

## Application in chromium (VI) removal of natural and dried cactus

F. Sakr\*, A. Sennaoui, M. Dinne, S. Alahiane, I. Bakas, M. Belmoden, A. Assabbane

*Laboratory of Electrochemistry, Catalysis and Environment, Team Catalysis and Environment, Faculty of Science, Ibn Zohr University, Agadir, Morocco*

### Abstract

This research presents two type of cactus (*Opuntia ficus-indica*) (natural cactus (NC) and dried cactus (DC)) as a biological adsorbent, evaluated for the effectiveness of hexavalent chromium Cr(VI) removal from artificially contaminated aqueous solutions. The characterization of the biosorbents were made using different techniques such as X-ray Fluorescence (XRF), Fourier transform infrared (FTIR) and Scanning Electron Microscope (SEM) to better understand the adsorption mechanism-property relationship. Adsorption kinetics showed that the adsorption behavior followed the pseudo-second-order kinetic model. The adsorption isotherms fitted by the Langmuir model showed that the highest Cr(VI) adsorption capacities using natural cactus and dried cactus are 21.19 and 2.63 mg/g respectively. Additionally, various physiochemical parameters such as contact time, adsorbent dosage, pH and temperature were investigated in a batch-adsorption technique. The results illustrated that the cactus have significant potential as economic, safe and effective adsorbent materials for the Cr(VI) adsorption from the aqueous solution.

© 2017 Portuguese Society of Materials (SPM). Published by Elsevier España, S.L.U. All rights reserved.

*Keywords:* Adsorption; natural cactus; dried cactus; hexavalent chromium; biosorbent; isotherms; kinetic.

### 1. Introduction

The pollution by heavy metal is one of the prime candidates for causing environmental problems. The presence of toxic heavy metals such as chromium contaminants in aqueous streams, arising from the discharge of untreated metal containing effluents into water bodies, is one of the most important environmental issues. Chromium can be in nature under many forms depending on its degree of oxidation, two most stable forms are Cr(III) trivalent and Cr hexavalent Cr(VI), but Cr hexavalent or Cr(VI) represents the greatest threat to the environment and human health, given its high toxicity and carcinogenic potential [1]. Cr(VI) has been used widely in a variety of industries such as photography, tannery, ceramic, glass industries, pigments, paints, fungicides chrome alloy and metallurgic industries. Wastewater generated from these industries has been found to contain significant amount of chromium. The maximum

permissible limit for hexavalent chromium in inland is 0.1 mg/L whereas for potable water is 0.05 mg/L, respectively [2].

Various methods adopted for the removal of chromium from industrial wastewater, including, ion exchange, cementation, electrochemical precipitation, reduction, chemical precipitation, membrane separation, solvent extraction, foam formation and evaporation [3]. However, these treatment procedures are limited by some factors such as high energy and chemical requirement, incomplete removal, generation of toxic sludge [4]. Recently, natural biosorbent materials available in large quantities or waste products may have the potentiality of high uptake of metal Cr. They can be disposed of without regeneration due to their lower cost. A variety of natural biosorbents like activated carbon from sugarcane bagasse [2], *Nymphaea rubra* [5], dried water hyacinth roots [6], sulphuric acid treated cashew nut shell [7], modified corn stalk [8], *Echornia crassipes* [9] and activated carbon from Tamarind wood [10] have been reported in many studies. There are four mechanisms of biosorption for Cr (VI) viz., anionic adsorption, adsorption coupled reduction,

\* Corresponding author.

*E-mail address:* [sakrfatima@gmail.com](mailto:sakrfatima@gmail.com) (F. Sakr)

anionic and cationic adsorption [3].

Cactus (*Opuntia ficus-indica*) is cultivated as a fruits throughout in North Africa, South Africa and Mexico. In this work, natural (NC) and dried cactus (DC) was prepared and subsequently characterized by various techniques such as X-ray Fluorescence (XRF), Fourier transform infrared (FTIR) and Scanning Electron Microscope (SEM) and evaluated as biosorbent for chromium Cr(VI) removal from artificially contaminated aqueous solutions. The physiochemical parameters investigated in the present study included pH, ionic strength, contact time, adsorbent dosage and temperature. A modeling of the biosorption isotherms and a kinetics study were also carried out in order to understand the nature of the reaction mechanisms involved in the present biosorption process.

## 2. Materials and methods

### 2.1. Adsorbent

The both rackets of the prickly pear (*Opuntia ficus-indica*) were washed, dried first in the open area, and then in an oven (103 °C) for 48 hours. After being crushed and sieved (particles size less than 40 µm), the crusts are stored in small sachets without any further pretreatment.

