RESEARCH ARTICLE OPEN ACCESS

Moringa Seed, Residual Coffee Powder, and Banana Peel as Biosorbents for Uranium Removal from Acid Mine Drainage

Marcelo L. Garcia*, Milena R. Boniolo**, Amauri A. Menegario***
** São Paulo State University (UNESP), Institute of Geosciences and Exact Sciences, Campus of Rio Claro. 1515 24-A Avenue, 13506-900, Rio Claro, SP, Brazil. E-mail: mlgarcia@rc.unesp.br*
*** São Paulo State University (UNESP), Institute of Geosciences and Exact Sciences, Campus of Rio Claro. 1515 24-A Avenue, 13506-900, Rio Claro, SP, Brazil. E-mail: milenaboniolo@yahoo.com.br*
**** São Paulo State University (UNESP), Center of Environmental Studies, Campus of Rio Claro. 1515 24-A Avenue, 13506-900, Rio Claro, SP, Brazil. E-mail: amenega@rc.unesp.br*

ABSTRACT
The uranium mining deserves attention with regard to environmental impacts and water pollution in Brazil. The research objective was to enable the use of biomass as cheap and available adsorbents for uranium removal from acid mine drainage. Three types of biomass were tested: banana peel, residual coffee powder, and moringa seed. Synthetic uranium solution (SS) and acid mine drainage (AMD) were used in the equilibrium adsorption experiments. Remarkable total uranium removal efficiencies were observed for moringa (96.8 ± 2.2 [SS] and 86.5 ± 0.8% [AMD]), coffee (89.4 ± 11.2 [SS] and 73.7 ± 2.2% [AMD]), and banana (48.2 ± 14.0 [SS] and 55.9 ± 4.8% [AMD]). The highest experimental adsorption densities were 18.7, 19.1, and 6.3 $mg \cdot g^{-1}$, respectively. Quantitative curves were described for each adsorbent and can be used for practical applications. Design and operating parameters for uranium removal from AMD as a post-treatment, polishing method can be determined beforehand.
Keywords**:** acid mine drainage, adsorption, coffee waste, moringa seed, uranium removal

I. INTRODUCTION

There was an increase on energy demand from different sources and nuclear power appeared once again in Brazil in the nineties, because of the social and economic model. The national Brazilian underground is rich in mineral deposits and energetic materials. According to the Brazilian Mining Association (2012)[1], Brazil is currently the world´s seventh largest uranium reserve and only 30% of the national territory has been investigated. The mining activities and uranium processing cause significant adverse environmental impacts that, at least, need to be monitored and controlled. Among a few environment problems that can be seen in the mining sector, acid mine drainage is recognized as the most serious one [2] as it presents acidic and toxic characteristics and can severely contaminate soils, surface water and groundwater [3].

An area that has been environmentally managed is the Osamu Utsumi, Minerium Treatment Unit of Brazilian Nuclear Industries (INB) (Caldas, SP, Brazil), in decommission phase since 1995. One of the main environmental concerns is the uranium presence in the acid mine drainage. The uranium is dissolved into the effluent because of the sulphide minerals oxidation in contact with water and oxygen, forming sulfuric acid, which in turn promotes metallic ions dissolution in acidic conditions.

Physicochemical processes such as precipitation and filtration are common treatment methods applied for metallic ions removal from these effluents or areas. If it is inefficient because of large effluent volumes with low metallic ions concentrations, processes interferences, or complex phenomena for real wastewaters, it is necessary the application of a tertiary (polishing) step; if it is efficient, alternative treatment methods can be acknowledged towards a more sustainable system. In both cases, adsorption becomes an attractive option for metallic ions removal from acid mine drainage. The final effluent should have a high water quality standard, which would enable its discharge in water bodies, preventing any type of environmental contamination.

Biosorption researches, in which low cost, residual and/or natural compounds are used as adsorbents, have been widely conducted and have showed promising results [4-5-6-7-8-9-10-11]. Biomasses, such as moringa seed, banana peel and residual coffee, have been showed to have appropriate adsorption characteristics for metallic ions removal [12-13-14], besides the fact of their high abundance in nature and/or easy availability.

In this context, the main objective of this work was to investigate the removal of total uranium of the Osamu Utsumi acid mine drainage by applying adsorption as the treatment method and banana peel, residual coffee powder and moringa seeds as adsorbents..

