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Removal of hexavalent chromium by using heat-activated bauxite

M. Erdem [a,*], H.S. Altundoğan [b], F. Tümen [b]

[a] Department of Environmental Engineering, Fırat University, 23279 Elazığ, Turkey
[b] Department of Chemical Engineering, Fırat University, 23279 Elazığ, Turkey

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Abstract

In this study, to increase the Cr(VI) adsorption capacity of bauxite, heat treatment method was tested and the effects of pH, adsorbent dosage, contact time, initial Cr(VI) concentration and temperature on the adsorption of Cr(VI) were investigated. Although heating provides an enhanced adsorption, the heat-activated bauxite was found to be a weak adsorbent for Cr(VI). The maximum adsorption yield (64.9%) was obtained at the conditions of pH 2, activated bauxite dosage of 20 $g\,l^{-1}$, contact time of 180 min, for the initial Cr(VI) concentration of 10 $mg\,l^{-1}$ and temperature of 20 °C by using the bauxite sample heated at 600 °C. The adsorption data fit a first-order rate expression and Langmuir isotherm. Enthalpy, free energy and entropy changes were calculated from the isotherm data. The adsorption of Cr(VI) onto heat-activated bauxite was found to be exothermic.

Keywords: Environmental; Pollution; Oxide ores; Ion exchange

1. Introduction

Chromium and its compounds have many industrial uses, such as alloying, electroplating, leather-tanning, corrosion prevention etc. As a result of unregulated applications and inappropriate waste-disposal practices, chromium contamination of surface and ground water has become a significant environmental problem. Chromium has two oxidation states in the water system, Cr(VI) and Cr(III), which their mobility and toxicity are different. Cr(VI) species, having mobile and strongly oxidant characters, are known as mutagen and potential carcinogen (Moore and Ramamoorthy, 1984). In contrast, Cr(III), having a limited hydroxide solubility and low toxicity, is generally regarded as a nondangerous pollutant. Because of these dramatic differences in physical and chemical properties of two chromium types and benign character of Cr(III), detoxification and immobilisation processing of Cr(VI) are based on its reduction to Cr(III).

In order to remove chromium from aqueous solutions, many different processes have been investigated. Principally, there are two main treatment methods for Cr(VI) removal. The first type of methods aim to remove Cr(VI) anions directly while the second type is based on the reduction of Cr(VI) to Cr(III). The precipitation of insoluble chromium hydroxide is a final step in the second type removal processes. The reduction–precipitation technique is widely practised for the treatment of wastewaters containing chromium.

In the last few decades, alternative methods such as adsorption, ion exchange and membrane techniques have received more concern for metal removal from waste streams. Since adsorption methods seem to be promising, attention has been focused on chromate adsorbents, which leads to remove hexavalent chromium in one step. Finding the cost effective adsorbents requires further investigation in the field of natural sorbents, industrial and agricultural wastes or by products. In recent studies, our efforts have been focused on Cr(VI) removal by using low-cost materials (Tümen et al., 1987; Özer et al., 1997; Günaydın et al., 1999). In this context, bauxite and its processing residue (red mud) have been investigated for the removal of some anions such as phosphate, arsenite, arsenate and floride from aqueous media (Lopez et al., 1998; Pradhan et al., 1999; Altundoğan et al., 2000, 2002; Altundoğan and Tümen, 2002, 2003; Çengeloğlu et al., 2002).

Bauxite, one of the abundant minerals, mainly consists of aluminium and iron oxide and is widely

* Corresponding author.
E-mail address: merdem@firat.edu.tr (M. Erdem).

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processed for alumina production. It has been shown that the bauxite has a good affinity for the adsorption of various type of phosphates from water (Altundoğan and Tümen, 2002). In a recent study dealing with activation of bauxite, we have reported that bauxite heated at 600 °C exhibited an enhanced phosphate adsorptivity (Altundoğan and Tümen, 2003). These findings suggest that bauxite may exhibit significant adsorptivity for chromates which resemble phosphates as structure. Additionally, chromate adsorbed bauxite may be reused for alumina production and thus bauxite may become a low-cost adsorbent for hexavalent chromium.