### 2.2. Adsorbate

A chromium standard stock solution of 1 g/L was prepared from potassium dichromate ( $K_2Cr_2O_7$ ) and distilled water. A serial dilution of the stock solution was made to prepare standard solutions of known concentration.

### 2.3. Instrumentation

The sample analysis of Cr(VI) was performed using JASCO V-630 UV-Visible spectrophotometer. The chemical analyzes of the cactus (NC and DC) powder were carried out using a Fluorescence spectrometer (Wavelength dispersion spectrometer - Type Axios). The Fourier transform infrared spectroscopy (FTIR) analysis was performed in the 400-4000  $cm^{-1}$  range using a “FTLA2000-102” model spectrometer. It is equipped with a measuring device in ATR (Attenuated Total Reflexion) model Golden Gate, with a diamond crystal model Specac. The powder morphology of cactus was characterized using a Scanning Electron Microscope (SEM) FEI Quanta 200.

### 2.4. Biosorption studies

The experiments of the adsorption of Cr(VI) on the two varieties of cactus were studied in a batch system. Different parameters influencing the adsorption processes, such as the dose of adsorbent, pH, ionic strength and temperature were studied.

#### 2.4.1. pH

The optimization of the pH was carried out in a range of 1 to 9 by adding an optimum dose of the prepared sorbent to 50 ml of a solution of 10 mg/L, at ambient temperature for 90 min as contact time. The pH adjustment is done by 0.1 M  $HNO_3$  or NaOH, and the pH of solutions was measured with a pH meter HANNA instruments (pH 209).

#### 2.4.2. Amount of biomass

In order to determine the optimum dose of the adsorbent, a series of support masses varying from 0.5 to 9 g/L brought into contact with a volume of 50 ml of bichromate, at initial pH, ambient temperature and concentration of 10 mg/L for a contact time equal to 90 min.

#### 2.4.3. Ionic strength

The salt effect was examined under the previous optimal conditions by changing the concentration of the NaCl salt from 0.1 to 1 M.

#### 2.4.4. Temperature

Under the optimized condition, the influence of temperature was studied in the range of 20 to 50 °C.

#### 2.4.5. Contact time

The optimum dose and pH allowed us to follow the adsorption kinetics, with the concentration of 10 mg/L at different time intervals varying from 0 to 120 min.

#### 2.4.6. Isotherm

In order to study the adsorption isotherms, a volume of 20 ml of potassium dichromate with a concentrations ranging from 5 to 200 mg/L was prepared with the optimum pH and dose.

### 2.4.7. Method of calculation

At the end of each adsorption experiment, the samples were filtered using 0.45  $\mu\text{m}$  syringe filters and the non-adsorbed concentration of Cr(VI) was measured according to the standard colorimetric method, which consists of taking a 1 ml sample of the solution mixed in the acid medium with a complexing agent of 1,5-diphenylcarbazide. Thus, a violet-red complex forms after 10 minutes and its intensity is measured by spectrophotometry at 542 nm [11].

The amount of Cr(VI) adsorbed,  $Q_a$  (mg/g), is calculated according to the following formula,

$$Q_a = (C_i - C_e) \frac{V}{m} \quad (1)$$

where  $C_i$  and  $C_e$  are the initial and final concentrations of chromium in solution expressed in mg/L.  $V$  is the volume in liters of the solution and  $m$  represents the mass of the cactus powder in gram, and the percentage removal of Cr (VI) is calculated using Eq. (2),

$$\% \text{ Adsorption} = \frac{(C_0 - C_e)}{C_0} * 100 \quad (2)$$

Where,  $C_0$  and  $C_e$  are the initial and equilibrium concentrations (mg/L) of the metal ion, respectively.

## 3. Results and discussion

### 3.1. Characterization of the adsorbent

#### 3.1.1. Elemental composition (XRF)

The chemical analysis of both (NC) and (DC) powder using fluorescence is given in Table 1. The XRF obtained results shows the presence of the same elements for the two adsorbents, with different percentages. The essential elements present in high percentages are O (69.4%) and C (24.8%) for the DC and O (67.3%) and C (23.5%) for NC. We noted also the presence of 3.06% of Mg in the chemical composition of NC, while the DC contains only 0.349% of Mg. Additionally, Mn and  $\text{MnO}_2$  were detected in the chemical composition of NC.

