

Postconsumer High-Density Polyethylene/Agave Fiber Foamed Composites Coated with Chitosan for the Removal of Heavy Metals

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ABSTRACT: Composites of postconsumer high-density polyethylene with agave fiber were prepared by single-screw extrusion with azodicarbonamide as a foaming agent to increase the surface area; the composite pellets were coated with chitosan afterward. A chemical pretreatment was applied to the pellets to enhance the chitosan gel compatibility. The adsorption capacities of the composites coated with chitosan were evaluated for Cd(II) and Cu(II) removal from aqueous solutions. The coated composites were characterized by scanning electron microscopy, attenuated total reflectance infrared spectroscopy, and X-ray photoelectron spectroscopy. Atomic absorption spectroscopy

was used to measure metal uptake in batch adsorption studies. The results of this study demonstrated the composites' ability to immobilize chitosan on their surfaces and their capacity to adsorb metal ions. The equilibrium isotherms for Cd(II) and Cu(II) adsorption on the chitosan-coated composites were described by the Langmuir model. This material represents an attractive low-cost recycled material for adsorbing metal ions from polluted waters. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 115: 2971–2980, 2010

Key words: composites; adsorption; infrared spectroscopy; processing; recycling

INTRODUCTION

Composites of natural fibers with thermoplastic materials provide engineers with new options for novel product development.¹ One of the principal purposes of composite production is to improve matrix mechanical properties, for example, by reinforcing its toughness and strength. The low cost of fillers from recycled material makes them attractive for the production of these solids. Among other desirable properties, the composites should possess enhanced biodegradability and should be reusable.^{2–4}

The removal of heavy metals from wastewaters is an important industrial challenge and is a concern to human health. Several solid adsorbents have been proposed for the removal of heavy metals from aqueous streams, for example, ion-exchange resins,⁵ membrane filters,⁶ metal hydroxide,⁷ activated carbons,⁸ and porous polymer beads.⁹ However, the

synthesis and application of these materials present economic disadvantages.^{4,10}

To overcome the aforementioned limitations, natural fibers or biopolymers have been used to adsorb metals from wastewaters. Kurniawan et al.¹¹ and Bayle et al.¹² evaluated the removal performance and cost effectiveness of various low-cost adsorbents derived from agricultural waste, industrial byproducts, and natural materials and compared them to those of activated carbon for the removal of several heavy metals from metal-contaminated wastewaters. Among biopolymers, chitin and chitosan have been used for metal-ion recovery because of their excellent metal chelating properties.^{10,11,13} Several researchers have reported chitosan–metal complexation from wastewaters.^{11,13} Chitin can be obtained in large quantities from the wasted crustacean shells of seafood processing industries, whereas chitosan is obtained from the deacetylation of chitin. The versatility of chitosan allows it to be used in different physical forms, including powder, flakes, and beads. Powder chitosan has a surface area up to 100 times higher than that of chitosan flakes, and its adsorption capacity varies for different metal ions.¹² Pure chitosan is soft, has a tendency to agglomerate or form gels in aqueous solutions, exhibits a low mechanical strength, and is difficult to manipulate.¹⁴

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There have been several attempts to overcome the manipulation problems of chitosan when it is applied to metal-ion removal from aqueous streams. These have included but are not limited to the coating of chitosan on different rigid supports used as affinity matrices, such as high-density polyethylene (HDPE),¹⁵ isotactic polypropylene,¹⁶ nylon 6,6,¹⁷ poly(ethylene terephthalate) (PET),¹⁷ perlite substrate prepared as spherical beads,¹⁸ and oil palm shell charcoal.¹⁹ Even sand has been coated with chitosan.²⁰

In view of our interest in obtaining new materials with some of the aforementioned characteristics, in this study, we aimed to prepare a composite made from recycled materials (postconsumer HDPE and agave fiber from residues of the tequila industry) foamed with azodicarbonamide (ACA) and used as chitosan support for the removal of Cd(II) and Cu(II) ions from aqueous streams. The chitosan-coated composite (CCC) was characterized by scanning electron microscopy, attenuated total reflectance infrared spectroscopy, and X-ray photoelectron spectroscopy (XPS) techniques. The capacity of immobilized chitosan on the composite pellets to extract these metal ions was compared to the corresponding capacity of chitosan thin films and chitosan-free composites. Equilibrium adsorption isotherms were obtained in batch mode to determine the maximum metal uptake, and the data were fitted to a Langmuir-type adsorption isotherm equation.

EXPERIMENTAL

Materials

The agave fibers used for this study were residues from tequila production industries (Jalisco, Mexico). HDPE was from scrapped milk bottles originally manufactured with Paxon AD60-007 (ExxonChemical, Houston, TX) with a melt index of 0.7 g/10 min and a density of 0.960 g/cm³. Both agave fibers and HDPE were washed, dried, and milled before processing. ACA (Sigma-Aldrich, Inc., St. Louis, MO) at 0.5 wt % was used as the chemical blowing agent to produce foams in the composite. Industrial-grade powder chitosan (America Alimentos, Jalisco, Mexico) with an average particle size of 173 μm (as determined by laser scattering with an Horiba LA-950 instrument, Irvine, CA) and 95% deacetylation (determined by infrared spectroscopy analysis) was used. Stock solutions containing Cd(II) and Cu(II) ions were prepared by the dissolution of CdO and CuO (J. T. Baker, Xalostoc, Mexico), respectively. Alkaline and acid solutions for chemical treatment were prepared with NaOH (Golden Bell, Jalisco, México), HNO₃ (J. T. Baker, Phillipsburg, NJ) and CH₃COOH (Sigma-Aldrich).

