



Chromium (VI) adsorption on boehmite

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ABSTRACT

Boehmite was synthesized and characterized in order to study the adsorption behavior and the removal of Cr(VI) ions from aqueous solutions as a function of contact time, initial pH solution, amount of adsorbent and initial metal ion concentration, using batch technique. Adsorption data of Cr(VI) on the boehmite were analyzed according to Freundlich, Langmuir and Dubinin–Radushkevich (D–R) adsorption models. Thermodynamic parameters for the adsorption system were determined at 293, 303, 313 and 323 K temperatures. The kinetic values and thermodynamic parameters from the adsorption process show that the Cr(VI) ions adsorption on boehmite is an endothermic and spontaneous process. These results show that the boehmite could be considered as a potential adsorbent for chromium ions in aqueous solutions.

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1. Introduction

In recent years, the use of inorganic materials in the adsorption process as adsorbent for removing heavy metals from polluted wastewater has come to the forefront [1–3]. Inorganic materials have proved to be useful and of common use due to their low costs and high effectiveness [4]. Their greatest advantage is that adsorption occurs and allows in the separation of small amounts of substances from a large volume of solution. A universal adsorbent has not been found yet, neither a perfect adsorbent for any given purpose has been developed. Knowledge of adsorptive properties of inorganic materials has become considerably important in many fields. The primary requirement for an economic adsorption process is an adsorbent with sufficient selectivity, high sorption capacity and resistance to high temperatures and high radiation levels. Up till now many researchers have studied the adsorption of chromium on different adsorbents [5–7].

Boehmite (γ -AlOOH) is an important precursor material for γ -Al₂O₃, which has been extensively used as catalyst support, adsorbent [8] and membrane, due to its high specific surface area and mesoporous properties. Another important application of boehmite is to produce α -Al₂O₃ by calcinations at high temperatures. The chemical and physical properties of boehmite are very much dependent on the experimental factors of its synthesis, such as the nature of Al(III)-salt, pH, temperature, time of aging, etc.

[9]. It is well known that boehmite possesses excellent mechanical, electrical, thermal and optical properties. The crystalline structure of boehmite has an essential effect on the characteristics of transition aluminas and the phase transition temperature of aluminas [10,11]. Moreover, boehmite is an energy-saving precursor material for the production of alumina, although it dehydrates at higher temperature than gibbsite. This is attributed to the low enthalpy of the dehydration reaction of boehmite compared to gibbsite. The structure of all transition aluminas is based on a face-centered cubic array of oxygen anions [12]. The structural differences between these forms only involve the arrangement of aluminum cations in the interstices of the face-centered cubic array of oxygen anions. Boehmite was thought to exist under two distinct forms, well-crystallized boehmite and pseudoboehmite, with significantly different morphologies, porosity and surface areas, but it was found that pseudoboehmite is simply micro- or rather nano-crystallized boehmite [13]. Thus, boehmite was selected as a model adsorbent because it possesses well-defined properties and has been extensively utilized as a representative aluminum oxyhydroxide phase (α -AlOOH) [14,15]; however, there are no reports on adsorption kinetics and thermodynamic parameters of chromium ions on boehmite.

The aim of this work is to examine the Cr(VI) ions adsorption behavior from aqueous solution on boehmite synthesized by batch method as a function of contact time, initial pH solution, initial metal ion concentration and amount of adsorbent. Additionally, some of the kinetic and thermodynamic parameters were determined to interpret and elucidate how the adsorption mechanism of chromium ions works.

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2. Materials and methods

2.1. Materials

All chemicals and reagents used in this work had a pure analytical quality. In all experiments, deionized water was used for preparation, dilution and analytical purposes of solutions.

2.2. Adsorbent preparation

The boehmite was synthesized via sol-gel method at 298 K by drop-wise addition of isopropanol and water mixture under vigorous stirring, in 100 mL of 0.5 mol L⁻¹ aluminum isopropoxide/isopropanol solution during 24 h to obtain a homogenization. For a complete hydrolyzation, mixture was heated in a reflux system at 328 K for 5 h. The obtained solid was filtered and washed with deionized water and the material was dried at 353 K [16].