The present work is focused on the determination of removal performance of hexavalent chromium by using heat-activated bauxite and the interpretation of the sorption mechanism using standard procedures, including pH optimization, sorption isotherms and kinetics.

2. Experimental

2.1. Materials

Bauxite used in the study was provided from Seydisehir Aluminium Plant, Konya (Turkey). Preparation and characterization of bauxite sample were explained in our recent studies (Altundoğan and Tümen, 2002, 2003) which the same bauxite was subjected to phosphate adsorption. The chemical and mineralogical compositions of bauxite sample determined in previous studies mentioned above are given in Table 1.

A 1000 mg-Cr(VI) l^{-1} stock chromate solution was prepared from potassium dichromate salt (Merck, 4862). In order to provide a constant ionic strength, stock solution was prepared in 0.01 M NaCl solution. For the same purpose, experimental solutions were made from this stock solution by using 0.01 M NaCl solution as diluent.

Table 1
Chemical and mineralogical compositions of raw bauxite

Chemical composition		Mineralogical composition	
Constituent	w/w (%)	Minerals	w/w (%)
Al_2O_3	56.91	Boehmite [AlOOH]	59.10
Fe_2O_3	16.95	Kaolinite [$Al_2Si_2O_5(OH)_4$]	11.34
SiO_2	8.62	Diaspore [AlO(OH)]	1.76
TiO_2	2.40	Haematite [α-Fe_2O_3]	15.39
CaO	0.91	Anatase [TiO_2]	1.49
CO_2	0.78	Calcite [$CaCO_3$]	1.29
P_2O_5	0.13	Quartz [SiO_2]	0.86
V_2O_5	0.032	Amorphous substances and others	8.77
S	0.032		
LOI[a]	12.36		

[a] LOI: loss on ignition (at 1000 °C).

Other reagents used in this study were of analytical grade. The initial pH of suspensions was adjusted to the required value by using NaOH or HCl solutions. The labwares used in the experiments were soaked in diluted HCl solution for 12 h, and then rinsed with distilled water.

2.2. Heat activation

For heat activation, the procedure in our previous study was followed (Altundoğan and Tümen, 2003). For this purpose, a 50 g of bauxite samples (<74 μm) placed in porcelain dish was heated in a muffle furnace at 200, 400, 600 and 800 °C for 2 h. After the heating period, the samples were cooled in a dessicator, dispersed in a mortar and sieved to −74 μm and preserved in closed vessels containing silica gel during the experiments.

To determine the influence of heat activation, bauxite samples obtained by heating at different temperatures were subjected to standardized Cr(VI) adsorption tests. The experiments were carried out by shaking (300 cycle min^{-1}) 100 cm^3 glass conical flasks containing 1 g of activated bauxite samples and 50 cm^3 of chromate solutions having a concentration of 10 mg-Cr(VI) l^{-1} in a temperature controlled water bath (Nuve ST 402) at 20 °C for 60, 120 and 180 min. The pH of mixtures was adjusted to 2 and 3 (±0.05) by using HCl solution. The initial pH of suspensions was measured and adjusted within a few minutes from the beginning. At the end of the shaking period, suspensions were centrifuged at 7000 rpm for 10 min. In the supernatant, then, the final pH was measured and the Cr(VI) content was determined.

Since the result of standardized Cr(VI) adsorption tests showed that the most effective bauxite was the one obtained by heating at 600 °C, this sample was selected and used in the remaining study. Some physical and physicochemical properties determined for raw bauxite (RB) and activated bauxite obtained by heating at 600 °C (HAB) in our previous phosphate adsorption study (Altundoğan and Tümen, 2002, 2003) are given in Table 2.

2.3. Adsorption studies

In order to determine the influence of initial pH on adsorption, 1 g of HAB sample was contacted with the 50 cm^3 chromate solutions containing 10 mg-Cr(VI) l^{-1} with the initial pH values varying from 2 to 9 for 60 min. Following a centrifugation, the final pH was measured and the Cr(VI) concentration of supernatant was determined. In this section of study, for a comparison, raw bauxite (RB) was also subjected to the same procedure.