Composite preparation

The agave fibers from tequila production industries were subjected to a treatment to eliminate dust and sugar remaining from the fermentation process and to disentangle and depith the fibers. The treatment process followed protocols described elsewhere.²¹ After this treatment, the fibers were compounded with recycled HDPE in a single-screw extruder (Haake Rheomex 254, Karlsruhe, Germany). The composite formulation was set at 30 wt % fiber and 70 wt % HDPE with 0.5 wt % ACA. The temperature profile in the extruder was 150, 160, 175, and 170°C, with a screw speed of 20 rpm. After extrusion, the material was pelletized. Samples after this treatment were identified as composite C (i.e., the pure composite). The pellets of composite C were subjected to a chemical treatment to incorporate chitosan (details can be found elsewhere^{17,22,23}). Briefly, the treatment consisted of immersion in an alkali bath (a 10 wt % NaOH solution) for 24 h followed by immersion for 3 h in a 2% v/v CH₃COOH solution. The materials were dried at 60°C for 6 h. The dried pellets (100 g) were immersed in 500 mL of different chitosan solutions (2, 4, and 6 wt %) previously dissolved in 2% v/v acetic acid, and solvent evaporation was done at room temperature to promote the incorporation of chitosan as a film on the pellet surface. The composite coated with chitosan was repeatedly washed with distilled water to remove the excess of chitosan (until the pH of the washings remained unchanged) and dried at 60°C before use. The composite samples after this step were identified as CCC.

Composite characterization

The surface morphology of CCC was studied via scanning electron microscopy (TM-1000 Hitachi tabletop microscope, Tokyo, Japan). Additionally, the treated composite was characterized with attenuated total reflectance infrared spectroscopy (Spectrum GX 2000, PerkinElmer, Buckinghamshire, UK).

XPS

XPS was used to determine the chemical states of the surface functional groups and to elucidate the nature of the metal surface complex formed on the synthesized composite. Samples were attached to the top of a sample holder by carbon adhesive tape. XPS data were obtained with a ThermoElectron (East Grinstead, UK) instrument with a XPS110 electron analyzer with nonmonochromatic Mg X-rays ($h\nu = 1253.6$ eV) at 15 W with an electron takeoff angle of 90°. The spectrometer was equipped with a seven-channel hemispheric detector. The calibration of the binding energy of the spectra was performed

with the C1s peak of the carbon due to atmospheric contamination, which was at 284.6 eV. The XPS peaks were decomposed into subcomponents with the software AAnalyzer v 1.07. The spectra were measured on composites C, CCC, and CCC with metals.

Equilibrium adsorption experiments

Adsorption measurements were conducted to determine the adsorption reaction equilibration time for each metal separately, specifically the time after which the amount of metal adsorbed remained unchanged during these experiments.

The adsorption equilibrium experiments were conducted independently for copper and cadmium in batch mode. Initial solutions were prepared at several different metal concentrations (10–1400 mg/L for cadmium and 50–400 mg/L for copper) and at a fixed pH (7.0 for cadmium and 6.0 for copper). Metal uptake studies were conducted in a pH range at which most industrial effluents are discharged.²⁴ The pH was adjusted with NaOH or HNO₃. We carried out the adsorption experiments in 15-mL glass vials by contacting [2 h for Cu(II) and 24 h for Cd(II)] about 1 g of CCC with 10 mL each of metal solution in a reciprocal Barnstead Shke5000-7 shaker bed at 298 K (West Chester, PA). When the reaction time was over, the metal solution was filtered with Whatman 40 filter paper with a glass funnel. The initial and final pH values were measured with an Oakton model 510 pH meter, and the solutions were analyzed for total metal concentration with an atomic absorption spectrophotometer (Varian SpectrAA 220, Victoria, Australia). The same procedure was used for the chitosan-free composite and chitosan thin films (1 cm² and thickness = 66 ± 16 μm). The amount of metal adsorbed [q (mg/g)] on the surface of both composites and thin films was calculated by a mass balance given by

$$q = \frac{V}{w} [C_0 - C_e] \quad (1)$$

where C_0 and C_e are the metal concentrations in the initial and equilibrium final solutions (mg/L), respectively; V is the volume of the solution containing the metal ions (L); and w is the weight of the composite or chitosan film (g). The composite samples after contact with the copper-ion and cadmium-ion solutions were identified as CCC–Cu and CCC–Cd, respectively.

RESULTS AND DISCUSSION

Chemical treatment of the composite surface

A chemical treatment was applied to the pellets to improve the extent of chitosan incorporation. The