2.3. Adsorbent characterization

The solid sample was characterized by X-ray diffraction using a Siemens D-5000 diffractometer coupled to a copper anode X-ray tube. The K_α radiation was selected with a diffracted beam monochromator. The compound was identified by comparing it with the JCPDS cards in the conventional way. Specific surface area and total pore volume of boehmite were measured by the N₂ Brunauer-Emmett-Teller (BET) method in a surface area analyzer Micromeritics Gemini 2360. A stock solution of chromium (VI) ions was prepared by dissolving of K₂Cr₂O₇ (Merck) in deionized water. Solutions with the desired concentrations (10⁻⁴ to 10⁻⁵ mol L⁻¹) of Cr(VI) were prepared by successive dilutions of the stock solution. The pH of the chromium solutions was adjusted by adding aqueous solutions of NH₄OH or HNO₃, for pH measurements of the aqueous solutions. A digital pH meter (Cole-Parmer model 05669-20) combined with a glass electrode was used for all experiments. Chromium concentrations in remaining solutions was determined by using a Shimadzu ultraviolet-visible 265 spectrophotometer analyzer at λ = 540 nm using the 1,5-diphenylcarbazide method [17].

2.4. Effect of contact time

Time of contact of adsorbent and adsorbate is of great importance in adsorption since contact time depends on the nature of the system used. Adsorption experiments for Cr(VI) on boehmite were carried out as follows: to each of the 0.1 g boehmite samples, 10 mL of solution containing 1 × 10⁻⁴ mol L⁻¹ of K₂Cr₂O₇ was added. The samples were shaken at room temperature for periods ranging from 5 min to 72 h, and then centrifuged and 5 mL portions of liquid phases were measured.

2.5. Effect of pH

The pH of the aqueous solution is a significant controlling factor in adsorption mechanism, in order to optimize the pH for maximum removal efficiency, batch experiments at room temperature were carried out by taking in contact 10 mL of chromium solution (1 × 10⁻⁴ mol L⁻¹ of K₂Cr₂O₇) with 0.1 g of boehmite for 1 h of shaking time (period needed to reach the complete adsorption equilibrium between the two phases was), at several pH values (3–13), adjusting continuously the solution pH with HNO₃ and NH₄OH solutions and the percentage uptake of the synthesized boehmite was obtained.

2.6. Effect of amount of adsorbent

Under optimum conditions of shaking time and pH, the effect of adsorbent dosage on adsorption of chromium was studied by shaking 10 mL of metal solution (1 × 10⁻⁴ mol L⁻¹ of K₂Cr₂O₇) with 0.02–0.12 g of adsorbent for 1 h at room temperature and at constant pH 5.5.

2.7. Adsorption experiments

Prior to use, the p*H*_{zpc} (point of zero charge) of samples was determined by using a DT300 Dispersion Technology equipment. Adsorption experiments were carried out in batch mode by mixing 0.1 g of boehmite and 10 mL of chromium solution in close vials, continuously shaking at different time intervals to attain equilibrium distribution in the studied system on a water bath flask shaker at fixed temperature. After shaking, solutions were centrifuged, and the percentage of chromium adsorbed by the boehmite was determined from the difference between initial [C]_i and final [C]_f concentrations of chromium ion in aqueous solution, before and after contact. The following equation was used for calculus:

$$\% \text{adsorption} = \frac{[C]_i - [C]_f}{[C]_i} \times 100 \quad (1)$$

In the formula C_i and C_f denote, respectively, the initial and final concentration of chromium ions in the solution. All experiments were carried out at room temperature except in the temperature dependence study where the temperature was varied from 293 to 323 K.

2.8. Effect of initial concentration

In adsorption processes, the concentration of the metal ion also plays an important role. For this investigation, the Cr(VI) adsorption on boehmite was studied at a constant amount of boehmite 0.1 g and varying chromium concentrations (10⁻⁴ to 10⁻⁵ mol L⁻¹) in the aqueous phase at pH 5.5, room temperature and 1 h of contact time. Experimental data obtained from this study, were evaluated with Freundlich, Langmuir and Dubinin-Radushkevich (D-R) isotherms models.

2.9. Effect of temperature

Temperature dependence on the adsorption process is associated with several thermodynamic parameters. The effect of temperature on the chromium removal was investigated by performing batch experiments at 293–323 K, initial metal ion concentration of 1 × 10⁻⁴ mol L⁻¹, contact time, 1 h and initial pH 5.5 on boehmite.

