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

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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.

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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,

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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.

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