II. MATERIAL E METHODS

Banana (Musa cavendishi) peel, residual Coffee (Coffea arabica) powder, and Moringa (Moringa oleifera lam) seeds were used as adsorbents. Biomasses samples were taken from, respectively, local area after individual consumption, a coffee machine from a local cafeteria after being subject to water for coffee extraction at conditions of 9 bar pressure and approximately 90ºC temperature, and a greenhouse located at Narandiba, SP, Brazil. After, biomasses were dried in an oven (FANEM Mod. 320 SE) at a temperature range from 35 to 40ºC for 12h until mass variation was no longer observed, grinded (Tecnal Mod. TE 633, except coffee that was grinded in an analytical grinder, IKA mod A11), and separated with a 250 µm sieve (Bronzinox).

Physical properties of the biosorbents (0.5 g each) were determined with a nitrogen adsorber, Acelerated Surface Area ADN Porosimetry System 2020 (ASAP) - Micromeritics at 77 K (-196ºC). Vaccuum was applied at a rate of 5 mmHg·s^{-1} until 5 mmHg (restricted) and, subsequently, 10 µmHg (non-restricted vacuum pressure) for 6 min. Temperature slope of 10ºC·min^{-1} was then applied until reaching the temperature of 170ºC, at which the experiment lasted for 24h. A pressure ratio programming for 37 points was set, of which 24 points were related to adsorption and 13 points to desorption. This analysis was performed at the Mechanical Engineering Department from University of São Paulo (São Carlos, SP, Brazil).

Equilibrium assays were conducted in an agitation equipment (Labnet Orbit 300). 10 mL volume of synthetic uranium solution was added into 50 mL vials. The general set-up conditions were agitation time (45 min), settling time (15 min), temperature (25ºC), pH (5), adsorbent size (250 µm), and adsorbent mass (0.1 mg). Initial uranium concentration was varied accordingly, from 5 to 200 mg·L^{-1}, with intervals of 25 mg·L^{-1}. Triplicates were prepared for each condition. Performance assessment was carried out by calculating uranium removal efficiencies (Eq. 1) adsorption densities (Eq. 2), and linear (Eq. 3), Freundlich (Eq. 4), Langmuir (Eq. 5), and sigmoidal Boltzmann isotherms (Eq. 6), whose results were then compared to acid mine drainage samples (three batches in triplicates each) from Brazil Nuclear Industries (INB), minerium treatment unit (UTM) Osamu Otsumi (Caldas, MG, Brazil). After the adsorption experiments, the supernatant was filtered with an apparatus of syringe (Injex) and cellulose acetate membrane filter (Sartorius) of 0.45 µm nominal pore size. The filtered supernatant portions were diluted with Milli-Q ultrapure water, and acidified with a 2% nitric acid solution for subsequent Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) analyses.

$E\ (\%) = \frac{C_0 - C}{C_0}$	(Eq. 1)
$C_s = \frac{(C_0 - C)\cdot V}{m}$	(Eq. 2)
$C_s = K \cdot C$	(Eq. 3)
$C_s = K \cdot C^{1/n}$	(Eq. 4)
$C_s = \frac{K \cdot C_{s,max} \cdot C}{1 + K \cdot C}$	(Eq. 5)
$C_s = \frac{A_1 - A_2}{1 + \exp\left(\frac{C - x_0}{dx}\right)} + A_2$	(Eq. 6)

Where: C_0 = initial concentration (mg·L^{-1}); C = equilibrium concentration (mg·L^{-1}); Cs = density adsorption (mg·g^{-1}); V = working volume (10 mL); m = adsorbent mass (0.1 mg); K = linear (L·g^{-1}), Freundlich (mg·g^{-1})(L·mg^{-1})^(1/n), and Langmuir (L·mg^{-1}) capacity constant; 1/n = freundlich intensity parameter; $C_{s,max}$ = maximum Langmuir adsorption density (mg·g^{-1}); sigmoidal Boltzmann constants: A_1 (mg·g^{-1}), A_2 (mg·g^{-1}), x_0 (mg·L^{-1}), and dx (mg·L^{-1}).