In the experiments where the effect of adsorbent dosage was explored, the HAB dosages of 5–40 g l^{-1} were studied for a concentration of 10 mg-Cr(VI) l^{-1} by

Table 2
Some physical and physicochemical properties of raw bauxite (RB) and heat-activated bauxite (HAB)

Properties	RB	HAB[a]
Mean particle diameter (μm)	18.54	26.34
Modal value (μm)	38.94	43.77
Single point N_2-BET surface area ($m^2\,g^{-1}$)	11.0 ± 0.5	86.0 ± 0.5
Apparent density ($g\,cm^{-3}$)	1.4713	1.3225
Skeletal density ($g\,cm^{-3}$)	2.1311	3.9844
Porosity ($cm^3\,cm^{-3}$)	0.30	0.668
Mean pore radius (μm)	3.689	0.0242
PZNPC	8.39	7.87

[a] Obtained by heating the bauxite at 600 °C for 120 min.

adjusting the initial pH to 2 (±0.05) and varying the contact time from 5 to 120 min. Thus, the effect of contact time on Cr(VI) adsorption onto HAB was also examined. For isotherm study, the solutions in various Cr(VI) initial concentrations in the range of 7.5–50 $mg\,l^{-1}$ were contacted with the HAB in the dosage of 20 $g\,l^{-1}$ for an equilibration time of 60 min.

2.4. Methods of analysis

The analysis of Cr(VI) was carried out colorimetrically with the 1,5 diphenyl carbazide method (APHA, 1989) by using a UV-1201V Model Shimadzu Spectrophotometer. The amount of adsorbed Cr(VI) was calculated from the difference in their initial and final concentrations.

The solution pH was measured using a Mettler Delta 350 pH meter.

All experiments were conducted in duplicate and average values were considered.

3. Results and discussion

3.1. Results of preliminary study

Results from preliminary study where raw bauxite (RB) and activated bauxite obtained by heating at the temperature of 200–800 °C and subjected to standardized adsorption tests at two different initial pH of 2 and 3 (±0.05) were given in Table 3. As seen, heating of bauxite has a positive effect on Cr(VI) adsorption efficiency. When the adsorption efficiency of the bauxite activated at 600 °C is compared with that of the raw bauxite, it can be seen that it increases nearly 2.4-fold by heating. However, heating of the bauxite over 600 °C decreases the adsorptivity. These results are in good agreement with those of a phosphate adsorption study (Altundoğan and Tümen, 2003) which reported that adsorptivity followed a similar trend. On the other hand, results obtained for pH 2 were found to be better than those for pH 3 probably due to a better protonation of surface at lower pHs.

Table 3
Results of preliminary study (10 $mg\,l^{-1}$ Cr(VI) solutions; adsorbent dosage: 20 $g\,l^{-1}$; ionic strength: 0.01 M NaCl; temperature: 20 °C)

Activation temp. (°C)	pH_i (±0.05)	pH_f	Contact time (min)	Cr(VI) ads. (%)
na[a]	2	4.73	60	20.8
		5.28	120	25.6
		6.49	180	26.9
200	2	4.09	60	40.9
		4.11	120	42.8
		4.21	180	42.8
400	2	4.16	60	53.0
		4.18	120	53.3
		4.22	180	54.2
600	2	3.59	60	61.3
		3.78	120	63.8
		4.01	180	64.9
800	2	4.16	60	20.8
		4.22	120	25.3
		4.52	180	25.6
na[a]	3	6.93	60	10.7
		7.32	120	11.4
		7.41	180	12.2
200	3	6.87	60	12.9
		7.11	120	13.8
		7.19	180	14.5
400	3	7.04	60	15.1
		7.18	120	16.1
		7.39	180	17.0
600	3	7.09	60	15.9
		7.12	120	16.6
		7.16	180	17.2
800	3	7.04	60	6.5
		7.11	120	6.8
		7.14	180	7.2

[a] Not activated.

In the phosphate adsorption study (Altundoğan and Tümen, 2003), it has been reported that the major factor governing the heat activation of bauxite is dehydration, which causes an increase in specific surface area and porosity depending on temperature. It has also been emphasized that further increase in temperature leads to a decline in adsorptivity probably due to a decrease in surface area by formation of more compact mineral phases such as corundum. Therefore, the bauxite sample heated at 600 °C was found to be favourable and was selected for remaining study.