3. Results and discussions

3.1. Adsorbent characterization

X-ray diffraction patterns showed that boehmite was obtained in the synthesized samples. This synthesis produces a fine white powder of nano-crystalline boehmite. The X-ray diffraction pattern of the synthetic boehmite sample is shown in Fig. 1. According to this synthesis, the boehmite sample showed a typical boehmite-type pattern when the compound was identified by making a comparison with the JCPDA 21-1307 card in the conventional way. The presence of sharp and intense lines at low values of the 2θ angle and less intense and fairly asymmetric lines at higher angular values, shows a moderate broadening of the lines due to crystallite

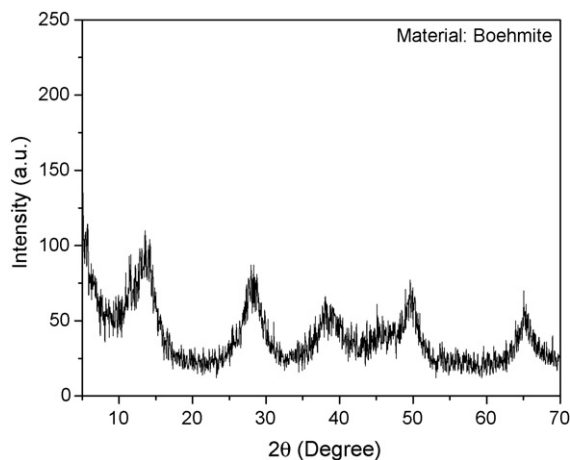


Fig. 1. X-ray diffraction (XRD) pattern of the synthetic boehmite sample.

size (700–1000 Å), analyzed by Sherrer equation [18]. The powder diffraction pattern of the boehmite after chromium adsorption did not show any important changes; therefore, the crystal structure was confirmed by powder X-ray diffraction. Specific surface area of boehmite was $224 \text{ m}^2 \text{ g}^{-1}$ and the total pore volume was $0.1527 \text{ cm}^3 \text{ g}^{-1}$. In general, those results are within the reported range in literature [19,20].

3.2. Effect of contact time

The adsorption processes as a function of time to determine the point of equilibrium were studied from adsorption experiments of Cr(VI) ions onto boehmite. These experiments were carried out at an initial pH 5.5, that is without pH adjustment, in the presence of $1 \times 10^{-4} \text{ mol L}^{-1} \text{ K}_2\text{Cr}_2\text{O}_7$ at room temperature. All experiments were run twice and a good reproducibility of the procedures was obtained. The results are shown in Fig. 2, where it is clear that adsorption of Cr(VI) ions into boehmite is rather quick and after 1 h the complete adsorption equilibrium between the two phases is obtained. The amount of Cr(VI) ions removed reached a maximum of $7.28 \times 10^{-4} \text{ mmol g}^{-1}$. No further adsorption above the quantity obtained in 1 h of contact time was obtained by placing adsorbent samples in contact with Cr(VI) solutions for 3 days of shaking time. This behavior shows that adsorption of Cr(VI) ions occurred in a single step and that the slow adsorption before 1 h can be explained

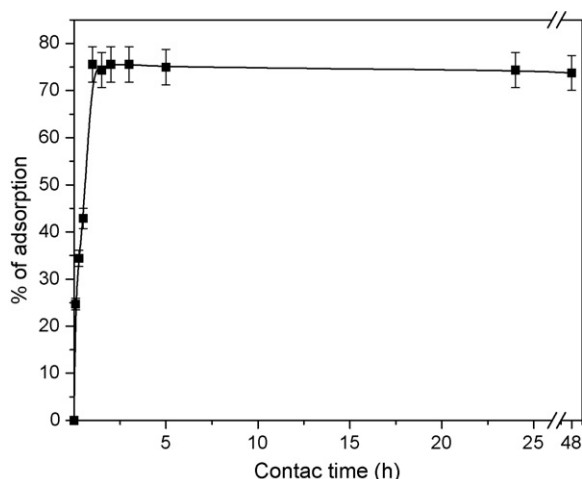


Fig. 2. Adsorption of Cr(VI) ions on boehmite as a function of contact time.