The ICP-OES analytical curve was determined from a standard mono-element solution with the same acid content of the prepared ICP-OES samples. The ICP-OES set-up was: pump flux rate (15 rpm), pump stabilization time (5 s), tube type (Tygon orange/white), power 1150 W, auxiliary gas flux (0.5 L·min^{-1}), and nebulization gas flow (0.5 L·min^{-1}).

III. RESULTS AND DISCUSSION

The moringa seed can be indicated as the adsorbent with the best adsorption physical properties, in comparison to banana peel and coffee waste (Table 1). The moringa seed surface area (0.55 m^2·g^{-1}) is about three and two times the values of banana and coffee, respectively. Similarly, the pore volume of moringa seed is about one order of magnitude greater than that of banana and coffee. Based on these numbers, it possible to anticipate that moringa seed will present a better performance on the uranium removal of acid mine drainage, followed by residual coffee powder and banana peel, in this order.

It is possible to infer that the minerals (clays) [15] have great potential to remove metallic ions from acid mine drainage, based on their physical properties. The authors showed successful Lead (Pb) removal efficiencies from an industrial effluent. It is likely that clay would satisfactorily remove uranium from acid mine drainage because their surface area and pore volume are much greater than the respective values for biomass. Activated carbon, a conventional, consolidated adsorbent material, has its physical properties presented as well for comparison (Table 1).

concentration of 989 mg·L^{-1} [data not shown]; other ion concentrations (mg·L^{-1}): F^- = 129, Cl^- = 0.5, NH_4^+ = 6.1; K^+ = 7.1, and Na^+ = 0.7). For instance, the adsorption density in the acid mine drainage assays were 0.33, 0.44, and 0.52 mg·g^{-1} for the adsorbents banana peel, coffee waste, and moringa seed, respectively. If the respective equilibrium concentrations and the best isotherm curves were used to calculate the expected adsorption density from the acid mine drainage experiments, the values of 0.53, 1.26, and 0.71 mg·g^{-1} would be found for banana peel (Langmuir model), coffee waste (Boltzmann model), and moringa seed (Boltzmann model), respectively, accounting for 63, 50, and 51%

Table 1. Physical properties of potential adsorbents

Adsorbent	**S_P** (m^2·g^{-1})**	**V_P (cm^3·g^{-1})**
Activated carbon*	662.57	0.25
Banana peel	0.16	$3.5 \cdot 10^{-4}$
Residual coffee powder	0.29	$8.8 \cdot 10^{-4}$
Moringa seed	0.55	$1.5 \cdot 10^{-3}$
Clay – type A*	36.56	0.15
Clay – type VP*	10.65	0.19
Peat*	19.17	0.10

* From Tomasella et al. (2013). Activated carbon used as control.

S_P: surface area. V_P: pore volume. ** BET surface area = Brunauer, Emmett, and Teller method for measuring surface area based on gas nitrogen adsorption. All materials were analyzed with the same analytical equipment.

Isotherms and their constant parameters were obtained from the adsorption experiments (Figure 1 e Table 2). The highest adsorption densities were found for moringa seed and coffee waste (~19 mg·g^{-1}), compared to values of about 6.2 mg·g^{-1} for banana peel (Figure 1). The models adjusted well to the uranium synthetic solution experimental data (Table 2), especially for the absorbents banana peel (Langumir [R^2 = 0.98] and Freundlich [R^2 = 0.98] models) and moringa seed (sigmoidal Boltzmann [R^2 = 0.99] and Freundlich [R^2 = 0.98] models). There was no acceptable adjustment for residual coffee powder as an adsorbent based on the correlation coefficient value, but some of its curves, mainly the sigmoidal Boltzmann model, can still be used for a reasonable quantitative first approximation.

Furthermore, the models represented well the acid mine drainage samples experimental data (Table 3), to a certain extent validating the adsorption constant parameters for real applications and covering a relatively wide range of conditions (acid mine drainage: pH of 3.6 and SO_4^{-2} of the projected adsorption capacity. This difference (i.e., the percentage complement) is certainly due to the interferences of other constituents found in the real wastewater coupled with possible isotherm parameter variations from other environmental and operating conditions. Nonetheless, the models and their parameters presented in this work can be considered robust, considering the complex phenomena that are involved in the adsorption.