3.2. Effect of pH

Since pH is an important parameter, the effect of initial pH of solution on the Cr(VI) adsorption onto heat-activated bauxite (HAB) was studied at the conditions of contact time, 60 min; adsorbent dosage, 20 $g\,l^{-1}$ and temperature, 20 °C. For a comparison, raw

bauxite (RB) was also subjected to the adsorption tests conducted at the same conditions. The results obtained at the pH range of 2–9 are shown in Fig. 1. As seen from Table 3 and Fig. 1, pH_f values are higher than pH_i values, which stems from an acid neutralisation effect and proton adsorption of hydroxylated mineral surface. These phenomena can be described by a ligand exchange mechanism proposed for phosphate adsorption on mineral surfaces (Goldberg and Sposito, 1985; Altundoğan and Tümen, 2002, 2003). It is widely believed that the mechanism for the adsorption of anions onto oxidic surfaces involves a surface complexation phenomenon in the adsorption process. Depending on the type of connection of an anion to an active surface site, the surface complexes formed are classified as inner and outer-sphere complexes. Formation of these surface complexes is mostly dependent on the degree of surface protonation or dissociation, which could be described as:

$$\equiv SOH_{(s)} + H^+_{(aq)} \leftrightarrows \equiv SOH^+_2(s) \quad (1)$$

$$\equiv SOH_{(s)} \leftrightarrows \equiv SO^-_{(s)} + H^+_{(aq)} \quad (2)$$

where S is the hydroxylated mineral surface and OH is a reactive surface hydroxyl. If the number of protonated surface groups is more than that of dissociated groups, the surface is positively charged and become suitable for anion adsorption. If the amounts of both species are equal, a condition for zero net proton charge (PZNPC) is achieved. Thus, the proposed complex-formation reactions for anions can be illustrated as:

In the case of outer-sphere complexes:

$$\equiv SOH^+_{2(s)} + A^{l-}_{(aq)} \leftrightarrows \equiv SOH^+_{2(s)} - A^{l-} \quad (3)$$

In the case of inner-sphere complexes:

$$\equiv SOH^+_{2(s)} + A^{l-}_{(aq)} \leftrightarrows \equiv SA^{(l-1)}_{(s)} + H_2O_{(l)} \quad (4)$$

where A^{l-} represents an anion.

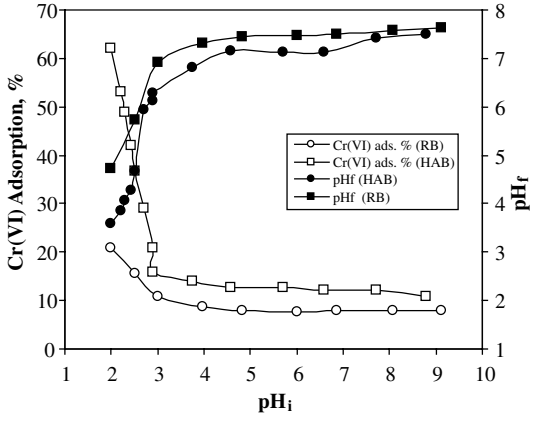

Fig. 1. The effect of pH on the Cr(VI) adsorption by raw bauxite (RB) and heat-activated bauxite (HAB) (10 mg l^{-1} Cr(VI) solutions; contact time: 60 min; adsorbent dosage: 20 g l^{-1}; ionic strength: 0.01 M NaCl; temperature: 20 °C; circle: RB; square: HAB).

On the other hand, the species of chromate anion present is dependent on the pH of aqueous solution. It is well known that the dominant species of Cr(VI) at the pH range of 2–5 is $HCrO^-_4$ (Sillen and Martell, 1964; Kotas and Stasicka, 2000). Increasing the pH will convert the $HCrO^-_4$ into the form of CrO^{2-}_4. A slight increase in pH with contact time, from pH_i to pH_f, can be explained by proton binding of the adsorbent in water, which will create positively charged sites (Eq. (1)). Protonated adsorbent surface, then, may bind chromate ions depicted in Eqs. (5) and (6) which are special forms of Eqs. (3) and (4).