#### 3.1.2. Infra-red spectroscopy

The FTIR spectra of the NC and DC are shown in Fig. 1. The obtained results show clearly that both of biosorbent (NC and DC) have nearly the same IR bands. The specter shows also wide and overlaid bands in the 3600–3200  $\text{cm}^{-1}$  region, which are due to the elongation of the O-H bonds.

Table 1. Chemical analysis of NC and DC by fluorescence.

Compound	Conc / %		Element	Conc / %	
	NC	DC		NC	DC
MgO	5.08	0.579	O	67.3	69.4
CaO	4.1	4.39	C	23.5	24.8
$\text{K}_2\text{O}$	1.3	0.323	Mg	3.06	0.349
Cl	1.05	0.116	Ca	2.93	3.14
$\text{SO}_3$	0.664	0.303	K	1.08	0.268
$\text{P}_2\text{O}_5$	0.64	0.178	Cl	1.05	0.116
$\text{SiO}_2$	0.566	1.87	P	0.28	0.0777
$\text{Al}_2\text{O}_3$	0.238	0.556	S	0.266	0.121
$\text{Na}_2\text{O}$	0.0713	0.0593	Si	0.265	0.876
$\text{Fe}_2\text{O}_3$	0.036	0.548	Al	0.126	0.294
$\text{MnO}_2$	0.0146	---	Na	0.0529	0.044
SrO	0.0099	0.0232	Fe	0.0252	0.384
I	0.00531	0.0322	Mn	0.0092	---
L.O.I	86.2	91.0	Sr	0.00841	0.0196
			I	0.00531	0.0322

L.O.I: Loss on ignition.

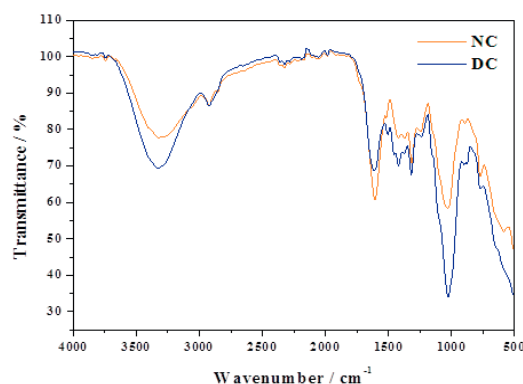


Fig. 1. Fourier-transform infrared (FT-IR) absorption spectrum of NC and DC.

The band at 2925  $\text{cm}^{-1}$  and 2847  $\text{cm}^{-1}$  are attributed to the vibrations of asymmetric elongation of  $\text{CH}_2$  and the symmetrical elongation of  $-\text{CH}_3$  of the aliphatic acids [12]. The band about 1600  $\text{cm}^{-1}$  is provided for the elongation vibration of the carboxylic groups. The band at 1319  $\text{cm}^{-1}$  originates from the elongation vibration of the  $-\text{OH}$  groups of the phenolic compounds. The band observed at 1370  $\text{cm}^{-1}$  reflect vibrations of symmetrical or asymmetric valency of the carboxylic groups of pectins [13]. The band at 1026  $\text{cm}^{-1}$  probably due to the vibration of the C-O-C or  $-\text{OH}$  groups and the polysaccharides [14]. Finally,

the absorption peaks in the 800  $\text{cm}^{-1}$  wave region can be attributed to nitrogen bioligands [15].

### 3.1.3. SEM studies

The microscopic observation makes it possible to visualize the morphology of the ground material. Fig. 2 shows that the ground material is formed of hollow fibers packed tightly into a membranes module sheet for larger surface areas (spongy tissue) in a smaller space for the DC. However, in the case of NC, particles structures are characterized by large pores of random form were observed.

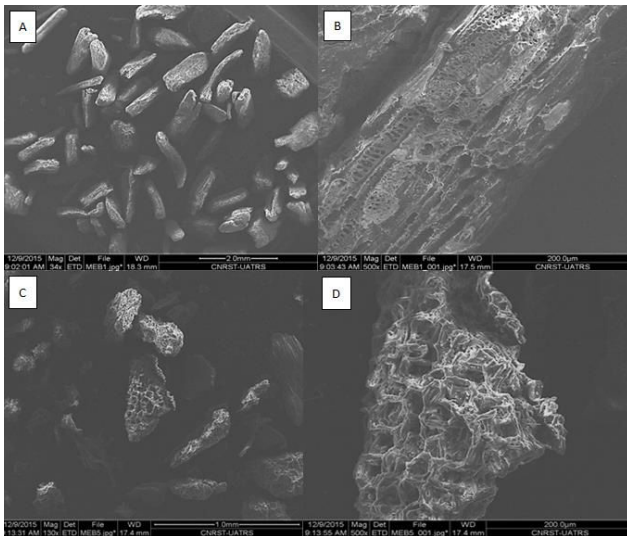


Fig. 2. Scanning electron micrographs of DC (A and B) and NC (C and D).