In the literature, results for uranium removal using biomasses as adsorbents are still scarce. It can be more usually found adsorption data for biomass with other elements (Table 4). However, it seems that biomasses are being increasingly considered as potential adsorbents, and it is clear that the three types of biomass investigated in this work, banana peel, coffee waste, and moringa seed, are able to remove a wide range of elements from wastewaters, with considerable quantitative performance.

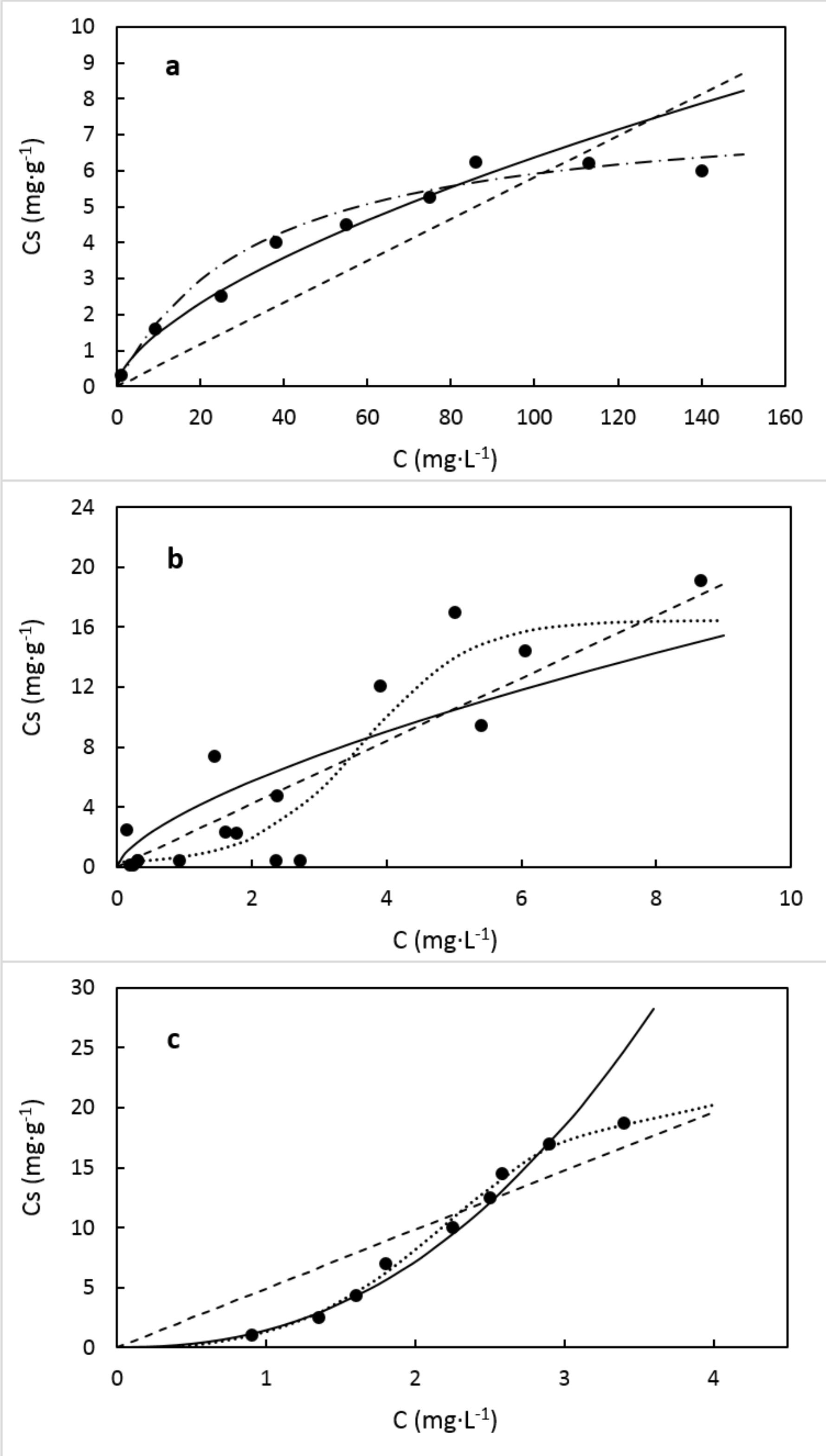

Figure 1. Adsorption density (C_s) (mg·g^{-1}) over equilibrium concentration (mg·L^{-1}) for the uranium synthetic solution: (a) banana peel, (b) residual coffee powder, (c) moringa seed; (●) experimental data; (----) linear, (—) freundlich, (-·-·-) langmuir, and (····) sigmoidal boltzmann model. From equations 2 and 1, total uranium removal efficiencies are 96.8 ± 2.2 (c), 89.4 ± 11.2 (b), and 48.2 ± 14.0% (a).