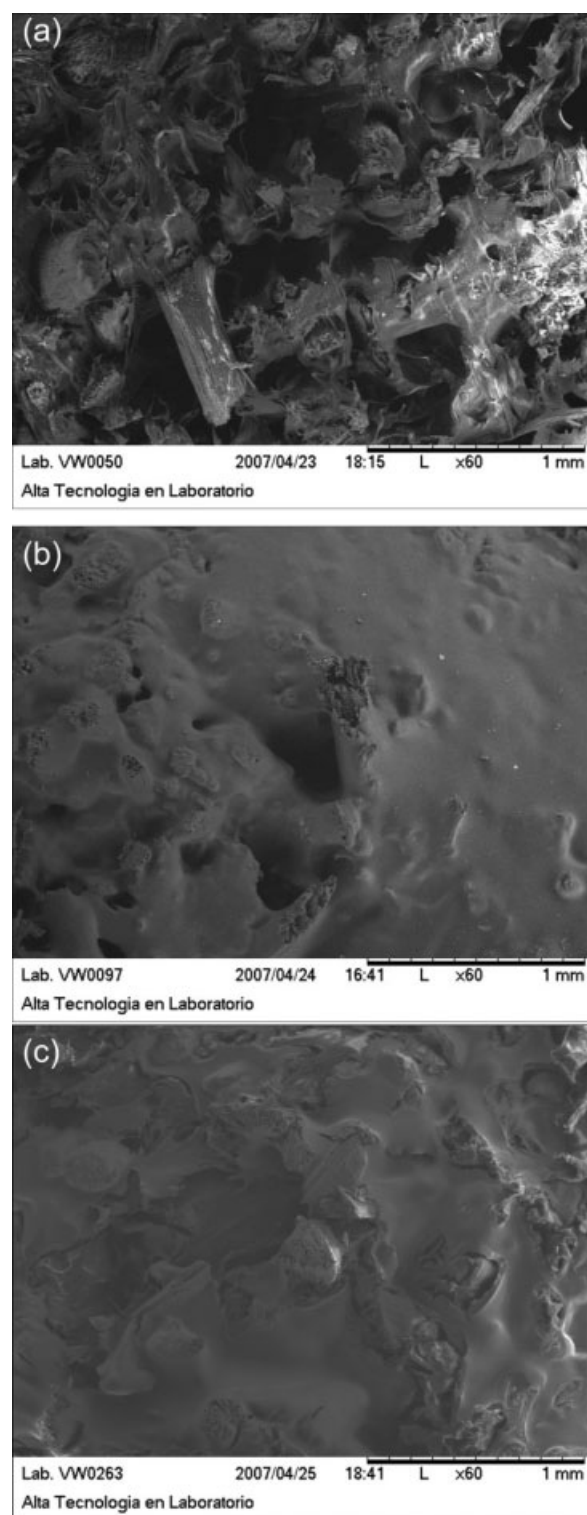


Figure 1 Micrographs of (a) the composite, (b) CCC, and (c) CCC after the washing step.

coating step was applied immediately after the pellets were removed from the acetic acid; otherwise, the surface charges might have been lost over time. Figure 1 shows micrographs of the composite without chitosan [Fig. 1(a)] and with chitosan [Fig. 1(b,c)]. We observed complete coverage of the surface of the

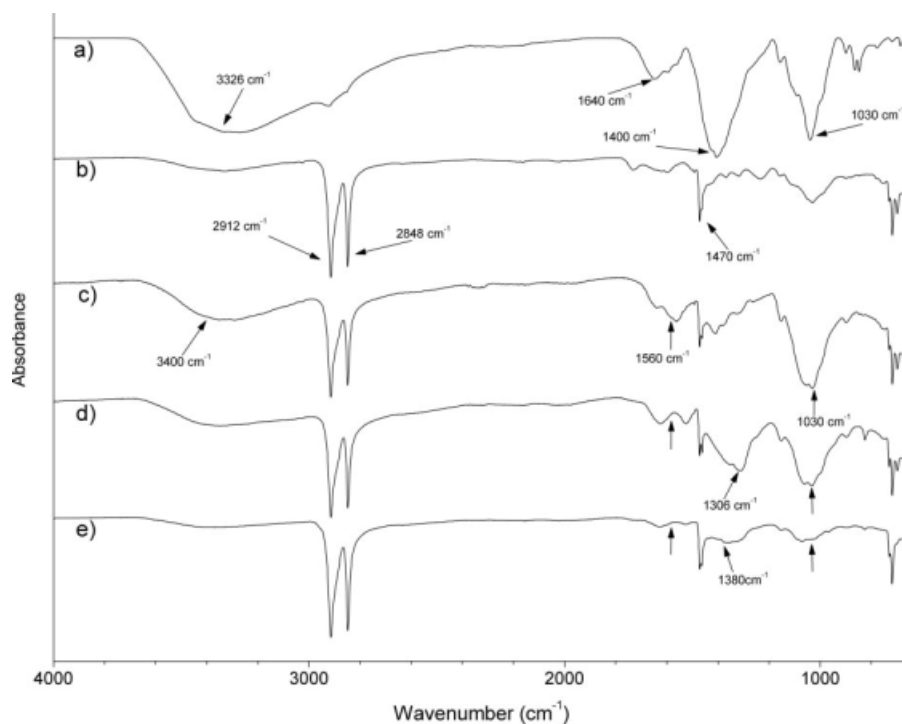


Figure 2 FTIR spectra of (a) agave fiber, (b) HDPE, (c) composite C, (d) CCC-Cd, and (e) CCC-Cu.

composite by chitosan [Fig. 1(b)], which remained even after the washing step [Fig. 1(c)]. Chitosan incorporation was mainly due to the surface modifications during the chemical treatment. In addition, it was possible that the exposure of agave fibers (in addition to the cavities obtained during foam processing) resulted in an irregular surface, which improved their apparent surface area (over a smooth pellet) and thus was reflected in an enhanced chitosan anchoring capacity. The use of a blowing agent reduced the density to 0.7 g/cm^3 . The amount of chitosan coating the composite was calculated by the weight difference. The results of chitosan adhesion on the composites for all of the compositions studied indicated an incorporation value of $3.0 \pm 0.3 \text{ wt } \%$.

Fourier transform infrared (FTIR) analysis

Information about the interaction between the metal ions and the chelating groups (e.g., $-\text{OH}$ and $-\text{NH}_2$) was obtained from the FTIR spectra of the agave fiber and composites C, CCC, CCC-Cd, and CCC-Cu, which are shown in Figure 2(a–e). The five samples showed a band of varying intensity in the region $3100\text{--}3600 \text{ cm}^{-1}$, whose origins were explained as follows: (1) in the case of the agave fiber sample [Fig. 2(a)], the band was located at about 3326 cm^{-1} and corresponded to the stretching vibrations of hydroxyl groups ($-\text{OH}$), mainly from cellulose (and to a lesser extent, from lignin);²⁵ (2) in the case of composite C [Fig. 2(b)], this band almost disappeared. This could

have been due to the total encapsulation of the underlying agave fiber structure as a result of the HDPE blending,²⁶ which suggests that the incorporation of HDPE encapsulated most of the $-\text{OH}$ groups from cellulose and made it difficult for them to absorb infrared energy. (3) In the case of the CCC samples, the band was located at about 3400 cm^{-1} , but the intensity slightly increased, which was attributed to the stretching vibrations of $-\text{OH}$ and $-\text{NH}$ groups from cellulose and chitosan. (4) In the case of the CCC-Cd and CCC-Cu samples, the intensity of this band decreased because of the presence of the metals, which suggests that metal interacted with the composite through both the $-\text{OH}$ and $-\text{NH}$ groups. Samples containing HDPE [Fig. 2(b–d)] showed two intense peaks at 2912 and 2848 cm^{-1} , assigned to CH stretching in the $-\text{CH}_2-$ groups of this polymeric matrix, and a weak band at 1460 cm^{-1} , characteristic of the HDPE long chains.²⁷ Furthermore, the five spectra showed characteristic bands in the region $1800\text{--}800 \text{ cm}^{-1}$. In the case of the agave fiber sample, the spectrum showed a band at 1640 cm^{-1} attributed to the stretching vibrations of the $\text{C}=\text{O}$ group from lignin and hemicelluloses;²⁵ the band at 1400 cm^{-1} was attributed to bending vibrations of the CH_2 group of the cellulose matrix,²⁸ and the peak at 1030 cm^{-1} was associated with stretching vibrations of the $\text{C}-\text{O}$ bond of cellulose and with deformation of the $\text{C}-\text{O}$ bond of primary alcohol groups of lignin.²⁹ The presence of this last band was explained, in the case of composite C, by the fact that after this sample