## 3.2. Adsorption study

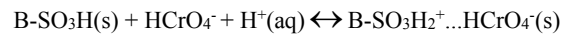
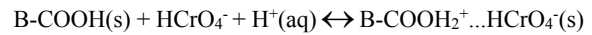
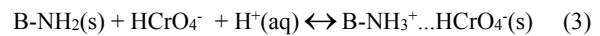
### 3.2.1. Effects of pH

The effect of the pH on the adsorption behavior was evaluated over a pH range from 1 to 9. The results (Fig. 3) showed that the maximum of Cr(VI) adsorption capacity was 1.39 mg/g (93.12%) for NC at pH = 1, and 1.61 mg/g (94.64%) for DC, at an initial concentration of 10 mg/L at pH = 2 and pH = 1.

The highest Cr(VI) adsorption capacity was 0.53 mg/g (34.56%) at pH between 1 and 2, but with the increasing of pH of the solution, the efficiency and Cr(VI) adsorption decreases as a result. According to this result, an important adsorption was observed at very acidic pH medium for DC. This result is probably due to the positively charged surface at the pH value from 1 to 2, since there is no competition to chromium

ions in solution leading to this significant adsorption capacity through electrostatic forces of attraction.

This behavior is explained by the functional groups present on the surface of the powder particles (amino, carboxyl and sulphonate groups) that undergo a strong protonation, which gives the biopolymers a positive global charge [16], as follows (where B: biomaterial):



As the pH increases, the concentration of hydroxyl ( $\text{OH}^-$ ) increases. Those radicals compete with the anionic Cr(VI) species, causing a decrease in the amount of chromium adsorbed at higher pH values since, so the active sites number drops significantly [17].

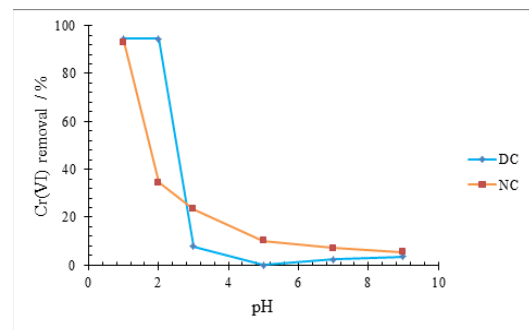


Fig. 3. Effect of pH on the adsorption of Cr(VI):  $C_0 = 10 \text{ mg/L}$ , Dose = 7 g/L for NC, 6 g/L for DC, room temperature and contact time = 90 min.

### 3.2.2. Effect of adsorbent dose

The effect of adsorbent dose on the adsorption capacity of the Cr(VI), was studied by varying the initial amount of the adsorbent while keeping a constant concentration of chromium solution (10 mg/L). The pH of the solution was fixed at 1. The influence of cactus mass on the adsorbed amounts of Cr(VI) is represented in Fig.4.

An increase in adsorbent dosage leads to an increase of removal efficiency from 42% to 89% when varying adsorbent amount from 1 to 8 g/L in NC case. However, the chromium adsorption efficiency increase from 24.5% to 97.8% for dosages from 1 to 8 g/L of DC biosorbent, which is probably due to the higher number of active sites at higher adsorbent concentration.

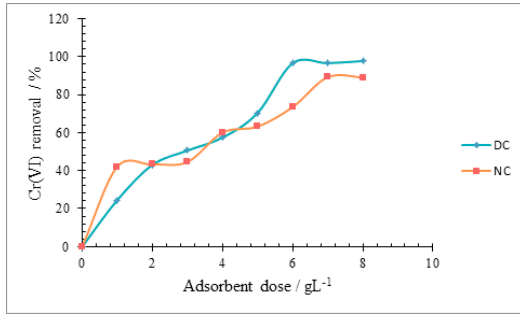
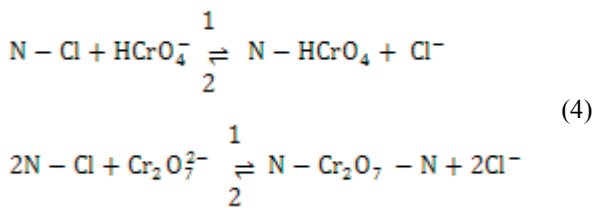


Fig. 4. Effect of adsorbent dose on the adsorption of Cr(VI): C<sub>0</sub> = 10 mg/L, room temperature, pH = 1 and contact time = 90 min.