Table 2. Constant parameters for Linear, Freundlich, Langmuir, and Boltzmann isotherm models and their statistical correlation coefficient.

Adsorbent	Linear		Freundlich			Langmuir		
	K ($L \cdot g^{-1}$)	R^2	K ($mg \cdot g^{-1}$)($L \cdot mg^{-1}$)^(1/n)	1/n	R^2	K ($L \cdot mg^{-1}$)	$C_{s,max}$ ($mg \cdot g^{-1}$)	R^2
Banana peel	0.058	0.62	0.35	0.63	0.98	0.03	7.87	0.98
Coffee waste	2.41	0.74	3.63	0.66	0.48	-	-	-
Moringa seed	4.91	0.81	1.41	2.34	0.98	-	-	-

Adsorbent	Sigmoidal (Boltzmann)				
	A_1 ($mg \cdot g^{-1}$)	A_2 ($mg \cdot g^{-1}$)	x_0 ($mg \cdot L^{-1}$)	d_x ($mg \cdot L^{-1}$)	R^2
Banana peel	-	-	-	-	-
Coffee waste	-0.16	16.49	3.66	0.79	0,85
Moringa seed	-0.29	20.83	2.19	0.51	0,99

Table 3. Adsorption experiments for acid mine drainage samples. Initial (C_0) and final (C) concentrations, uranium removal efficiency (E), and adsorption density (Cs).

Sample/Biosorbent	C_0 ($mg \cdot L^{-1}$)	C ($mg \cdot L^{-1}$)	E (%)	Cs ($mg \cdot g^{-1}$)
Acid mine drainage 1	5.97	---	---	---
Acid mine drainage 2	6.13	---	---	---
Acid mine drainage 3	5.76	---	---	---
	---	2.96		
Banana peel	---	2.48	56 ± 4.8	0.33
	---	2.44		
	---	1.58		
Residual coffee powder	---	1.74	74 ± 2.2	0.44
	---	1.38		
	---	0.86		
Moringa seed	---	0.78	87± 0.8	0.52
	---	0.78		

Table 4. Maximum adsorption capacities ($mg \cdot g^{-1}$) for biosorption processes.

Adsorbent	Element	Concentration ($mg \cdot L^{-1}$)	Cs ($mg \cdot g^{-1}$)	Reference
Banana peel (nanofibers)	Cd	50 – 300	26.94	[19]
Banana peel	Pb/ Cd	30 – 80	5.71 (Cd) 2.18 (Pb)	[16]
Banana peel	Cr	250 – 1500	3.00	[17]
Orange peel	Cr	250 – 1500	3.00	[17]
Banana peel	Cr VI	0,1 – 100	2.53 1.16	[26]
Treated banana peel	Cd	0,1 – 100	35.52	[18]
Coconut fiber	Pb	5 – 200	52.0	[27]
Mango leaves	Pb	5 – 200	31.5	[27]
Coffee grains	Cd	10 – 700	15.6	[21]
Coffee powder	Cr	0 – 500	39.0	[22]
Coffee processing residue	Cu Cd Zn Cr	50 - 100	7.77 (Cu) 6.84 (Cd) 5.57 (Zn) 6.96 (Cr)	[23]
Moringa Oleifera	As	5 -20	6.23	[28]
Moringa seed	Cd	10 – 900	7.86	[24]
Moringa seed	Mn	5 – 45	5.61	[25]
Moringa skin	Ni	20 - 200	26.84 29.46 30.38	[29]
Moringa skin	Pb	20 – 200	34.60	[30]
Banana peel	U	50 – 500	7.95	[20]
Banana peel	U	5 - 200	7.87	This work
Residual coffee powder	U	5 - 200	19.1	This work
Moringa seed	U	5 - 200	18.7	This work