was subjected to the alkaline and acid treatment, the amount of exposed cellulose groups on the fiber increased, and consequently, the presence of reactive hydroxyl, carbonyl, and carboxylic groups on the surface also increased.^{30,31} On the other hand, the presence of metal caused changes in the intensity of characteristic bands in the case of CCC–Cd and CCC–Cu compared to CCC. For example, the spectrum of CCC showed an intense band at 1030 cm^{-1} , which corresponded to the stretching vibration of the C–N group, and a weak band at 1560 cm^{-1} , which corresponded to bending vibrations of the NH group,³² with both groups from chitosan. However, the intensity of these two bands decreased when cadmium was present in the CCC–Cd sample and almost disappeared in the case of the CCC–Cu sample. These results suggest again metal interactions through the amine groups of CCC. In summary, the FTIR results suggest that the interaction of cadmium and copper with CCC took place simultaneously through the OH/NH groups present in chitosan. The interaction appeared to be strong between these groups and copper compared to cadmium, which indicated that the extent of coordination was different between the CCC–Cu and CCC–Cd complexes. Elucidation of the surface–metal complex (cadmium or copper) formed on the CCC composite was obtained by XPS measurements.

XPS analysis

The composites were studied by XPS before and after metal deposition (cadmium or copper) to determine the chemical states of the surface functional groups and to investigate the interaction between the metal and surface functional groups not seen by FTIR. Figure 3 shows the wide-scan XPS spectra for the C [Fig. 3(a)], CCC [Fig. 3(b)], and CCC–Cd composites with cadmium adsorbed [Fig. 3(c)]. The predominant peaks were O1s (532.1 eV) and C1s (284.6 eV). The presence of N1s in Figure 3(b) corresponds to the amino group of chitosan in agreement with the molecular structure. Figure 3(c) shows the characteristics of the Cd3d peak around 400 eV. In the case of CCC–Cu (Fig. 4), the XPS survey data also showed the corresponding peak positions of carbon, oxygen, nitrogen, and metal loaded present in CCC, similar to those in Figure 3. The fingerprints of divalent copper [Cu(II)] in the Cu2p spectrum are also shown in this figure as a doublet with peaks at 936 and 956 eV; they corresponded to Cu2p_{3/2} and Cu2p_{1/2}, respectively. The presence of these two additional satellite bands in the regions 949–941 and 968–961 eV occurred when the electronic configuration was unsaturated; this indicated the presence of Cu(II) in the layers close to the surface.³³ The peak at 78.3 eV suggested Cu3p [Fig. 4(c)]. Our results were in agree-

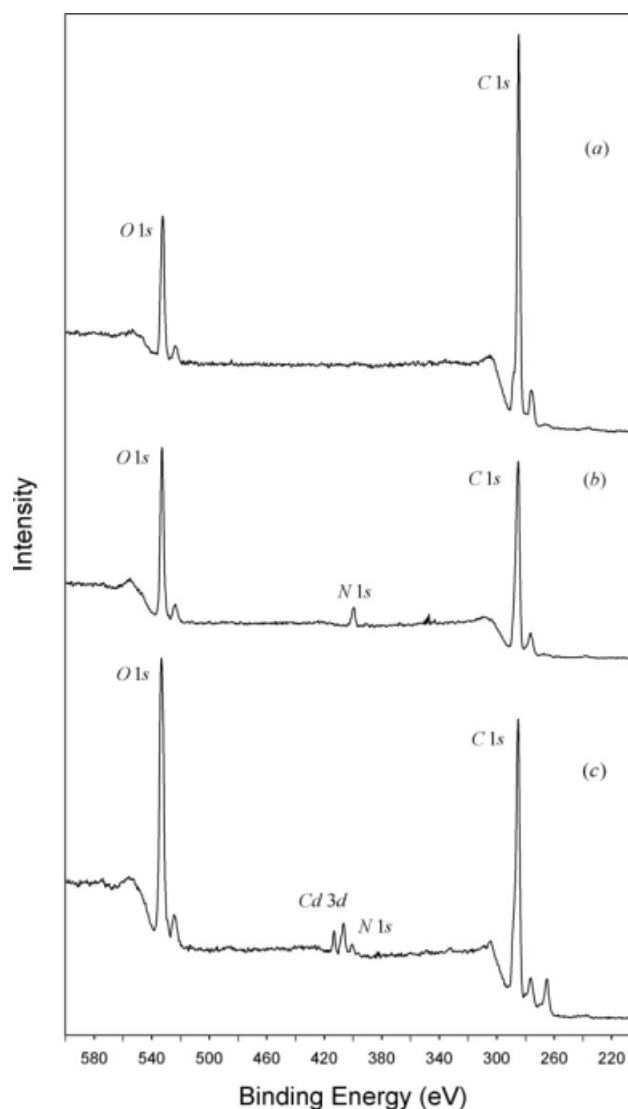


Figure 3 XPS wide-scan spectra of (a) composite C, (b) CCC, and (c) CCC–Cd.

ment with the literature, where similar findings on copper sorption by chitosan were reported.³⁴