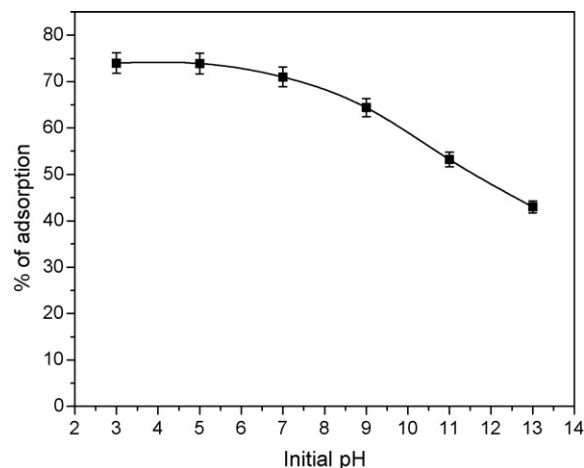


Fig. 3. Influence of initial pH on Cr(VI) ions adsorption.

by ion exchange of the chromium ions on the surface of boehmite [21].

3.3. Effect of pH

In adsorption processes, the adsorption of metal ions on mineral surfaces can be reduced or increased by the initial pH values of the solutions, due to interactions of metal ions with adsorbed functional groups on the mineral surfaces that are weaker than interactions with the surface hydroxyls of the mineral. Some experiments were carried out to examine the influence of initial pH on the adsorption of chromium ions with $1 \times 10^{-4} \text{ mol L}^{-1}$ solutions. The initial pH of chromium solutions was adjusted from 3 to 13 with HNO_3 and NH_4OH solutions. The pH stability was verified by periodic measurement. The results obtained are shown in Fig. 3. In boehmite, Cr(VI) adsorption follows a typical metal anion adsorption behavior, where negligible adsorption occurs at a high pH and a sharp decrease in adsorption in alkaline media, therefore, for anionic chemical species, adsorption decreased when alkaline media is increased [22]. So, it would be expected that the maximum adsorption of chromium ions could occur at higher acid pH values, because, at initial acid media the chromium ions form negatively charged the hydrolyzed species. Chromium is an active metal that exists in several oxidation states, the most stable in aqueous solution being the hexavalent, Cr(VI) and the trivalent, Cr(III). In solution at pH higher than 5.5, Cr(VI) is present in form of CrO_4^{2-} ions [23]. At lower pH values, the Cr(VI) is present either as HCrO_4^- or as $\text{Cr}_2\text{O}_7^{2-}$ depending on the Cr concentration, which is adsorbed onto the boehmite surface, thereby leading to high percentage of adsorption. The increase of alkaline media suppresses the hydrolysis of chromium ions leading to lower percentage adsorption values and the boehmite acts as ion exchanger. However, the maximum adsorption of chromium ions occurred at slightly initial acid pH values. Solutes interact with mineral surfaces because they have acquired an electrical surface charge, because of the reactions involving functional groups (H^+ , OH^-) on the mineral surface and ions in solution. A pH_{zpc} (point of zero charge) of 8.6 has been previously reported for boehmite [14], additionally the pH_{zpc} of boehmite was determined and was found to be 8.4. Then, only anionic species could be adsorbed on this material below of their (zero point charge, zpc) value. Anionic Cr(VI) species could be retained on the charged surfaces of boehmite. Results show that the electrical properties of the surface of this material, that is the charge of the surface groups, are in part responsible for the Cr(VI) ions adsorption. Therefore, Cr(VI) species adsorption on boehmite

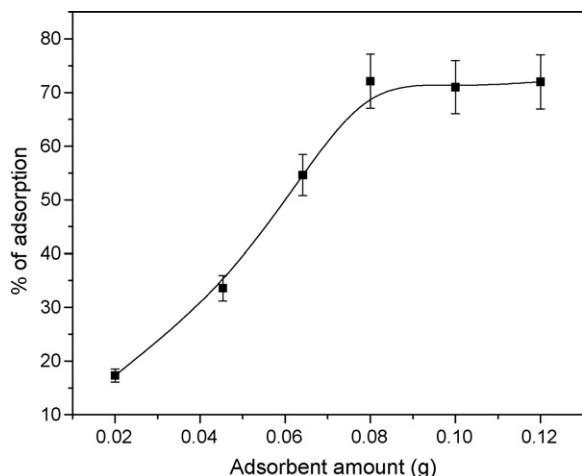


Fig. 4. Dependence of Cr(VI) ions adsorption on the amount of adsorbent.

is partially attributed to the direct exchange of ions with a specific group on an adsorbing surface, according to the concept of zpc.

