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FULL LENGTH ARTICLE

Removal of cadmium from aqueous solution using marine green algae, *Ulva lactuca*

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Abstract The present study aimed to evaluate the efficiency of marine algae for removal of metals from the aqueous solution. The green alga, *Ulva lactuca*, collected from the intertidal zone of the Suez Bay, northern part of the Red Sea was used to reduce cadmium levels from the aqueous solutions. The biosorption mechanisms of Cd^{2+} ions onto the algal tissues were examined using various analytical techniques: Fourier-transform infrared spectroscopy (FT-IR) and Scanning electron microscopy (SEM). Results indicated that at the optimum pH value of 5.5; about 0.1 g of *U. lactuca* was enough to remove 99.2% of 10 mg L^{-1} Cd^{2+} at 30 °C in the aqueous solutions. The equilibrium data were well fitted with the Langmuir and Freundlich isotherms. The monolayer adsorption capacity was 29.1 mg g^{-1}. The calculated R_L and '*n*' values have proved the favorability of cadmium adsorption onto *U. lactuca*. The desorption test revealed that HCl was the best for the elution of metals from the tested alga. In conclusion, the seaweed *U. lactuca* was the favorable alternative of cadmium removal from water.

Introduction

Environmental pollution due to toxic heavy metals is a significant worldwide problem due to their incremental accumulation in the food chain and continued persistence in the ecosystem (Aneja et al., 2010). The removal and recovery of toxic heavy metal ions from wastewaters are of great importance from an environmental viewpoint. The major sources of Cd(II) release into the environment through wastewater streams are electroplating, smelting, paint pigments, batteries, fertilizers, mining and alloy industries (Iqbal and Edyvean, 2005).

Cadmium is one of the toxic heavy metals with a greatest potential hazard to humans and the environment. It causes kidney damage, bone diseases and cancer. Chronic exposure to elevated levels of cadmium is known to cause renal dysfunction, bone degeneration and liver damage (Iqbal et al., 2007).

Conventional techniques for removing heavy metals from industrial effluents include chemical precipitation, chemical reduction, adsorption, ion exchange, evaporation and

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membrane processes, while the biosorption process offers potential advantages such as low operating cost, minimization of chemical or biological sludge, high efficiency of heavy metal removal from diluted solutions, regeneration of biosorbents, possibility of metal recovery and being environmentally friendly (Ahluwalia and Goyal, 2007).

Biosorption is an innovative technology using living or dead biomasses to remove toxic metals from aqueous solutions. Various biomasses such as bacteria, yeast, fungi and alga for biosorption of metal ions have been widely used (Vieira and Volesky, 2000). Among the biological materials, marine alga have high metal binding capacities due to the presence of polysaccharides, proteins or lipid in the cell wall structure (Davis et al., 2003). The mechanism of biosorption is mainly based on physical adsorption (electrostatic attraction–Vanderwaal forces of attraction) and/or chemical adsorption (covalent binding between negative charge of cell surface and cationic ions (Vijayaraghavan and Yun, 2008). The physiochemical phenomena besides being rapid are reversible (Darnall et al., 1986).

The main objective of this study was to evaluate the biosorption performance of locally marine macroalga *Ulva lactuca* for the removal of cadmium ions from aqueous solutions, as well as to study the effect of pH, biomass amount, time, initial metal concentration and temperature on the treatment process. Langmuir and Freundlich isotherm equations were employed to quantify the biosorption equilibrium. In addition to study the efficiency of different elutants to desorp the cadmium from the algae tissues.

Materials and methods

Materials

Preparation of cadmium

The analytical grade salt $Cd(NO_3)_2$ was used to prepare stock solution (1000 mg L^{-1}) of Cd^{2+}. The desired concentrations were prepared by dilution of the stock solution with deionised water. The initial pH was adjusted with concentrated HCl or NaOH. The initial metal concentration (10 mg L^{-1}) was measured using a flame atomic absorption spectroscopy (Perkin Elmer AAnalyst 100). Samples were diluted before the required analysis to set the calibration linear range.

Preparation of adsorbent

U. lactuca (green alga) was collected from the Suez Bay shore. The collected alga was washed with excess tap water and finally with distilled water to remove salt and particulate materials from the surface, dried at room temperature, then ground as powder using an electrical mill and sieved to uniform particle sizes (0.210 mm).

Methods

Effect of pH

During the experiment of pH effect, the parameters of temperature, solution volume, biosorbent amount, initial metal ion concentration, and shaking time were fixed at 30 °C, 10 mL, 10 mg L^{-1}, 0.1 g and 120 min, respectively. Effects of pH were tested at pH 2, 3, 4, 5, 5.5, 6 and 8 (Karaca, 2008).

Effect of biomass amount

This part of the experiment was performed to verify the effect of biosorbent weight on the sorption process. Different weights of biosorbents (0.05, 0.1, 0.2 and 0.4 g) were mixed and shaken with 10 mL solution of 10 mg Cd/L at 30 °C, pH 5.5 for 120 min (Ajaykumar et al., 2008).

Initial cadmium concentration

The extent of removal of heavy metals from aqueous solution depends strongly on the initial metal concentration. In order to assess, different Cd concentrations of 3, 5, 7, 10, 25, 50, 75 and 100 mg/L were examined at constant parameters, pH 5.5 with 0.1 g of biosorbent added into 10 ml solutions at 30 °C (Meral Karaca, 2008).

Effect of temperature

Biosorption process was carried out at different values of temperature (20, 25, 30 and 35 °C), at constant pH 5.5, 0.1 g biosorbent weight, volume of 10 ml of 10 mg Cd/L for 120 min (Ajaykumar et al., 2008).

Metal removal efficiency

Biosorption capacity (q_e), the amount of metal adsorbed per gram of biosorbent, can be calculated at equilibrium in mg/g as follows:

$$q_e = (C_0 - C_e)V/m \quad (1)$$

where C_0 is the initial concentration of metal ions in the solution (mg/L), C_e is the equilibrium concentration of metal ions in the solution (mg/L), V is the volume of solution (in L) and m is the mass of biosorbent applied (in g) (Hashim and Chu, 2004). Metal uptake can also be displayed by the percentage of metal removal given by (Zhang et al., 1998; Volesky, 1992):

$$\text{Metal removal } (\%) = 100(C_0 - C_e)/C_0 \quad (2)$$

Cadmium measurement

The collected samples from different experiments were filtered with filter paper (47 μm) and Cd^{2+} concentration was measured by an Atomic Absorption Spectrometer (Perkin Elmer AAnalyst 100). The analyses were carried out at the wavelengths of 228.8 nm.

Characterization of biomass

Fourier-transform infrared analysis (FTIR)

Dry *U. lactuca* samples (before and after cadmium biosorption) were examined with a Model Tensor – 27. Bruker FTIR within the wave number 200–5000 cm^{-1} under ambient conditions. This technique was used to elucidate the chemical characteristics relevant to metallic ion sorption by the algal biomass (Raize et al., 2004).

Scanning electron microscopy (SEM)

Dry *U. lactuca* samples (before and after cadmium biosorption) were glued and coated with gold. The coated samples were put into a JEOL, JSM-52500 LV SEM, Japan and different sections