Figure 5 shows the high-resolution N1s core-level spectra resolved into individual components for samples CCC [Fig. 5(a)], CCC–Cd [Fig. 5(b)], and CCC–Cu [Fig. 5(c)]. In the case of sample CCC, the required two peaks for the curve fit, one at 399.1 eV corresponding to the primary amine ($-\text{NH}_2$) and the other low intensity peak at 401.3 eV corresponding to the protonated ammonium ion ($-\text{NH}_3^+$), whereas in the case of sample CCC–Cd, the peaks at 405.6 and 412.6 eV suggested interaction of cadmium ions with oxygens from hydroxyl surface groups. Additionally, the peak that appeared at 407.4 eV was reported to be an interaction of the type Cd–O, as in oxides.³⁵ In CCC–Cu spectra, we observed a peak at 400.0 eV, which was assigned to amide groups ($-\text{NHCOCH}_3$); as shown in the XPS spectrum, the N1s peak was shifted to 407.1 and 408.5 eV. These shifts were a

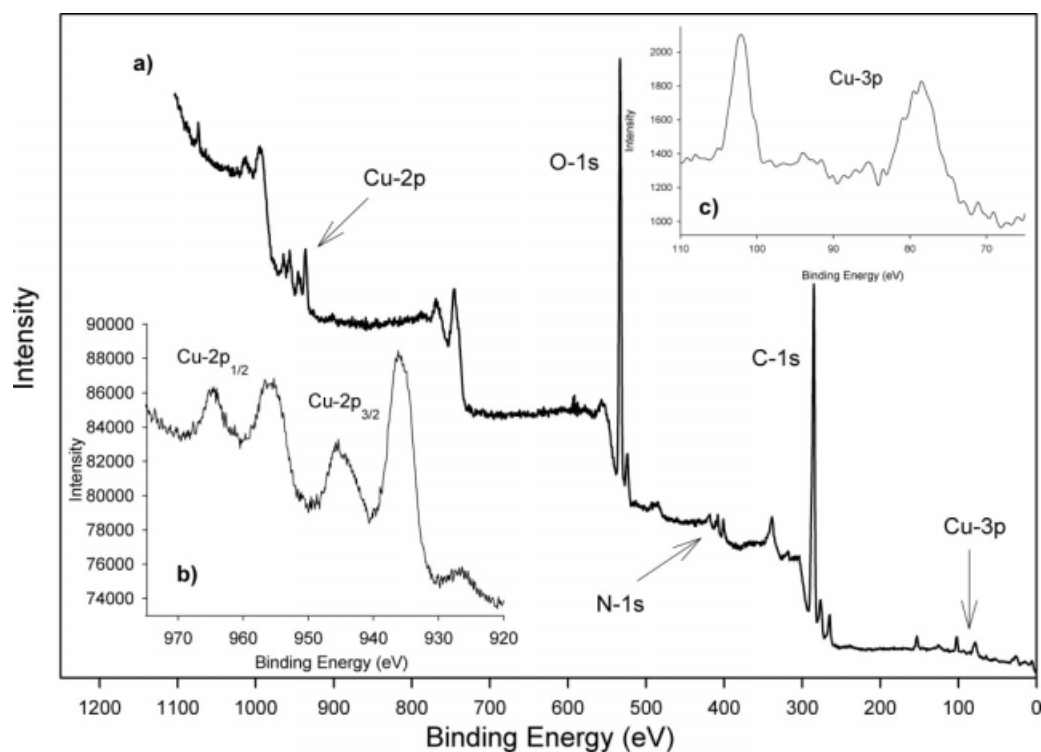


Figure 4 XPS wide-scan spectra of (a) CCC-Cu, (b) Cu2p, and (c) Cu3p.

result of the chemical interaction of Cd(II) and Cu(II) with the functional groups in chitosan and indicated that Cd(II) and Cu(II) were strongly bound to the NH_2 groups on chitosan.¹⁸

Figures 6(a–d) and 7(a–d) display the transition windows of C1s and O1s for composites C, CCC,

CCC-Cd, and CCC-Cu, respectively. Figure 6(a) could be fitted with four peaks, principally due to C–C bonds and C–H carbon atoms, mostly from HDPE and, to a lesser extent, to carbon atoms present in the agave fiber. The intense peaks at 286.0 eV shown in Figure 6(b) were attributed to the presence

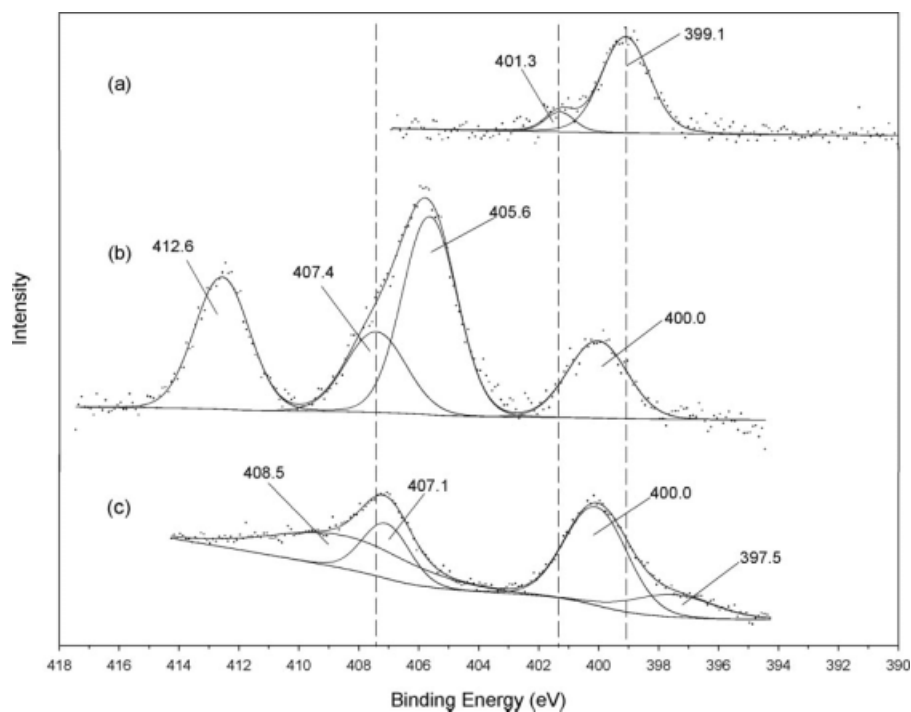


Figure 5 N1s core-level XPS spectra of (a) CCC, (b) CCC-Cd, and (c) CCC-Cu.