3.4. Effect of amount of adsorbent

The results from the dependence of chromium adsorption by variation of different amount of boehmite in the system was carried out at pH 5.5 and equilibration time of 1 h for the adsorption process and they are presented in Fig. 4. Removal efficiency was found to increase proportionally with the amount of boehmite until a certain value was reached; afterwards, the removal efficiency is maintained constant even if boehmite is added. So, 0.08 g of adsorbent is enough for the quantitative removal of chromium from wastewater.

3.5. Effect of initial concentration

Assessment of the effect of initial concentration on the adsorption of chromium on boehmite was carried out by varying the adsorptive concentrations (10^{-4} to 10^{-5} mol L $^{-1}$) at 293 K for 1 h and the results of the adsorption of Cr(VI) ions are shown in Fig. 5. It was found that the adsorption of Cr(VI) onto boehmite was strongly dependent on initial metal ion concentration. As is seen in Fig. 5, the percentage of adsorption decreased when initial concentration of

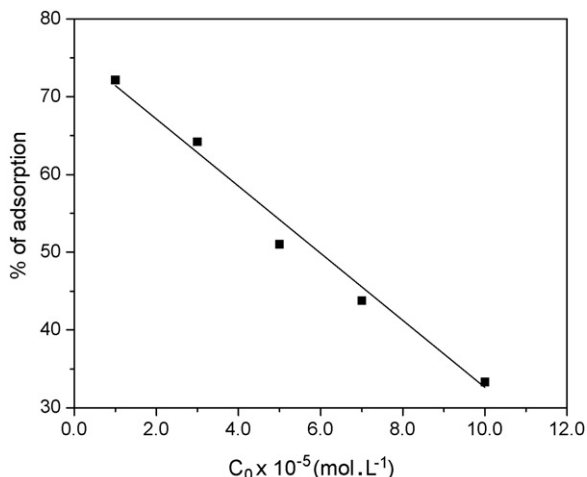


Fig. 5. Effect of Cr(VI) ions initial concentration on its adsorption.

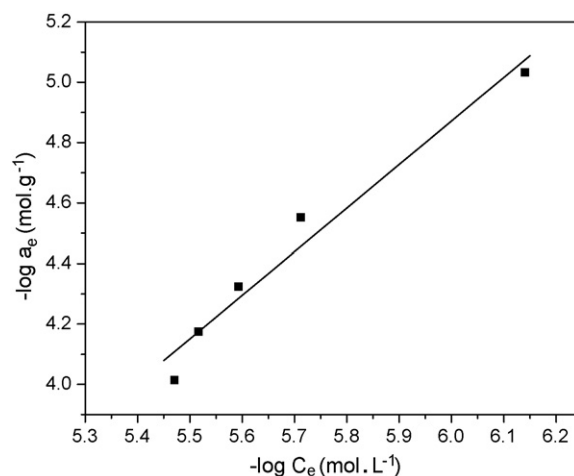


Fig. 6. Freundlich adsorption isotherm for Cr(VI) ions adsorption on boehmite.

chromium ions increased. The increase of adsorption is explained by the interaction of metal ions adsorbed onto the surfaces, by a mechanism that involves specific metal ion adsorption at a limited number of surface sites, because there are more surface active sites per gram of sorbent available for deposition at higher dilution.

3.6. Adsorption isotherms

In order to describe the chromium adsorption behavior in the boehmite, isotherms data obtained were fitted to the Freundlich, Langmuir and Dubinin–Radushkevich adsorption models. The Freundlich behavior was tested by the following equation:

$$\log a_e = \frac{1}{n} \log C_e + \log K \quad (2)$$

where a_e is the amount of chromium adsorbed at equilibrium (mol g $^{-1}$), C_e is the equilibrium concentration of chromium in solution (mol L $^{-1}$) and K as well as $1/n$ are Freundlich constants. The values of $1/n$ and K , which roughly correspond to the adsorption intensity and maximum adsorption capacity, respectively, they were evaluated with the help of slope and intercept of the linear plot shown in Fig. 6 and were found to be 0.670 ± 0.002 and $(1.88 \pm 0.02) \times 10^{-3}$ mol g $^{-1}$, respectively. This empirical model can be applied to non-ideal adsorption on heterogeneous surfaces as well as multilayer adsorption. Relatively higher fractional values of $1/n$ ($0 < 1/n < 1$) indicate a fair validity of classical Freundlich isotherm over the entire concentration of chromium and according to the correlation coefficient ($R^2 = 0.9907$), this isotherm shows flexibility to fit the experimental results. The obtained fractional value of $1/n$ was assigned due to the heterogeneous nature of adsorbent surface with an exponential distribution of the adsorption energy of sites [24].