Banana peel has been used as an adsorbent for the removal of Cadmium (Cd), Lead (Pb), and Chromium (Cr) from aqueous solution, with adsorption densities ranging from 1.16 to 5.71 $mg \cdot g^{-1}$ [16-17-18]; its capacity is considerably enhanced (from 5.71 to 26.94-35.52 $mg \cdot g^{-1}$ for Cd), when it is subjected to an special pretreatment [19-18]. With respect to Uranium (U) removal, it is interesting to note that adsorption densities were consistent with previous findings (7.87 $mg \cdot g^{-1}$ [this work] and -7.95 $mg \cdot g^{-1}$ [20] and higher compared to the elements Cd, Pb, and Cr. Coffee-based adsorbents were also used to remove Cd and Cr, and Zinc (Zn) and Copper (Cu) from aqueous solutions [21-22] and dye contaminated waters [23]. Adsorption densities varied from 5.57 to 15.6 (up to 39.0) $mg \cdot g^{-1}$, i.e., greater performances for coffee compared to untreated banana. Residual coffee powder resulted in a maximum adsorption density of 19.1 $mg \cdot g^{-1}$ (this work). Finally, Cd, Manganese (Mn), and U were removed from aqueous solutions (adsorption densities of 7.86, 5.61, and 18.7 $mg \cdot g^{-1}$, respectively) by using moringa seed as the adsorbent [24-25-this work]. The three types of biomasses investigated in this work seems to have improved performance for uranium removal compared to the other elements.

Besides demonstrating the great potential of banana peel, residual coffee powder, and moringa seed for uranium removal from acid mine drainage in terms of removal efficiencies and adsorption densities, a significant contribution of this work is the quantitative curves for predicting adsorption capacities, which could be used for other applied scenarios. The authors recommend the following equilibrium isotherms for banana peel (Eq. 7), residual coffee powder (Eq. 8), and moringa seed (Eq. 9) as adsorbents. It was not anticipated the use of a sigmoidal model for the adsorption experiments. It indicates that a surface alteration probably have to occur before reaching the removal exponential phase and, then, an eventual saturation level, for coffee waste and moringa seed. Several other adsorption fundamentals, such as removal mechanisms, determination of optimum parameters, etc., need to be addressed for a full comprehension of the complex phenomenon.

$C_s = \dfrac{0.03 \cdot 7.87 \cdot C}{1 + 0.03 \cdot C}$	(Eq. 7)
$C_s = \dfrac{-0.16 - 16.49}{1 + \exp\left(\frac{C - 3.66}{0.79}\right)} + 16.49$	(Eq. 8)
$C_s = \dfrac{-0.29 - 20.83}{1 + \exp\left(\frac{C - 2.19}{0.51}\right)} + 20.83$	(Eq. 9)

IV. CONCLUSION

Banana peel, residual coffee powder, and moringa seed can be used as adsorbents for uranium removal from wastewaters, presenting remarkable biosorption characteristics. In comparison, moringa seed can be indicated as the best biosorbent, with greater physicochemical properties and adsorption performances, although residual coffee powder is a promising material and had as high adsorption densities (~19 $mg \cdot g^{-1}$) as moringa seed. An adsorption saturation level (~6 $mg \cdot g^{-1}$) was reached for banana. The best fits were Langmuir model for banana ($K = 0.03\ L \cdot g^{-1}$; $C_{s,max} = 7.89\ mg \cdot g^{-1}$) and Boltzmann model for moringa ($A_1 = -0.29\ L \cdot g^{-1}$; A2 = 20.83 $mg \cdot g^{-1}$; $x_0 = 2.19\ mg \cdot L^{-1}$; $dx = 0.51\ mg \cdot L^{-1}$) and coffee waste ($A_1 = -0.16\ L \cdot g^{-1}$; $A_2 = 16.49\ mg \cdot g^{-1}$; $x_0 = 3.66\ mg \cdot L^{-1}$; $dx = 0.79\ mg \cdot L^{-1}$).