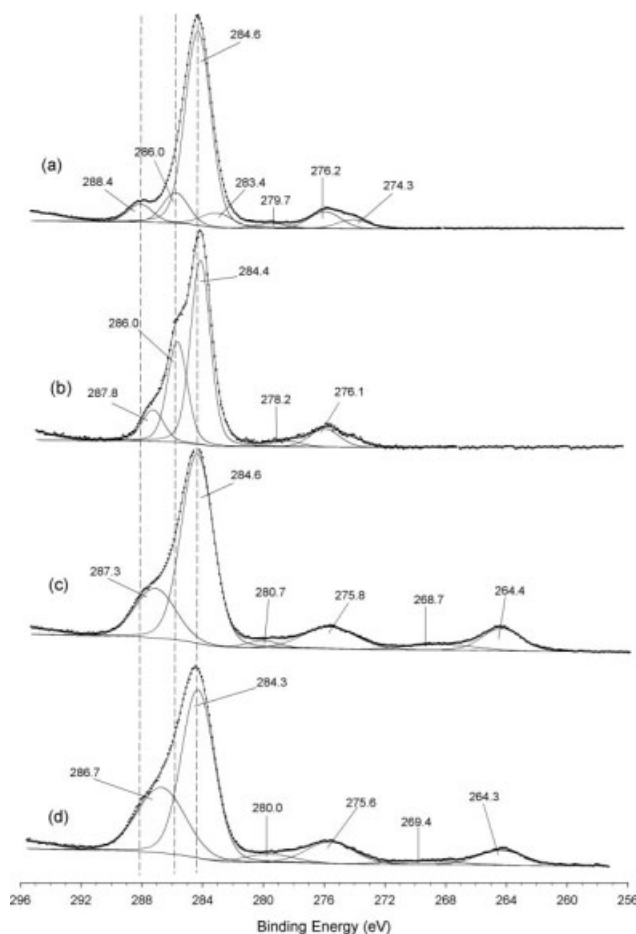


Figure 6 C1s core-level XPS spectra of (a) composite C, (b) CCC, (c) CCC-Cd, and (d) CCC-Cu.

of carbon in C—OH and C—N from chitosan; the peak at 287.8 eV was assigned to the C=O of amide. In Figure 6(c–d), the peak at 286.0 eV disappeared after the CCC was in contact with the metal solution; it seemed to be a carbon reduction, which appeared in a new peak close to 264 eV. Also, the peak at 287.3 eV remained like a stretching C—OH from chitosan and the cellulose of the agave fiber. The peak at 286.7 eV was assigned to methylene carbon atoms bound to oxygen (—CH₂—O—).¹⁷ In Figure 7, the four O1s peaks were identified after deconvolution. The peak at 531.1 eV practically remained unchanged; this was C=O from the amide group. The binding energy (BE) of 532.1 eV corresponded to a single bond between C and O, whereas these peaks moved to higher energy and were due to a C—OH bond in the case of CCC (same case of C1s) and, when they reached 532.8 eV for CCC-Cd and 532.7 eV for CCC-Cu, could be attributed to a carbonyl group (—C=O) being able to form coordination complexes.

In summary, our XPS results suggest that both cadmium and copper ions interacted with the composite CCC, mainly through amine groups from chi-

tosan and, to a lesser extent, through OH groups from chitosan and/or the cellulose fiber. These results were in accordance with our FTIR results.

Results for metal uptake by the composite

The Langmuir adsorption isotherm represented by the linearized eq. (2) was used here to fit the experimental adsorption data:³⁶

$$\frac{C_e}{q_e} = \frac{1}{q_{\max}b} + \frac{C_e}{q_{\max}} \quad (2)$$

where q_e is the equilibrium solid-phase metal concentration (mg/g), C_e is the aqueous phase metal concentration at equilibrium (mg/L), q_{\max} is the maximum uptake of metal (mg/g), and b is a coefficient related to the strength of adsorption, where $b = k_a k_d^{-1}$ (where k_a is the rate constant of adsorption and k_d is the rate constant of desorption). The results of the fitted data are shown in Figures 8 and 9, and Table I presents the parameters of eq. (2). For comparison with composite C, chitosan films were also used to assess the metal uptake capacity with both

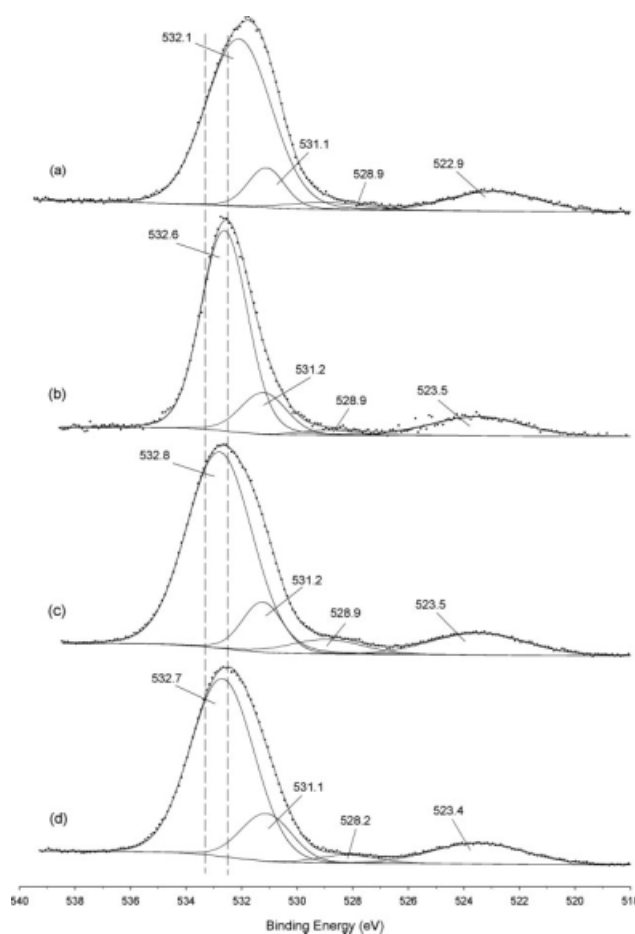


Figure 7 O1s core-level XPS spectra of (a) composite C, (b) CCC, (c) CCC-Cd, and (d) CCC-Cu.

