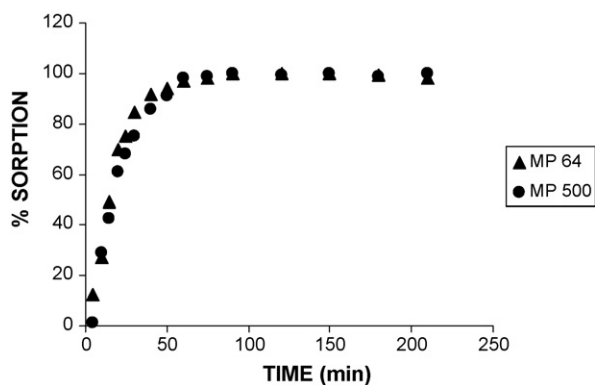


Fig. 1. Effect of contact time on the sorption of Cr(VI) by Lewatit MP 64 and Lewatit MP 500 (conditions: initial concentration of Cr(VI), 1×10^{-3} M; amount of resin, 0.04 g; volume of adsorption medium, 25 ml; temperature, 25 ± 1 °C; stirring rate 180 rpm; initial pH, 5.0).

of Cr(VI). To find out the optimum pH for maximum removal efficiency, experiments were conducted by changing the pH of Cr(VI) solution from 2 to 8. Cr(VI) is very soluble in aqueous solutions, and their solubilities increase with pH; therefore, it was practical to employ resins at solution pH values 7.0 and below. As seen in Fig. 2, for Lewatit MP 64 and Lewatit MP 500 anion exchange resins, the removal efficiency of Cr(VI) decreased from 88.0 to 80.0; 84.0 to 78.0, respectively as pH of the solution changed from 5 to 2. The maximum recovery (>84%) was obtained in the pH range of 3–5.

The pH dependence of ion exchange may suggest that the Cr(VI) ions are sorbed according to the ion exchange mechanism. The resins are suitable sorbents for the anions since the amine functionalities using the ion exchange mechanism are able to bind Cr(VI) ion. A significant reduction in the adsorption of Cr(VI) at higher pH is possibly due to the abundance of OH⁻ ions resulting in an increased hindrance to the diffusion species. For that reason, the uptake decreases at high pH values. At very low pH values, the surface of exchanger would also be surrounded by the hydronium ions, which enhanced the Cr(VI) interaction with binding sites of the sorbent by greater attractive forces. As the pH is increased, however, the overall surface charge on the sorbents became negative and ion exchange decreased. This sorption trend can likely be ascribed to the effect of competitive binding between Cr(VI) and hydrogen ions for the binding sites on the surface of the resins. At low pH, an excess of hydrogen ions can compete effectively with Cr(VI) for bonding sites, resulting in a lower level of Cr(VI) uptake.

The sorption of Cr(VI) ion on the resins is clearly very favorable at pH values between 3.0 and 5.0. Fig. 2 shows that Cr(VI) removal reaches a plateau at pH values greater than 4.0 for Lewatit MP 64. Our results show that Cr(VI) removal remained almost constant at

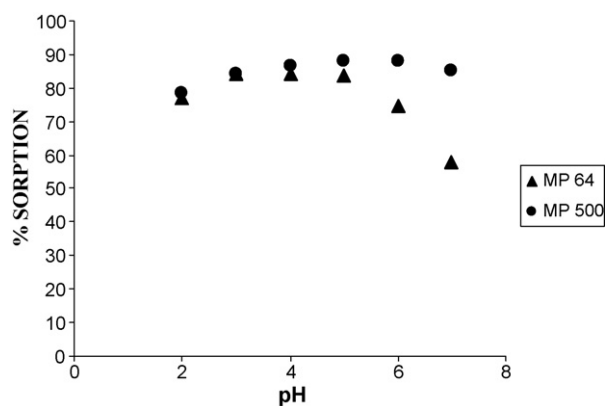


Fig. 2. Effect of pH on the sorption of Cr(VI) by Lewatit MP 64 and Lewatit MP 500 (conditions: initial concentration of Cr(VI), 1×10^{-3} M; amount of resin, 0.04 g; volume of adsorption medium, 25 ml; temperature, 25 ± 1 °C; stirring rate 180 rpm; stirring time, 50 min).

equilibrium pH values between 4.0 and 6.0 for Lewatit MP 500. Vincent and Guibal [35] noted that the decrease in extraction efficiency above pH 5 is related to the speciation of Cr(VI), and especially to a decrease in the fractions of HCrO_4^- and $\text{Cr}_2\text{O}_7^{2-}$ by increasing pH. Since we did not observe any decrease in Cr(VI) removal above pH 5 for Lewatit MP 500, we concluded that Lewatite MP 500 can easily remove Cr(VI) above pH > 4 conditions when chromate is mainly present as the ion CrO_4^{2-} .