The adsorption data were also tested using Langmuir isotherm equation in the linearized form:

$$\frac{C_e}{a_e} = \frac{1}{K a_{\max}} + \frac{C_e}{a_{\max}} \quad (3)$$

where C_e is the equilibrium concentration of the metal ion in solution (mol L $^{-1}$), a_e is the amount of chromium adsorbed at equilibrium (mol g $^{-1}$), and K and a_{\max} are Langmuir constants, related to the binding constant and the maximum adsorption capacity, respectively. Langmuir equation is probably the most widely applied model for isotherm adsorption, it considers that the adsorption energy of each molecule is the same, independently of the surface of material, the adsorption takes place only on some sites

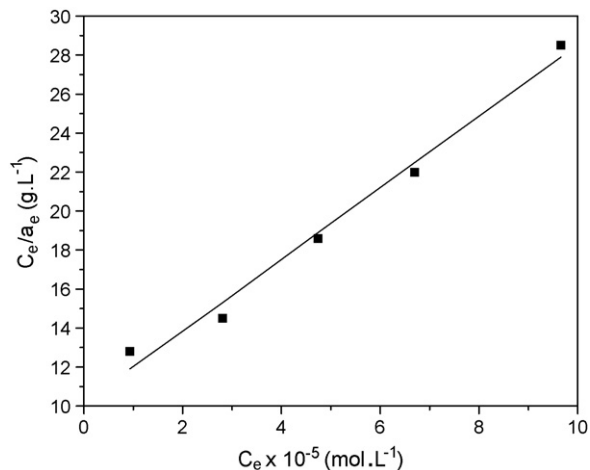


Fig. 7. Langmuir adsorption isotherm for Cr(VI) ions adsorption on boehmite.

and there are no interactions between the molecules. A linear plot was obtained when C_e/a_e was plotted against C_e (Fig. 7) over the entire concentration range evaluated, the straight line indicates that the adsorption complies with the Langmuir model as shown in Fig. 6. The slope of the plot is $a_{\max} = (5.432 \pm 0.01) \times 10^{-6} \text{ mol g}^{-1}$ and intercept is $K = (1.81 \pm 0.1) \times 10^4 \text{ dm}^3 \text{ mol}^{-1}$, with a higher correlation coefficient ($R^2 = 0.9930$). On the other hand, data were also tested with D–R equation in the linearized form [25,26]:

$$\ln C_e = \ln a_{\max} - \beta \varepsilon^2 \quad (4)$$

where β is a constant and ε is Polanyi potential which is equal to

$$\varepsilon = RT \ln \left(1 + \frac{1}{C_e} \right) \quad (5)$$

where R is the gas constant, $8.314 \times 10^{-3} \text{ kJ mol}^{-1} \text{ K}^{-1}$ and T is the absolute temperature in K. A plot of $\ln a_e$ vs. ε^2 is shown in Fig. 8. The straight line indicates that the adsorption data are well adjusted to D–R model in all concentrations of Cr(VI) ions studied. The obtained values of maximum amount of chromium that can be adsorbed on boehmite and the mean adsorption energy from the slope and intercept of this straight line were $a_{\max} = (5.90 \pm 0.04) \times 10^{-5} \text{ mol g}^{-1}$ and $E = 9.80 \pm 0.10 \text{ kJ mol}^{-1}$, respectively, with a correlation coefficient ($R^2 = 0.9912$). The adsorption energy mean E , which is the free energy mean of transference for 1 mol of solute from infinity (in solution) to the surface of boehmite, was evaluated using

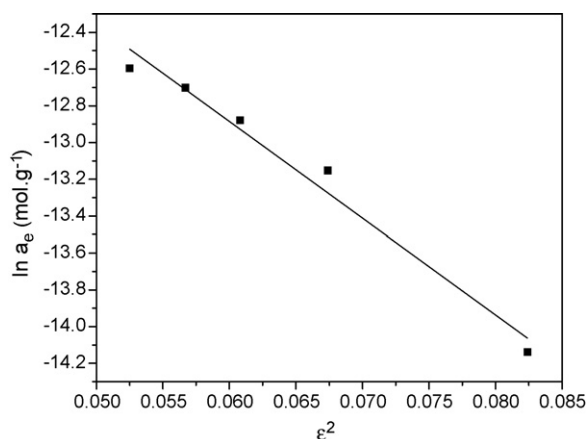


Fig. 8. Dubinin–Radushkevich (D–R) adsorption isotherm for Cr(VI) ions adsorption on boehmite.