$$\equiv SOH^+_{2(s)} + HCrO^-_{4(aq)} \leftrightarrows \equiv SOH^+_2 - HCrO^-_{4(s)} \quad (5)$$

$$\equiv SOH^+_2(s) + HCrO^-_4(aq) \leftrightarrows \equiv SHCrO_{4(s)} + H_2O_{(l)} \quad (6)$$

The pH change stemming from hydrolysis and adsorption must be very small at low pH, since the solutions are well buffered by the acids used in this pH range. However, significant changes found in this study may be caused by neutralizing reactions of metal oxide hydrates or carbonates, which can simultaneously occur with adsorption reactions (Eqs. (7) and (8)).

$$2H_3O^+ + MeO \cdot xH_2O \leftrightarrows Me^{2+} + (x+3)H_2O \quad (7)$$

$$2H_3O^+ + MeCO_3 \leftrightarrows Me^{2+} + 3H_2O + CO_2 \quad (8)$$

In highly acidic media of pH 2, it can be stated that the adsorbent surfaces might be highly protonated and favour the uptake of Cr(VI) in the anionic form, $HCrO^-_4$. With an increase in pH_i from 2 to 3, corresponding pH_f values (after a contact period of 60 min) increase from 3.59 to 6.93 but the adsorption efficiency dramatically decreases. With a further increase in the pH_i, from 3 to 9, the degree of protonation of the surface reduces gradually and hence decreased adsorption is observed.

3.3. Effect of HAB dosage

Fig. 2 shows the effects of contact time and HAB dosage on the adsorption of Cr(VI) from the solution of 10 mg l^{-1} at 20 °C and pH_i 2. It is obvious that the Cr(VI) adsorption yield increased with contact time from 5 to 45 min. A further increase in contact time has a negligible effect on the removal. However, although pH_i values of solutions was adjusted to 2 (±0.05), an adsorbent dosage more than 20 g l^{-1} does not exhibit an enhanced removal since the acid/HAB ratio may not be sufficient for a good protonation of active sites. Additionally, it is a fact that the increasing amount of acid-reactive metal compounds in HAB used leads to an increased acid consumption by neutralisation. The increased values in pH_f supports this idea.

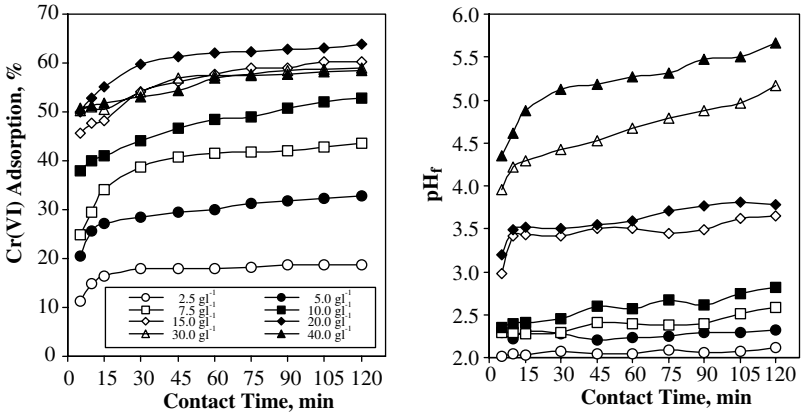

Fig. 2. The effects of adsorbent dosage and contact time on the Cr(VI) adsorption by heat-activated bauxite (HAB) (10 mg l^{-1} Cr(VI) solutions; initial pH: 2 (±0.05); ionic strength: 0.01 M NaCl; temperature: 20 °C).

3.4. Effect of temperature

Fig. 3 shows the effect of temperature on the Cr(VI) adsorption depending on contact time. Cr(VI) adsorption efficiency onto HAB decreases by increasing the temperature. For a contact time of 60 min, Cr(VI) adsorption efficiencies were found to be 61.3%, 47.0% and 27.8% at 20, 35 and 45 °C, respectively. The decreases in Cr(VI) adsorption by increasing the temperature suggest that the mechanism governing the adsorption process may be physical.