Cr(VI) is a strong oxidizing agent and the oxidation power of Cr(VI) is influenced by the structure of the reagent, the nature of the reaction medium and its pH. Strong acids enhance the oxidizing power of Cr(VI). We observed a distinct decrease in Cr(VI) removal at an equilibrium pH below 3.0 (see Fig. 2). Vincent and Guibal [35] also observed this decrease in acidic solution and explained it by considering that protonated amine groups are saturated by counter anions existing in the solution and also the reduction of Cr(VI) to Cr(III) is strongly increased. Besides, the decrease in Cr(VI) extraction at acidic pH may be explained by Cr(VI) will form H_2CrO_4 as a non-anionic species and therefore does not participate in the anion exchange process.

3.3. Adsorption isotherms

Adsorption isotherm is a very convenient way of presenting the variation of sorption with respect to the concentration of adsorbate in the bulk solution at constant temperature. Sorption data are described by Langmuir and Freundlich adsorption isotherms. These isotherms relate Cr(VI) uptake per unit weight of sorbent, q_e , to the equilibrium sorbate concentration in the bulk fluid phase, C_e (Fig. 3). The general form of both these models were described as follows.

Langmuir equation:

$$\frac{C_e}{q_e} = \frac{1}{K_b A_s} + \frac{C_e}{A_s} \quad (4)$$

where A_s (mol/g) and K_b (l/mol) are coefficients, q_e is the weight adsorbed per unit weight of adsorbent and C_e is the metal concentration in bulk solution at equilibrium. The Langmuir model represents one of the first theoretical treatments of non-linear sorption, and has been successfully applied to a wide range of systems that exhibit limiting or maximum sorption capacities. The Langmuir treatment is based on the assumption that maximum ion exchange depends on the saturation level of a monolayer of adsorbate molecules on the adsorbent surface, that the energy of ion

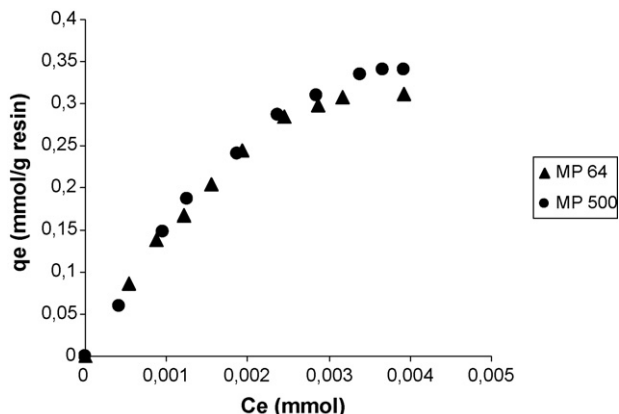


Fig. 3. Sorption isotherm of Cr(VI) on Lewatit MP 64 and Lewatit MP 500 (conditions: initial concentration of Cr(VI), 1×10^{-4} to 1×10^{-3} M; amount of resin, 0.04 g; volume of adsorption medium, 25 ml; temperature, 25 ± 1 °C; stirring rate 180 rpm; stirring time, 50 min; initial pH, 5.0).

Table 2

Parameters of Freundlich isotherm for sorption of chromium on Lewatit MP 64 and Lewatit MP 500 resins

Resin	Freundlich isotherm			Langmuir isotherm		
	k	n	R^2	K_b	A_s^a	R^2
Lewatit MP 64	83.4	0.96	0.97	378.0	0.55	0.94
Lewatit MP 500	13.2	1.97	0.99	75.5	1.72	0.85

^a mmol/g resin.

exchange is constant, and that there is no transmigration of adsorbate molecules in the surface plane [23].

Freundlich adsorption isotherm is the relationship between the amounts of metal adsorbed per unit mass of the adsorbent (x/m) and the concentration of the metal at equilibrium (C_e).

Freundlich equation:

$$\left(\frac{x}{m}\right) = k C_e^{1/n} \quad (5)$$

where x is the amount of metal adsorbed (mmol), m the amount of sorbent (g), C_e the equilibrium concentration (mM) and k and n are Freundlich constants. The logarithmic form of the equation becomes:

$$\log\left(\frac{x}{m}\right) = \log k + \frac{1}{n} \log C_e \quad (6)$$

Here k and n are constants representing the adsorption capacity and intensity of adsorption, respectively. Analysis of the relationship between the sorption capacity of the resin and the Cr(VI) concentration at equilibrium was performed using the equation of Freundlich (5). From the Freundlich isotherm of metal ion it could be assumed that the stronger binding sites are occupied first; and then the binding strengths are decreased with increasing degree of site occupation [36,37].