Table 1

Temperature effect on the percentage of Cr(VI) ions adsorbed on boehmite at equilibrium

Temperature (K)	Percentage sorbed (%)
293	70.9 ± 0.1
303	76.6 ± 0.2
313	83.7 ± 0.1
323	86.8 ± 0.1

the relation $E = 1/\sqrt{-2\beta}$ with $\beta = -0.0052 \text{ mol}^2 \text{ kJ}^{-2}$. The obtained value of E is in the expected range of 8–16 kJ mol^{-1} for ion exchange phenomena [27].

3.7. Effect of temperature

The effect of temperature in the adsorption of chromium (VI) ions on boehmite was also investigated. The temperature was varied from 293 to 323 K at pH 5.5, contact time of 2 h and chromium ions concentration of $1 \times 10^{-4} \text{ mol L}^{-1}$. It was observed that the adsorption of chromium ions at various temperatures increases with the increase of temperature (Table 1), this fact indicates that there is a better adsorption at higher temperature. The increase in amount of chromium adsorbed with an increase in temperature is provoked by more mobility of the ionic species present in the bulk solution, with acceleration of some originally slow adsorption steps or by creation of some new active sites on the adsorbent surface.

Data from Cr(VI) ions adsorption at different temperatures were tested with the first-order rate law Lagergren equation:

$$\log(a_e - a_t) = \log a_e - \frac{k_1}{2.303} t \quad (6)$$

where a_e and a_t are the concentrations of Cr(VI) adsorbed at equilibrium and at contact time interval t , respectively; k_1 is the overall adsorption rate constant. Adsorption rate constants at different temperatures have been estimated from the slopes of straight lines obtained from $\log(a_e - a_t)$ vs. time plots. Obtained values are listed in Table 2 is worthy to note that the adsorption rate for the system increase when temperature is increased, this is in agreement with the reported literature [28]. This behavior indicates that the boehmite has more affinity for Cr(VI) when the temperature increases. Meanwhile the Arrhenius plots of $\log k_1$ vs. $1/T$ (Fig. 9) gave the activation energy for the adsorption process of Cr(VI) ions as $E_a = (2.315 \pm 0.3) \times 10^{-2} \text{ kJ mol}^{-1}$. This value of activation energy for the system indicates that processes of adsorption occurs even under normal conditions of temperature and pressure; it also indicates that the barriers to adsorption are low and the rate-determining step does not involve complex series of rearrangements of ions or molecules.

Data of chromium adsorbed at equilibrium at different temperatures have been used to evaluate the thermodynamic parameters ΔH° , ΔS° and ΔG° for the adsorption system by using the following equations:

$$\log K_d = -\frac{\Delta H^\circ}{2.303R} \left(\frac{1}{T} \right) + \frac{\Delta S^\circ}{2.303R} \quad (7)$$

Table 2

Kinetics parameters for adsorption of Cr(VI) ions on boehmite as a function of temperature: initial concentration of adsorptive solution, $1.0 \times 10^{-5} \text{ mol L}^{-1}$; initial pH 5.5

Temperature (K)	Rate constants ($\times 10^{-2} \text{ min}^{-1}$)
293	7.1 ± 0.02
303	7.5 ± 0.01
313	11.1 ± 0.01
323	16.9 ± 0.13

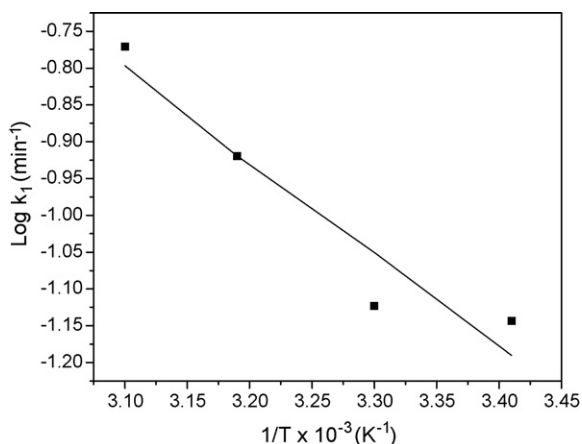


Fig. 9. Arrhenius plot for Cr(VI) ions adsorption on boehmite.