3.2.3. Effect of ionic strength

We studied the influence of sodium chloride (NaCl) at various concentrations on the elimination of Cr(VI), at ambient temperature, pH = 1 and contact time of 90 min. The obtained results are shown in Fig. 5. Whereas NC, the presence of the Cl<sup>-</sup> ions affects the adsorption capacity of the Cr(VI) ions. For low concentrations of Cl<sup>-</sup> (0.1 mol/L; 0.4 mol/L), it is found that there is no significant influence on the removal of the Cr(VI) ions. The competitive effect of the Cl<sup>-</sup> ions towards the Cr(VI) ions adsorption under HCrO<sub>4</sub><sup>-</sup> form was small, even negligible because the electrostatic charges being the same in this case. For a higher concentration of Cl<sup>-</sup> ions (1 mol/L), there was a significant decrease in the elimination of Cr(VI) (from 96% to 68%). So, the influence of the ionic strength of the medium becomes important, preventing the fixation of the Cr(VI) ions, and the reaction equilibrium is strongly displaced in the direction 2 (Eq. 4), due to the very high Cl<sup>-</sup> concentration [18]:



In the case of DC, it was found that the percentage of chromium removal decreases from 80% to 66% when the Cl<sup>-</sup> ion concentration increases.

3.2.4. Effect of temperature

The study of the influence of temperature on the adsorption of Cr(VI) on the cactus, at an initial concentration of 10 mg/L at pH = 1, was conducted in a range of 20 °C to 50 °C.

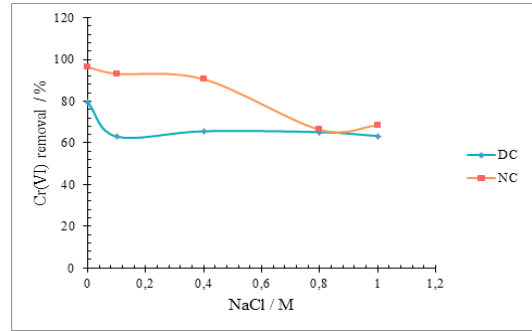


Fig. 5. Effect of salt on the adsorption of Cr (VI): C<sub>0</sub> = 10 mg/L, Dose = 7 g/L for NC; 6 g/L for DC; room temperature; pH = 1 and time = 90 min.

Under the previously optimized conditions, a marked decrease in the equilibrium biosorption capacity is recorded as the temperature increases. Indeed, by increasing the reaction temperature from 20 to 50 °C, the amount of chromium adsorbed at equilibrium decreased from 1.4 to 0.24 mg/g for NC. In the DC case, a decrease from 0.75 to 0.11mg/g when a temperature increase from 20 to 30 °C was observed. This can be explained by the fact that at lower temperatures, the kinetic energy of Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> anions is low. Therefore, the contact probability between Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> and active sites in the cactus structure is low, leading to a decrease in adsorption efficiency. In the other hand, at higher temperatures, the kinetic energy of Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> anions significantly exceeds the attraction potential between Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> and active sites in the cactus structure. The adsorption nature is more of a physical than a chemical property with an exothermic process [19].

3.2.5. Effect of contact time

To obtain the adsorption equilibrium, a series of measurements were carried out by varying the reaction time. The evolution of the reaction is illustrated in Fig. 6, where the percentage of elimination of Cr(VI) (%) is plotted as a function of the reaction time t.

The fixation of Cr(VI) to the support is relatively fast (68% for NC and 44% for DC in the first 5 min of contact). At the end of 60 min, equilibrium was established between the bichromate ions and the sites of support (for NC). This equilibrium remaining almost stable after 2 hours. The same trend was observed for DC, but with a sluggish difference in equilibrium time (at 75min).

The biosorption occur in two stages like initial rapid uptake (surface of cell wall components attract metal ions) and subsequent slow uptake is due to their

membrane transport. The biosorption rate depend on structural properties of sorbate and biosorbent (e.g. protein and carbohydrate composition), surface charge density, topography, surface area, initial concentration of metal ions and existence of other ions [20].