3.5. Effect of initial Cr(VI) concentration

The effect of initial Cr(VI) concentration in the range of 2.5–50 mg l^{-1} on the adsorption was investigated under the specified conditions (initial pH of 2; contact time of 60 min; adsorbent dosage of 20 g l^{-1}; and temperature of 20 °C). The Cr(VI) adsorption efficiencies and calculated adsorption densities depending on the initial concentration are shown in Fig. 4. As expected, Cr(VI) adsorption percentage decreased by increasing initial concentration. While the Cr(VI) adsorption yield was found as 87.2% for 2.5 mg l^{-1} of initial concentration, this value was 19.4 for that of 50 mg l^{-1}.

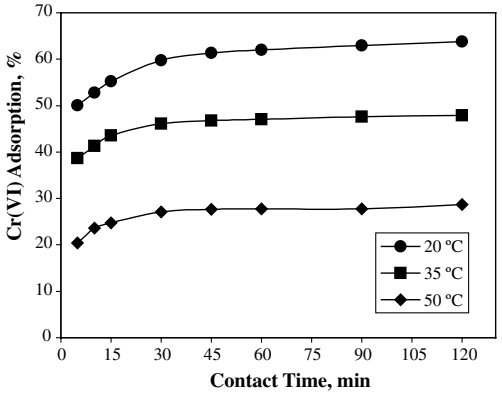

Fig. 3. The effect of temperature on the Cr(VI) adsorption by heat-activated bauxite (HAB) (10 mg l^{-1} Cr(VI) solutions; initial pH: 2; adsorbent dosage: 20 g l^{-1}; ionic strength: 0.01 M NaCl).

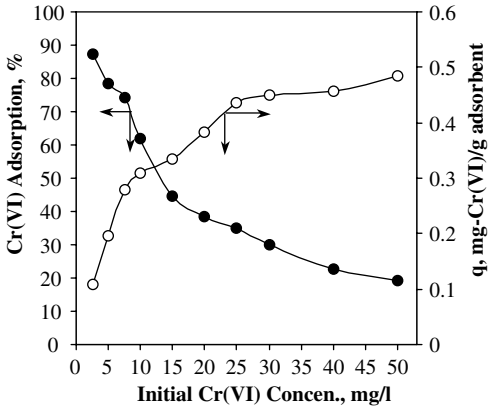

Fig. 4. The effect of initial Cr(VI) concentration on the Cr(VI) adsorption by activated bauxite (initial pH: 2; contact time: 60 min; adsorbent dosage: 20 g l^{-1}; ionic strength: 0.01 M NaCl; temperature: 20 °C).

3.6. Cr(VI) adsorption kinetics

Kinetic analyses were made on the basis of effect of temperature on the Cr(VI) removal depending on contact time (Fig. 3). As seen from the figure, Cr(VI) adsorption is equilibrated at the end of 60 min for all temperatures. Data obtained in this study were fitted to the following first-order rate expression of Lagergren (Fig. 5):

$$\ln(q_e - q) = \ln q_e - k_{ads} t \quad (9)$$

where q_e and q are the amounts of Cr(VI) adsorbed at the equilibrium and at any time (t) and k_{ads} is adsorption rate constant. It is evident from Fig. 5 that the linear plot of $\ln(q_e - q)$ vs t shows the applicability of the

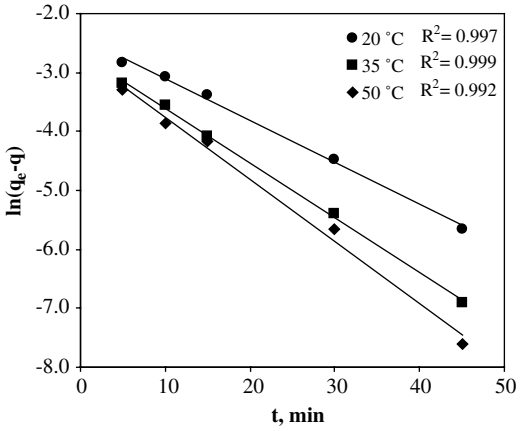

Fig. 5. Lagergren plot for the adsorption of Cr(VI) on activated bauxite (10 mg l^{-1} Cr(VI) solutions; initial pH: 2; adsorbent dosage: 20 g l^{-1}; ionic strength: 0.01 M NaCl).