The influence of the amounts of the chromium for the sorption procedure was investigated by using 1×10^{-4} to 1×10^{-3} M Cr(VI) solutions. For this aim, various concentrations of Cr(VI) solution were added to the resin in a beaker. The Freundlich model (Eq. (5)) was applied for ion exchange equilibrium. Taking into consideration the values of the correlation coefficient as a criterion for goodness of fit for the system, the Freundlich model shows better correlation for the whole concentration range than Langmuir model (Table 2). The maximum Cr(VI) adsorption at an optimum pH of 5.0 was 0.40 and 0.41 mmol/g of weight Lewatit MP 64 and Lewatit MP 500 anion exchangers, respectively. At higher concentrations, the available sites of sorption became fewer and subsequently the removal of Cr(VI) depended on the initial concentrations of Cr(VI). At higher initial concentration, it is not likely that Cr(VI) ions were only adsorbed in a monolayer at the outer interface of anion exchangers. In fact, the diffusion of exchanging ions within resin particles may govern the sorption rate at higher initial concentrations. It appears that the Freundlich equation yielded the best fit for Cr(VI) adsorption on the resins. Lewatit MP 500 exhibited higher sorption capacity than the Lewatit MP 64. The magnitude of k and n illustrated the separation of Cr(VI) ions from aqueous solution and the high sorption capacity of resins as shown in Table 2.

3.4. Effect of temperature on Cr(VI) adsorption

Temperature of the resin mixture and Cr(VI) solution was ranged from 25 to 45 °C. The adsorption rate and equilibrium adsorption level decreased by increasing temperature. Thermodynamically, parameters such as free energy change (ΔG°), enthalpy change (ΔH°) and entropy change (ΔS°) can be calculated using the following Eqs. (7)–(9) where K_c is equilibrium constant, C_{Ae} is the

Table 3
Thermodynamic parameters for the adsorption of Cr(VI) on Lewatit MP 64 and Lewatit MP 500 resins

Resin	ΔH° (J mol ⁻¹)	ΔS° (JK ⁻¹ mol ⁻¹)	ΔG° (J mol ⁻¹)		
			T = 298 K	T = 308 K	T = 318 K
Lewatit MP 64	17244.1	67.94	-3045.9	-3585.0	-4410.6
Lewatit MP 500	20050.8	77.16	-2938.2	-3718.4	-4481.8

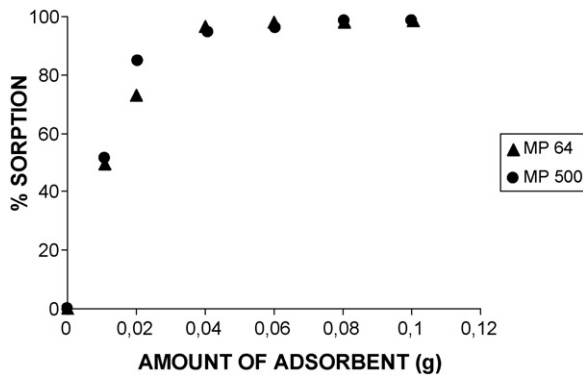


Fig. 4. Effect of resin amount on the sorption of Cr(VI) by Lewatit MP 64 and Lewatit MP 500 (conditions: initial concentration of Cr(VI), 1×10^{-3} M; volume of adsorption medium, 25 ml; temperature, 25 ± 1 °C; stirring rate 180 rpm; stirring time, 50 min; initial pH, 5.0).

equilibrium concentration (mg/l) of the Cr(VI) ion on the resin and C_e is the equilibrium concentration (mg/l) in the solution.

$$K_c = \frac{C_{Ae}}{C_e} \quad (7)$$

$$\Delta G^\circ = -RT \ln K_c \quad (8)$$

$$\log K_c = \frac{\Delta S^\circ}{2.303R} - \frac{\Delta H^\circ}{2.303RT} \quad (9)$$

ΔG° , ΔH° and ΔS° are changes in free energy, enthalpy and entropy, respectively. The linear property of $\log K_c$ against $1/T$ has been proven in some studies on heavy metal adsorption by ion exchange materials [3]. ΔG° , ΔS° and ΔH° can be calculated from a plot of $\log K_c$ versus $1/T$. The removal of Cr(VI) from the solution of initial concentration decreases as the temperature increases and agitation rate of 180 rpm with resin indicates the endothermic nature of the process. As seen from Table 3, the negative values of ΔG° , indicates exothermic and spontaneous nature of the process and favorable adsorption. The sorption decreases with increasing temperature. Therefore, a general temperature range is suggested to be 25–35 °C.