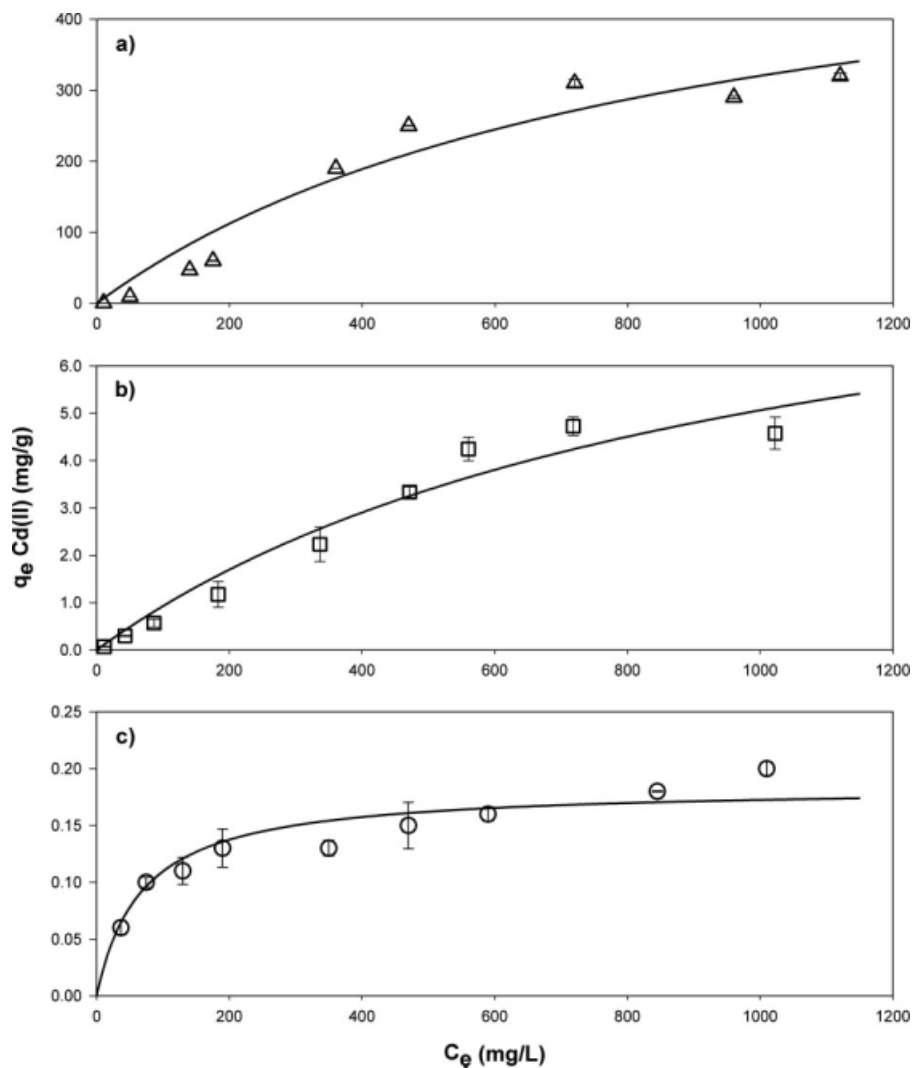


Figure 8 Cadmium adsorption isotherms for (a) chitosan films, (b) CCC, and (c) composite C (pH = 7.0, temperature = 298 K). The continuous lines are predictions by the Langmuir model.

metals studied. Furthermore, in the case of copper uptake, the experiments were conducted at a lower pH value (cf. cadmium) to prevent precipitation problems. The isotherms were well predicted with eq. (2) over the concentration range studied, as indicated by the coefficient of determination (R^2). The maximum observed metal uptake values by composite CCC were 1.15 and 4.85 mg/g for Cu(II) and Cd(II), respectively [Figs. 8(b) and 9(b)]. These values compared well with those predicted by q_{\max} of the Langmuir isotherm in Table I, namely, 1.21 mg/g of CCC for Cu(II) (equivalent to 39.1 mg/g of chitosan) and 4.78 mg/g of CCC for Cd(II) (equivalent to 154 mg/g of chitosan). This isotherm takes into account adsorption sites with the same energy, where the formation of a monolayer occurs on the surface of the composite with saturation of the sites. Hence, our fitted results suggest homogeneous adsorption on the composites, which indicated monolayer coverage of the metal. On the other hand, the

low metal uptake displayed by composite C was substantially improved after the incorporation of amine groups and, to a lesser extent, of OH groups in chitosan in sample CCC for both Cd(II) and Cu(II).

For the chitosan films [Figs. 8(a) and 9(a)], as expected, the calculated values of metal uptake were higher: 416 mg of Cd(II)/g of chitosan and 312 mg of Cu(II)/g of chitosan. In this case, the data from Figure 9(a) were linear because the experiments were conducted in this concentration range to prevent further metal precipitation problems. In general, the q_{\max} values reported in the literature have been widely dispersed. For example, for cadmium adsorption, values as low as 0.007 mg/g of rice husk³⁷ have been reported, and values as high as 518 mg/g of magnetic chitosan beads have been reported.³⁸ For copper adsorption, the lowest values reported have been 4.5 mg/g of activated carbon,³⁹ and the highest value was 300 mg of Cu(II)/g of chitosan.⁴⁰ The adsorption capacity is a parameter