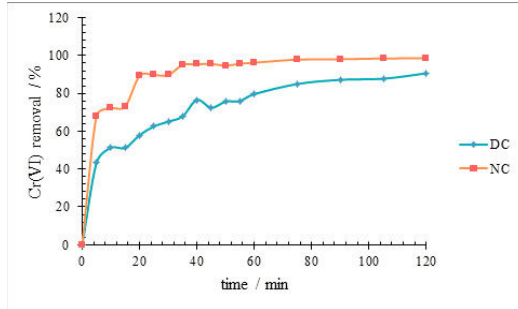


Fig. 6. Effect of contact time on the adsorption of Cr(VI):  $C_0 = 10$  mg/L, Dose = 7g/L for NC; 6 g/L for DC; room temperature and pH=1.

### 3.2.5.1. Kinetics and kinetic models:

To study the adsorption kinetics of Cr(VI) on the cactus, the first-order Lagergren model and the second-order model were used,

$$\ln(Q_e - Q_t) = \ln Q_e - k_1 t \quad (5)$$

$$\frac{t}{Q_t} = \frac{t}{Q_e} + \frac{1}{k_2 Q_e^2} \quad (6)$$

where  $Q_e$  and  $Q_t$  (mg/g) represent the amounts of Cr(VI) ions adsorbed per unit weight of the adsorbents at equilibrium and time  $t$  (min), respectively, and  $k_1$  ( $\text{min}^{-1}$ ) is the rate constant of the pseudo-first-order kinetic model for the adsorption process. Where  $k_2$  (g/mg.min) is the rate constant for pseudo-second order adsorption. The plots of  $t/Q_t$  versus  $t$  gave straight lines for both adsorbents. The kinetics parameters and correlation coefficients have been calculated from linear plots of  $\ln(Q_e - Q_t)$  versus  $t$  and  $t/Q_t$  versus  $t$ , the results are presented in Table 2.

The correlation coefficients of the pseudo-second-order kinetic model were higher than those of the pseudo-first-order model. Moreover, the values of  $Q_e$  calculated according to the pseudo-second-order model approach very consistently the values determined experimentally. Moreover, in the majority of the adsorption systems studied, the first-order model and in particular the Lagergren equation isn't fitting with the experimental values along the entire adsorption period and is generally applicable in first 20-30 minutes of the adsorption process [17].

Table 2. Pseudo-first-order and pseudo-second-order parameters for the adsorption of Cr(VI)

Parameters	Pseudo-first-order		Pseudo-second-order		
	NC	DC	Parameters	NC	DC
$Q_e$ calc. (mg/g)	0.638	1.010	$Q_e$ calc. (mg/g)	1.447	1.510
$k_1$ ( $\text{min}^{-1}$ )	0.055	0.031	$k_2$ (g/mg.min)	0.4781	0.439
$R^2$	0.9498	0.9702	$R^2$	0.9985	0.9879
$Q_e$ exp. (mg/g)	1.38	1.34	$Q_e$ exp. (mg/g)	1.38	1.34

Consequently, it seems that the reaction involved in the present biosorption phenomenon on the cactus is of the second order, thus suggesting a probable process of chemisorption, involving valence forces, resulting from an exchange or of an electron sharing between the dichromate ions and the functional groups of the adsorbent [21].

### 3.2.6. Isotherm

The experimental adsorption curves of the present work were adjusted to the Langmuir and Freundlich models. The nonlinear and linear forms of the Langmuir isotherm are represented by the following equations,

$$Q_a = \frac{Q_0 K_L C_e}{1 + K_L C_e} \quad (7)$$

$$\frac{C_e}{Q_a} = \frac{1}{K_L Q_0} + \frac{C_e}{Q_0} \quad (8)$$

where  $Q_a$  is the amount of pollutant adsorbed on the surface of the support at equilibrium (mg/g),  $Q_0$  is the maximum adsorbate amount (mg/g) and  $K_L$  is the energy-adsorption (L/g).

The graphical representation of the variation of the ratio  $C_e/Q_a$  as a function of  $C_e$  gives rise to straight lines, from which the theoretical values  $Q_0$  and  $K_L$  are calculated using the slopes and the ordinates at the origin. The nonlinear and linear forms of the Freundlich isotherm are given by the following equations,

$$Q_a = K_F (C_e)^{\frac{1}{n}} \quad (9)$$

$$\ln Q_a = \ln K_F + \frac{1}{n} \ln C_e \quad (10)$$

such that  $K_F$  is the Freundlich constant and  $n$  is a factor related to the adsorption intensity, also known

as the heterogeneity factor. The graphical representation of the variation of  $\ln Q_a$  as a function of  $\ln C_c$  leads to straight lines of regressions from which the theoretical values  $n$  and  $K_F$  are calculated.