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

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (9)$$

where ΔH° , ΔS° , ΔG° and T are, respectively, the enthalpy change, entropy change, Gibbs free energy of adsorption and absolute temperature in K; R is the universal gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$). Enthalpy change was calculated from the slope of straight line plot between $\log K_d$ and $1/T$ in Fig. 10, derived from application of the van't Hoff equation in linearized form [25]:

$$\log K_d = \frac{-\Delta H^\circ}{2.303RT} + \text{constant} \quad (10)$$

Enthalpy change, obtained was $\Delta H^\circ = 11.94 \pm 0.3 \text{ kJ mol}^{-1}$, where positive value indicates an endothermic nature of the adsorption process. The magnitude of ΔH° is related to the reaction mechanism. If ΔH° is in the range of $8\text{--}16 \text{ kJ mol}^{-1}$, adsorption is governed by ion exchange [27,29].

The value of ΔS° was also estimated from the intercept of plot with y -axis from Fig. 10, whereas ΔG° was evaluated using Eq. (8). ΔG° was found to be $-8.77 \pm 2.0 \text{ kJ mol}^{-1}$; its negative value reveals the spontaneity of the adsorption process. Meanwhile ΔS° was found to be $(7.0 \pm 0.2) \times 10^{-2} \text{ kJ K}^{-1} \text{ mol}^{-1}$ and its positive value suggests the increase in randomness at the solid solution interface by the fixation of chromium ions on the boehmite. When the ions are adsorbed at the surface of boehmite, water molecules that were previously bounded to the metal ions are released and dispersed in the solution, resulting in an increase in the entropy change.

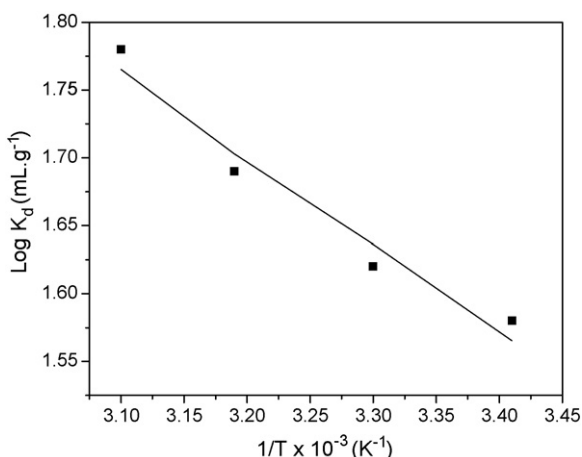


Fig. 10. Plot of $\log K_d$ vs. $1/T$ for Cr(VI) ions adsorption on boehmite.

Therefore, the results indicate that boehmite is an adsorbent for the removal of Cr(VI) ions from aqueous solutions under the tested experimental conditions. The benefits of using boehmite instead of other solids, for example, composite alginate–goethite beads, nanocrystalline akaganeite and aniline formaldehyde [28,30,31], is that the metallic oxides used as sorbents as boehmite are useful for the extraction and recovery of metallic ions due to their great thermal stability, chemical resistance and low solubility in a wide pH interval. Thus, boehmite, a solid rich in aluminates, may be useful for the removal of pollutants in water in specific chromium with good results.

4. Conclusions

Boehmite has been prepared and characterized in this study. Adsorption equilibrium is attained within a short contact time of 1 h and the ion exchange of chromium ions at the surface of boehmite controls the adsorption process. The Cr(VI) ions adsorption was favored at higher temperatures and at slightly initial acid pH values in the equilibrium. Experimental isotherms of Cr(VI) ions were successfully fit to Freundlich, Langmuir and Dubinin–Radushkevich isotherms models over all concentration range studied. The main energy of adsorption was calculated using the linearized form of D–R adsorption isotherm. The values of ΔH° , ΔS° and ΔG° prove that the adsorption of chromium ions on boehmite is an endothermic and a spontaneous process. The results indicate that boehmite is an effective adsorbent for the removal of Cr(VI) ions from aqueous solutions under the tested experimental conditions, and it could be useful in the treatment processes of industrial wastes or for analytical applications.

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