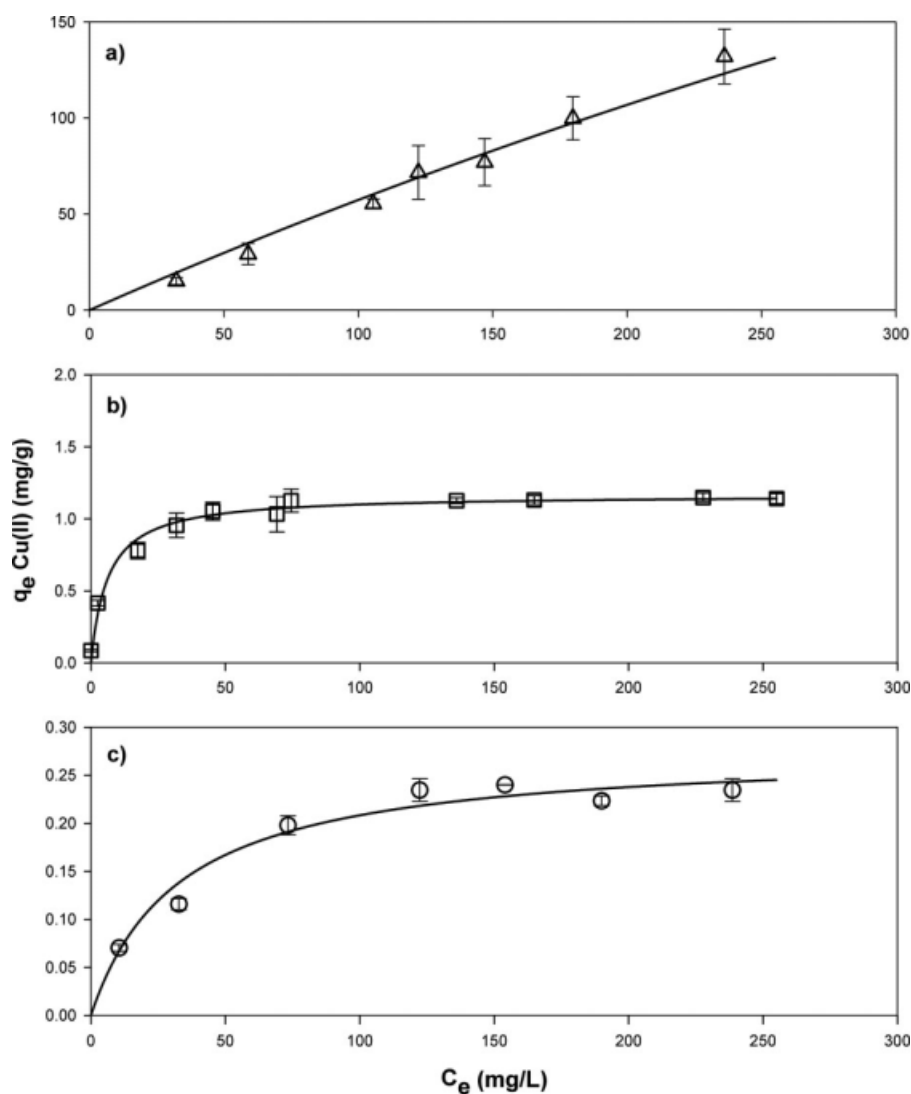


Figure 9 Copper adsorption isotherms for (a) chitosan films, (b) CCC, and (c) composite C (pH = 6.0, temperature = 298 K). The continuous lines are predictions by the Langmuir model.

used to evaluate the performance of the sorbent. However, there are other important factors, such as fabrication and operation costs.

The adsorption capacity for metal ions in coated chitosan systems is a function of the chitosan content. In the case of the higher values reported for chitosan-coated perlite^{18,33} for Cd(II) and Cu(II), the chitosan content was around 30%. Similar results for

the adsorption capacity for Cu(II) were reported by Wan et al.²⁰ for a solution of 300 mg of Cu(II)/L over 2 h; they incorporated 5 wt % chitosan. In the case of cadmium, the adsorption capacity of the CCC was acceptable as only 3% chitosan was incorporated into the pellets.

By coating the composites with chitosan, we created a low-cost adsorbent that required little processing,

TABLE I
Parameters of the Langmuir Adsorption Isotherm at 298 K

Metal ion	Material	b (L/mg)	q_{\max}		R^2
			mg/g of CCC	mg/g of chitosan	
Cd(II) at pH 7.0	CCC	0.0485	4.78	154.8	0.996
	Composite C	0.0565	0.25	—	0.981
	Chitosan film	0.0275	—	416.0	0.945
Cu(II) at pH 6.0	CCC	0.1315	1.21	39.1	0.998
	Composite C	0.0083	0.21	—	0.972
	Chitosan film	0.0014	—	312.0	0.947

displayed a good adsorption capacity, and could be used to recover other heavy metals than those reported here because of the good chelating ability of chitosan reported elsewhere.^{10–13} The agave fiber and chitosan were industrial byproducts, and the HDPE was recycled. The composite could eventually be made out of any kind of natural fiber and recycled plastic, as we know for sure that these material sources are available everywhere, which will help with environmental care. Furthermore, this composite, made from postconsumer materials, represents a potential alternative to clean others wastes, such as contaminated effluents.

The results of this study will certainly help to optimize and improve the processing conditions related to chitosan coating in composites, especially to increase the chitosan content. Several other parameters, such as agave fiber content, the polymer matrix, chemical treatment, regeneration of composite, pH, and other heavy metals, are being analyzed to increase the adsorption capacity and diversify the applications of this material.

CONCLUSIONS

A new application for a natural fiber/HDPE composite was presented in this article. Immobilization of chitosan on the composite surface was crucial for metal-ion adsorption. By coating the composite with chitosan, we created an adsorbent requiring little processing and featuring enhanced adsorption capacities for toxic metal-ion removal, such as Cu(II) and Cd(II); this was attributed to the good chelating ability of chitosan. The agave fiber and chitosan were industrial byproducts, and HDPE was recycled. The results of this study will certainly help to optimize and improve the processing conditions related to chitosan coating on composites, especially to increase the chitosan content. The XPS analyses suggested that amino and OH groups present in chitosan act as the main chelating sites. The experimental adsorption equilibrium data for Cd(II) and Cu(II) were described by the Langmuir model, which suggested monolayer coverage of the metal on the composite. The results suggest the potential use of our environmentally friendly composite in the removal of toxic heavy metals from aqueous streams.

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