The quality of Langmuir isotherm can be determined by the magnitude of a dimensionless constant  $R_L$  known as the separation factor expressed in Eq. (11) [22],

$$R_L = \frac{1}{1 + K_L C_0} \quad (11)$$

where  $C_0$  is the initial concentration of the Cr(VI) ions in mg/L and  $K_L$  is the Langmuir constant described earlier. The adsorption process is favorable within the range  $0 < R_L < 1$ , unfavorable when  $R_L > 1$ , becomes linear when  $R_L = 1$ , and the process is irreversible when  $R_L = 0$ .

The results for the constants of the different models are given in Table 3:

Table 3. Langmuir and Freundlich isotherm constants for the adsorption of Cr (VI).

Langmuir			Freundlich		
Parameter	NC	DC	Parameter	NC	DC
$Q_{max}$ (mg/g)	21.19	2.63	$n$	1.607	0.740
$K_L$	0.041	0.616	$K_F$	1.430	0.479
$R^2$	0.9924	0.9309	$R^2$	0.9778	0.9141
$R_L$	0.110- 0.832	0.008- 0.245			

The values of the correlation coefficient ( $R^2$ ) are higher for the Langmuir isotherm than for the Freundlich isotherm, which means that the Langmuir isotherm equation better represents the process of adsorption of Cr(VI) by the two adsorbents. This is due to the uniform distribution of active sites on the surface of both cactus biosorbent. The maximum adsorption capacity of Langmuir ( $Q_m$ ) is 21.19 and 2.63 mg/g for NC and DC respectively. The adsorption capacity of Cr(VI) on NC was much higher than that on DC. It could be due to the strong  $\pi$ - $\pi$  electron-donor-acceptor interaction between Cr(VI) molecules and the highly polarizable graphene sheets of NC [23]. The values for NC and DC indicate that the Cr (VI) adsorption process is favorable. The Freundlich constant,  $n$  should have values lying in the range of 1–10 for classification as favorable adsorption. The value of  $1/n$  reported in Table 3 is less than 1 and also positive for the two adsorbents indicating a favorable adsorption process [24]. In addition, we carried out a comparative study of the

adsorption capacities of Cr(VI) between the cactus rackets and other potential adsorbents, based on the amount of chromium adsorbed at equilibrium according to the Langmuir model, taking into account the experimental conditions used. The results of this comparison are presented in Table 4.

Table 4. Comparison of the maximum adsorption of cactus and various adsorbents with Cr(VI).

Adsorbent	$Q_{max}$ (mg/g)	pH	Refer
Coconut tree sawdust	3.46	3	[25]
Soya cake	0.28	1	[19]
Leaf mould	43	2	[26]
Activated Alumina	7.44	4	[27]
Activated Charcoal	12.87	2	[27]
Calcined Bauxite	2.021	7.4	[28]
Coal	6.78	2	[29]
Almond	10.616	2	[29]
Biochar	12.23	3	[30]
Feuilles de Posidonia			
oceanica	6.9	2	[17]
Natural Cactus	21.19	1	This study
Dried Cactus	2.63	1	This study

#### 4. Conclusions

Cactus or *Opuntia ficus-indica* (natural and dried), originally from southern Morocco, was successfully utilized as a low cost alternative adsorbent for the removal of hexavalent chromium Cr(VI) removal of from artificially contaminated aqueous solutions. Spectroscopic analyses were carried on to better understand the adsorption mechanism of Cr(VI)-biomaterials. FTIR analysis shows that the prickly pear contains a variety of organic functional groups. The chemical analysis of the cactus powder by fluorescence presented different elements by different percentage. The SEM study also made support to it by observing the morphology of material, showed that the powder is formed of agglomerates of small particles, and the presence of grains and small pieces of material in its structure. The adsorption behavior of Cr(VI) onto cactus was investigated under various experimental conditions. The adsorption capacity was found to be relatively high. At pH = 1 and room temperature. The experimental adsorption data were described using Langmuir and Freundlich isotherm models and the results showed a good correlation with the Langmuir isotherm reached the adsorption capacity of 21.19 and 2.63 mg/g for NC and DC.

Experimental data indicated that the adsorption capacity of cactus for the Cr(VI) was higher in acidic rather than in basic solutions, and further indicated that the removal of Cr(VI) decreased with increase in the ionic strength of solution. Also the results of kinetics adsorption study suggest that the adsorption of Cr(VI) on the cactus is an essentially chemical phenomenon, probably combined with physical interactions.