3.5. Effect of resin amount

It may be concluded that the removal efficiency increases but ion exchange density decreases by increasing the ion exchanger amount. The percentage metal removal was higher at the beginning due to large number of resin exchange sites available for the sorption of the metal. The decrease in ion exchange density can be attributed to some of the ion exchange remains unsaturated during the sorption process; whereas the number of available ion exchange sites increases by an increase of sorbent (Fig. 4) and the removal

Table 4
Rate constants for the removal of Cr(VI) with Lewatit MP 64 and Lewatit MP 500 resins

Resin type	Cr(VI) amount (mmol)	Overall rate constant, $K = k_1 + k_2$ (h ⁻¹)	Forward rate const., k_1 (h ⁻¹)	Backward rate const., k_2 (h ⁻¹)
Lewatit MP 64	1	0.0997	0.0771	0.0226
Lewatit MP 500	1	0.0778	0.0596	0.0182

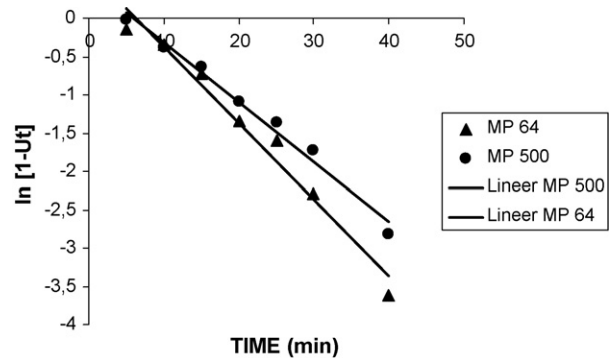


Fig. 5. Kinetic fit for the adsorption of chromium on ion exchange resins: Lewatit MP 64 and Lewatit MP 500.

efficiency increases [38]. The equilibrium concentration increases with increasing sorbent doses for a given initial Cr(VI) concentration, because increasing sorbent doses provide a greater surface area or ion exchange sites for a fixed initial solute concentration [38–40].

3.6. Adsorption kinetics

Experiments were also performed in order to understand the kinetics of Cr(VI) removal by these resins. It is a well-established fact that the adsorption of ions in aqueous system follows reversible first-order kinetics, when a single species is considered on a heterogeneous surface. It must be remembered that the two important physicochemical aspects for parameter evaluation of the sorption process as a unit operation are the kinetics and the equilibria. Evaluation of Fig. 1 shows that the concentration of Cr(VI) decreases rapidly within 30–60 min and the sorption is virtually complete within 60 min for Lewatit MP 64 and 75 min for Lewatit MP 500. Fig. 1 also indicates a high initial rate of removal of chromium with much slower subsequent removal rates that gradually approach an equilibrium condition. Using the kinetic equations, the overall rate constant, the forward and backward rate constants were calculated.

The sorption of chromium from liquid to solid phase may be expressed as



where k_1 is the forward reaction rate constant, k_2 the backward reaction rate constant. Using the kinetic equations in our early publication [7], overall rate constant, the forward and backward rate constants were calculated. By plotting $\ln(1 - U_t)$ versus t (Fig. 5), the overall rate constant k for given concentration of chromium was calculated by considering the slope of straight line in Fig. 5. By using equations in reference [7], the equilibrium constant K_c ,

forward and backward rate constants k_1 and k_2 were calculated and shown in Table 4. From this table, it is seen that the forward rate constants for the removal of chromium were higher than the backward rate constants namely the desorption process. This result shows that the rate of adsorption is clearly dominant.

4. Conclusion

Strong-base anion exchange resins were used to reduce trace concentrations of Cr(VI) in aqueous solution to low levels. The present work demonstrated that both resins have a large collective sorption with Cr(VI) ion, but Lewatit MP 500 shows stronger binding. The isotherm plots showed a high sorption for pH 3–5 for both of the resins. Optimum pH for ion exchange was 5.0 for Lewatit MP 64 and 6.0 for Lewatit MP 500. The adsorption of Cr(VI) increased with agitation period and attained an optimum at about 60 min for Lewatit MP 64, 75 min for Lewatit MP 500. The Freundlich and Langmuir adsorption models were used for the mathematical description of the biosorption of Cr(VI) ions to ion exchangers and the isotherms constants were evaluated to compare the sorption capacity of the Lewatit MP 64 and Lewatit MP 500 for Cr(VI) ions. The maximum Cr(VI) adsorption at an optimum pH of 5.0 was 0.40 and 0.41 mmol/g of weight Lewatit MP 64 and Lewatit MP 500 anion exchangers, respectively.

These ion exchangers can be used as an efficient sorbent for the removal of Cr(VI) from aqueous solution. These anion exchangers are thus attractive sorbents for the treatment of wastewater containing Cr(VI) ion at trace levels. For a given Cr(VI)-bearing wastewater, it is possible to design a batch treatment system to remove Cr(VI) ion at any pH within the range of 3–6. A batch reactor requires about 60 min contact time to achieve 82–88% removal from aqueous solution. As a result, Lewatit MP 64 and Lewatit MP 500 resins can be used for reversible uptake of Cr(VI) and successfully applied to water and industrial wastewater samples.

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