Lagergren equation. Correlation coefficients (R^2) for 20, 35 and 50 °C were calculated as 0.997, 0.999 and 0.992, respectively. The k_{ads} values, calculated from the slopes of the lines in figure, are 0.072, 0.093 and 0.106 min^{-1} for 20, 35 and 50 °C, respectively. The activation energy for Cr(VI) adsorption onto HAB can be calculated by using the Arrhenius equation described below:

$$k = Ae^{-Ea/RT} \tag{10}$$

where k is rate constant at temperature of T (K), A is frequency factor, R is universal gas constant (8.314 J mol^{-1} K^{-1}) and Ea (J mol^{-1}) is activation energy for the process. When the $\ln k$ values are plotted vs $1/T$, activation energy value can be calculated from the slope of the line obtained. The Arrhenius plot for Cr(VI) adsorption on HAB is shown in Fig. 6. Calculated activation energy value for the adsorption process is 10.27 kJ mol^{-1}. This low value of activation energy suggests that the adsorption process is governed by physical forces.

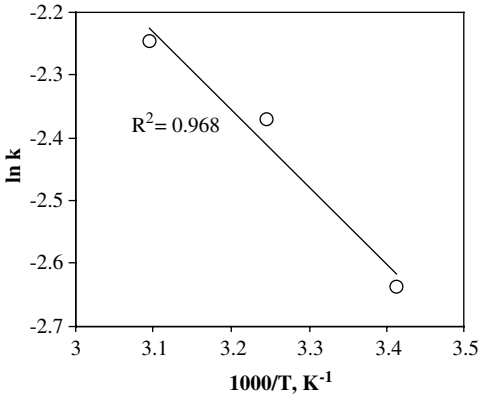

Fig. 6. Arrhenius plot for the Cr(VI) adsorption onto HAB.

3.7. Adsorption isotherms and thermodynamic parameters

As discussed in earlier sections, the adsorption of Cr(VI) onto HAB was found to be concentration and temperature dependent. The experimental data obtained under the various concentrations and temperatures were plotted in a linearised form of Langmuir and Freundlich adsorption isotherms (Eqs. (11) and (12), respectively):

$$C_e/q_e = 1/(bQ^\circ) + C_e/Q^\circ \tag{11}$$

$$\ln q_e = \ln K_F + n \ln C_e \tag{12}$$

where C_e is equilibrium concentration (mg l^{-1}), q_e is amount adsorbed at equilibrium (mg g^{-1}), Q°, b, K and n are isotherm constants. Q° and K_F are defined as adsorption maxima or adsorption capacity (mg g^{-1}) for Langmuir and Freundlich isotherms, respectively.

Langmuir and Freundlich plots for the adsorption of Cr(VI) on HAB are shown in Fig. 7. Calculated correlation coefficients and isotherm parameters for both equations at different temperatures are also given in Table 4. The Langmuir equation fits best the experimental data. As seen from the table, estimated Langmuir adsorption capacity values decrease by increasing the temperature. The other Langmuir parameter b shows a similar trend. It can be concluded that the nature of Cr(VI) adsorption on the HAB is physical. Also, the activation energy value calculated for this process supports this idea.

Some thermodynamic evaluations can be made from the results of isotherm studies. Standard Gibbs free energy (ΔG°), standard enthalpy (ΔH°) and entropy (ΔS°) changes for the Cr(VI) adsorption process have been calculated from Eqs. (13)–(15), respectively.

$$\ln(1/b) = \Delta G^\circ/RT \tag{13}$$

$$\ln b = \ln b_o - \Delta H^\circ/RT \tag{14}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \tag{15}$$

Where, b is Langmuir constant which is related with the energy of adsorption, b_o is a constant, R is ideal gas constant and T is temperature (K).

Calculated values of thermodynamic parameters ΔG° and ΔS° are given in Table 5. It can be stated that the Cr(VI) adsorption on the HAB is an exothermic phenomenon from calculated ΔH° value of –33.238 kJ g mol^{-1}. This result can also be seen from estimated Q° values (Table 4). The negative Gibbs' free energy values indicate the adsorption is spontaneous. The increase in free energy change with the rise in temperature shows an increase in feasibility of adsorption at lower temperatures. The negative values of entropy change suggest no structural changes in adsorbate and adsorbent.