## References

- [1] A.K. Shanker, C. Cervantes, H. Loza-Tavera, S. Avudainayagam, *Environ. Int.* 31 (2005) 739.
- [2] K.J. Cronje, K. Chetty, M. Carsky, J.N. Sahu, B.C. Meikap, *Desalination* 275 (2011) 276.
- [3] B. Saha, C. Orvig, *Coord. Chem. Rev.* 254 (2010) 2959.
- [4] Z. Zainul Akmar, S. Marlina, M. Nurfadilah, A. Wan Azlina, *Desalination* 244 (2009) 109.
- [5] R.Y. Taj, S. Renganathan, N. Partha, G. Baskar, M. Velan, *Clean – Soil, Air, Water* 37 (2009) 787.
- [6] D. Sarkar, S.K. Das, P. Mukherjee, A. Bandyopadhyay, *Clean – Soil, Air, Water* 38 (2010) 764.
- [7] P.S. Kumar, S. Ramalingam, R.V. Abhinaya, S.D. Kirupha, A. Murugesan, S. Sivanesan, *Clean – Soil, Air Water* 40 (2012) 188.
- [8] S. Chen, Q. Yue, B. Gao, Q. Li, X. Xu, K. Fu, *Bioresour. Technol.* 113 (2012) 114.
- [9] K. Mohanty, M. Jha, B.C. Meikap, M.N. Biswas, *Chem. Eng. J.* 117 (2006) 71.
- [10] J.N. Sahu, J. Acharya, B.C. Meikap, *J. Hazard. Mater.* 172 (2009) 818.
- [11] J. Rodier, B. Legube, N. Merlet, Coll., *L'analyse de l'eau*, 9ème edition, Dunod, Paris 2009.
- [12] F.T. Li, H. Yang, Y. Zhao, R. Xu, *Chinese Chem. Lett.* 18 (2007) 325.
- [13] N.V. Farinella, G.D. Matos, M.A.Z. Arruda, *Bioresour. Technol.* 98 (2007) 1940.
- [14] J.V. Ibarra, R. Moliner, *J. Anal. Appl. Pyrolysis* 20 (1991) 171.
- [15] N. Barka, K. Ouzaouit, M. Abdennouri, M. Makhfouk, *J. Taiwan Inst. Chem. Eng.* 44 (2013) 52.
- [16] D. Park, S.R. Lim, Y.S. Yun, J.M. Park, *Bioresour. Technol.* 99 (2008) 8810.
- [17] B. Mahjoub, I. Fkih, M.C. Nacibi. Élimination du chrome hexavalent des solutions aqueuses par adsorption sur feuilles brute de de *Posidonia oceanica* (L.): cinétiques, équilibres et modélisation, *Déchets - Revue francophone d'écologie industrielle*, Sousse, 2009, pp. 19-26.
- [18] M.J. Sarre, M. Mazet, *Rev. Sci. Eau* 1 (1988) 55.
- [19] N. Daneshvar, D. Salari, S. Aber, *J. Hazard. Mater. B94* (2002) 49.
- [20] A. Asfaram, M. Ghaedi, G.R. Ghezlbash, *RSC Adv.* 6 (2016) 235999.
- [21] M.C. Ncibi, B. Mahjoub, M. Seffen, *J. Hazard. Mater. B139* (2007) 280.
- [22] O. Samson, Owalude, C. Adedibu, Tella, *J. Basic & Appl. Sci.* 5 (2016) 377.
- [23] B. Song, G. Zeng, J. Gong, P. Zhang, J. Deng, C. Deng, J. Yan, P. Xu, C. Lai, C. Zhang, M. Cheng, *Chemosphere* 172 (2017) 449.
- [24] C. Kannan, K. Muthuraja, M.R. Devi, *J. Hazard. Mater.* 10 (2013) 244.
- [25] K. Selvi, S. Pattabhi, K. Kadirvelu, *Bioresour. Technol.* 80 (2001) 87.
- [26] D. C. Sharma, C. F. Forster, *Bioresour. Technol.* 49 (1994) 31.
- [27] S. Mor, K. Ravindra, N.R. Bishnoi, *Bioresour. Technol.* 98 (2007) 954.
- [28] S. S. Baral, S. N. Das, P. Rath, G. R. Chaudhury, *Bioch. Eng. J.* 34 (2007) 69.
- [29] M. Dakiky, M. Khamis, A. Manassra, M. Mer'eb, *Adv. Environ. Res.* 6 (2002) 533.
- [30] N. Zhu, T. Yan, J. Qiao, H. Cao, *Chemosphere* 164 (2016) 32.