ACKNOWLEDGEMENTS

The authors are grateful to the São Paulo Research Foundation (FAPESP), grant number 2015/06246-7, to the National Council for Scientific and Technological Development (CNPq), grant number 400034/2016-6, for providing financial support, to Ms. Daniela Andresa Mortari, from the Mechanical Engineering Department at University of São Paulo (São Carlos, SP, Brazil) for performing the porosimetry analyses, and to Ms. Lauren Nozomi Marques Yabuki, from Center of Environmental Studies at São Paulo State University (Rio Claro, SP, Brazil), for assistance with the uranium assays.

REFERENCES

[1]. Brazilian Mining Association. Information and analyses of Brazilian mineral economy. [Instituto Brasileiro de Mineração. Informações e análises da economia mineral brasileira] [in portuguese], 7th. ed., p. 59. 2012.
[2]. Akcil, A; Koldas, S. Acid mine drainage (AMD): causes, treatment and case studies. Journal of Cleaner Production. v. 14, p. 1139-1145, 20006.
[3]. Peppas, A; Komnitsas, K; Halikia, I. Use of organic covers for acid mine drainage control. Minerals Engineering, v.13, p. 563-574, 2000.
[4]. Parvathi, K.; Nagendran, R.; Nareshkumar, R. Lead biosorption onto waste beer yeast by-product, a means to decontaminate effluent generated from battery manufacturing

industry. Elletronic Journal of Biotechnology, v. 10, n.1. 2007.
[5]. Kadirvelu, K.; Kavipriya, M.; Karthika, C.; Radhika, M.; Vennilamani, N.; Pattabhi, S. Utilization of various agricultural wastes for activated carbon preparation and application for the removal of dyes and metal ions from aqueous solutions. Bioresource Technology, v.87, n.1, p. 129-132. 2003.
[6]. Low, K.S.; Lee, C. K.; Leo, A. C. Removal of metals from electroplating wastes using banana pith. Bioresource Technology, v. 51, p. 227-231. 1995.
[7]. Sekar, M.; Sakthi, S.; Rengaraj, S. Kinetics and equilibrium adsorption study of lead (II) onto activated carbon prepared from coconut shell. Journal of Colloid and Interface Science, v. 279, p. 307-313. 2004.
[8]. Namasivayam, C.; Kanchana, N. Waste banana pith as an adsorbent for color removal from wastewaters. Chemosphere, v. 25, p. 1691-1705. 1992.
[9]. Namasivayam, C.; Yamuna, R.T. Adsorption of chromium (VI) by a low cost adsorbent biogas slurry. Chemosphere, v.30, p, 561-578. 1995.
[10]. Senthilkumaar, S.; Bharathi, S.; Nithyanandhi, D.; Subburam, V. Biosorption of toxic heavy metals from aqueous solutions. Bioresource Technology, v.75, p. 163-165. 2000.
[11]. Senthilkumar, P.; Ramakrishnan, K.; Gayathri, R. Removal of nickel(II) from aqueous solutions by ceralite ir 120 cationic exchange resins. Journal of Engineering Science and Technology, v.5, n 2, p. 232-243. 2010.
[12]. Bhatnagar, A.; Sillanpaa, M.; Witek-Krowiak, A. Agricultural waste peels as versatile biomass for water purification – A review. Chemical Engineering Journal, v. 270, p. 244–271. 2015.
[13]. Bhatnagar, A.; Sillanpaa, M. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment—a review. Chemical Engineering Journal, v. 157, p. 277–296. 2015.
[14]. Rodrigues, M.J.; Barros, L.S.S. Using moringa oleífera seed extract and solar radiation in the treatment of water intended for human consumption. ARS Veterinaria, v. 29, p. 98-103. 2013.
[15]. Tomasella, R.C.; Oliveira, E.G.; Angelis, D.F.; Garcia, M.L. Evaluation of the potential of natural compounds (clay, peat and activated carbon) for the removal of lead and toxicity of an industrial effluent [Avaliação do potencial de compostos naturais (argila, turfa e carvão) na remoção de chumbo e toxicidade de um efluente industrial] [in portuguese]. Eng. Sanit. Ambient. v.20, pp. 251-258. 2015.
[16]. Anwar, J.; Shafique, U.; Zaman, W.; Salman, M.; Dar, A.; Anwar, S. Removal of Pb(II) and Cd(II) from water by adsorption on peels of banana. Bioresource Technology, v. 101, p. 1752-1755. 2010.
[17]. Pakshirajan, K.; Worku, A.N.; Acheampong, M.A.; Lubberding, H.J.; Lens, P.N.L. Cr(III) and Cr(VI) Removal from Aqueous Solutions by Cheaply Available Fruit Waste and Algal Biomass. Applied Biochemistry Biotechnology, v. 170, p. 498-513. 2013.
[18]. Memon, J. R.; Memon, S.Q.; Bhanger, M.I.; Memon, G.Z.; El-Turki, A.; Hallam, K.R.; Allenc, G.C. Characterization of banana peel by scanning electron microscopy and FT-IR spectroscopy and its use for cadmium removal. Colloids and Surfaces B: Biointerfaces, v. 66, p. 260-265. 2008.
[19]. Saumya, P.; Deepa, B.; Abraham, E.; Girija, N.; Geetha, P.; Jacob, L.; Koshy, M. Biosorption of Cd(II) from aqueous solution using xanthated nano banana cellulose: Equilibrium and kinetic studies. Ecotoxy and Environmental Safety, v. 98, p. 352-360. 2013.
[20]. Boniolo, M.R.; Monteiro, R.A.; Yamaura, M. Residual biomass for uranyl ion removal. [Biomassa residual para remoção de íons uranilo][in portuguese]. Química Nova, v. 33, p. 547-551. 2010.
[21]. Azouaoua, N.; Sadaouia, Z.; Djaafri, A.; Mokaddema, H. Adsorption of cadmium from aqueous solution onto untreated coffee grounds: Equilibrium, kinetics and thermodynamics. Journal of Hazardous Materials, v. 184, p. 126-134. 2010.
[22]. Prabhakaran, S.K.; Vijayaraghavan, K.; Balasubramanian, R. Removal of Cr (VI) Ions by Spent Tea and Coffee Dusts: Reduction to Cr(III) and Biosorption. Industrial & Engineering Chemistry Research, v. 48, p. 2113–2117. 2009.
[23]. Oliveira, L.S.; Franca, A.S.; Alves, T.M.; Rocha, S.D.F. Evaluation of untreated coffee husks as potential biosorbents for treatment of dye contaminated waters. Journal of Hazardous Materials, v. 156, p. 507-512. 2008.
[24]. Meneghel, A,P.; Gonçalves, A.C.; Rubio, F.; Dragunski, D. C.; Lindino, C.A.; Strey, L. Biosorption of Cadmium from Water Using Moringa (Moringa oleifera Lam.) Seeds. Water Air Soil Pollution, v. 224, p. 1383-1387. 2013.