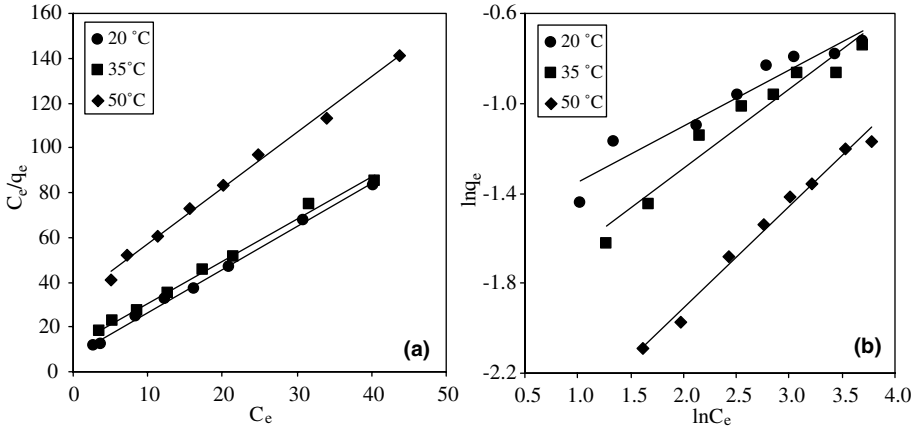

Fig. 7. Langmuir (a) and Freundlich (b) plots for Cr(VI) adsorption by HAB.

Table 4
Calculated correlation coefficients and isotherm parameters for Langmuir and Freundlich models

Temperature (°C)	Langmuir isotherm			Freundlich isotherm		
	r^2	b ($l\,mg^{-1}$)	$Q°$ ($mg\,g^{-1}$)	r^2	K_F ($mg\,g^{-1}$)	n
20	0.9966	0.276	0.522	0.9276	0.202	0.249
35	0.9938	0.168	0.502	0.9457	0.137	0.350
50	0.9945	0.077	0.403	0.9861	0.060	0.450

Table 5
Thermodynamic parameters for the adsorption of Cr(VI) on HAB

Temperature (°C)	$-\Delta G°$ ($kJ\,gmol^{-1}$)	$-\Delta S°$ ($kJ\,gmol^{-1}\,K^{-1}$)
20	23.317	0.034
35	23.239	0.032
50	22.276	0.034

4. Conclusions

The following conclusions can be drawn from this study in which heat-activated bauxite (HAB) was used as an adsorbent for Cr(VI) adsorption from aqueous solution.

Cr(VI) adsorption capacity of bauxite increases with heating up to 600 °C. Adsorption of Cr(VI) on HAB is highly pH and temperature dependent. For the solution of 10 mg-Cr(VI) l^{-1}, the maximum adsorption yield is found as 64.9% at the conditions of adsorbent dosage: 20 $g\,l^{-1}$, pH: 2 and temperature: 20 °C.

The kinetic studies indicated that equilibrium in the adsorption of Cr(VI) on HAB was reached in the contact time of 60 min. The first-order rate constant for Cr(VI) adsorption on HAB has been found to be 0.072 min^{-1} at 20 °C, and it decreases with increasing the temperature.

That the adsorption capacity decreases with an increase in temperature shows that the adsorption process is exothermic.

Although the heat activation of bauxite provides an increased adsorption for Cr(VI), the adsorption capacity is still rather limited. Since the further experiments showed that acid-washing of heated-bauxite exhibited more enhanced Cr(VI) adsorption efficiency, our future research will be focused on acid activation of bauxite for chromate removal.

Bauxite is one of the abundant minerals and widely used as a raw material for alumina production by the Bayer Process. In spite of the fact that it has low Cr(VI) adsorption capacity, the use of the activated bauxite for adsorption of Cr(VI) from wastewater streams having low Cr(VI) concentration seems to be feasible. Bauxite ground for alumina production, can be utilized in Cr(VI) adsorption before the production and Cr(VI) adsorbed-bauxite can be recycled to the Bayer Process. Therefore, it can be concluded that the bauxite may be used as a low-cost adsorbent for Cr(VI) removal especially in districts of bauxite mining or alumina production.

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