[25]. Marques, T.L.; Alves, V. N.; Coelho, L.M.; Coelho, N.M.M. Assessment of the Use of Moringa oleifera Seeds for Removal of Manganese Ions from Aqueous Systems. BioResources, v. 8, p. 2738-2751. 2013.

[26]. Memon, J.R.; Memon, S.Q.; Bhanger, M.I.; El-Turki, A.; Hallam, K.R.; Allenc, G.C. Banana peel: A green and economical sorbent for the selective removal of Cr(VI) from industrial wastewater. Colloids and Surfaces B: Biointerfaces, v.70, p. 232-237. 2009.

[27]. Gupta, S.; Kumar, D.; Gaur, J.P. Kinetic and isotherm modeling of lead(II) sorption onto some waste plant materials. Chemical Engineering Journal, v.148, p. 226-233. 2009.

[28]. Sumathi, T.; Alagumuthu, G. Adsorption Studies for Arsenic Removal Using Activated Moringa oleifera. International Journal of Chemical Engineering, v. 2014, p. 1-6. 2014.

[29]. Reddy, D.H.K.; Ramana, D.K.V.; Seshaiah, K.; Reddy, A.V.R. Biosorption of Ni(II) from aqueous phase by Moringa oleifera bark, a low cost biosorbent. Analytical Desalination, v. 268, p. 150-157. 2011.

[30]. Reddy, D.H.K.; Seshaiah, K.; Reddy, A.V.R.; Lee, S.M. Optimization of Cd(II), Cu(II) and Ni(II) biosorption by chemically modified Moringa oleifera leaves powder. Carbohydrate polymer, v.88, n.3, p. 1077-1086. 2012.