Study of removal of heavy metals cadmium and lead using biosorption process

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ABSTRACT

The main purpose of this paper is to remove synthetic sewage contaminants containing the heavy metals, cadmium, and lead, through the sorption process of the sewage treatment station sludge as a biosorbent. The biosorbent was added in three reactors, the first reactor was fed only with distilled water. The second reactor was fed with a synthetic effluent prepared from distilled water and the metal cadmium and the third reactor was fed with synthetic effluent prepared from distilled water and lead metal. Average removal of 98.7% cadmium(II) and 98.8% lead was obtained. Since the third reactor was not fed with cadmium or lead, the removal result was null. The greater removal efficiency of lead in relation to the cadmium was observed, followed by a gradual increase of biosorption capacity of biosorbent with the passage of time. Through the data and statistical analysis, it was observed that the time factor influenced the reduction of metal concentration in the effluent. The elemental composition of the inorganic fraction of the samples (biosorbent) was obtained by an energy-dispersive X-ray spectrometer. The X-ray fluorescence test showed the presence of the metals after the sorption process in the biosorbents, where the sludge showed cadmium and lead in its composition confirming retention of these metals by the biosorbent (sludge) in the process of biosorption.

Keywords: Biosorption; Heavy metals; Sludge; Cadmium; Lead

1. Introduction

The terminology "heavy metals" has been used extensively in the scientific literature to refer to a group of elements associated widely with pollution, contamination, and toxicity. Some heavy metals are essential micronutrients for living beings as Cu^{2+}, Zn^{2+}, Mn^{2+}, Co^{2+}, Mo^{6+}, and Se^{2-}, and other non-essential as Pb^{2+}, Cd^{2+}, Hg^{2+}, As^{3+}, and Ti^{2+}. Heavy metals are non-biodegradable, toxic, and carcinogenic, tending to be accumulated in organisms and resulting in reductions in species diversity [1–3]. Contamination of water by heavy metals can occur naturally during soil

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erosion and flooding [4,5] or anthropogenically by leaching of municipal wastes, agricultural pesticides and effluent and wastewater from industrial manufacturing and mining [6–8]. The release of industrial effluents containing an excessive amount of toxic metals to the environment has caused serious problems with regard to water quality. Heavy metals such as Cr, Cu, Ni, Pb, and Zn can be found in the effluents of metal plating, battery manufacturing, leather finishing, mining, and smelting industries [9]. Because of their potential risks, there are specific laws that limit the release of these metals in the environment.

Resolution No. 397 of the National Environmental Council (CONAMA), of April 3, 2008, establishes standards for effluent discharge, the maximum limit of the total lead of 0.5 mg Pb^{2+} L^{-1} and the total cadmium of 0.2 mg Cd^{2+} L^{-1}. The Technical Standard 202.R-10 applies to indirect releases of liquid effluents, from polluting activities, in inland or coastal waters, surface or groundwater of the state of Rio de Janeiro, through any means of disposal, including the public sewerage system. This standard establishes the maximum permissible limit of total cadmium of 0.1 mg L^{-1} and for total lead 0.5 mg L^{-1}. For the Ministry of Environment of Japan, the maximum permissible level of cadmium and lead and its compounds is 0.1 mg L^{-1} for effluent discharge.

There are several available technologies that are used to remove heavy metals from industrial wastewater such as chemical precipitation [10], coagulation, flocculation [11], and membranes [12]. However, many of these techniques are not practical to implement due to several drawbacks such as high operating cost, high energy consumption, low selectivity, and generation of toxic slurries [13]. Recently, biological methods have also been deployed as good alternatives for the removal of toxic materials from wastewater [14]. Compared to abiotic methods, the biological methods are more simple, more efficient, and inexpensive for the removal of heavy metals because of the low cost, short operating time, high efficiency, no toxic compounds production, and environmentally friendly [15].

During the last several decades, biosorption has gained significant attention as an efficient alternative method for the removal of heavy metals from wastewater effluents. Low-cost biomasses of vegetal or microbial origin such as bacteria, fungi, yeast, algae [16–18] provide remarkable economic benefits in biosorption processes [19].

Biosorption has been investigated as one of the most promising methods for toxic metal removal. It appears that biosorption is an ideal candidate for replacing conventional methods for the removal of metals from wastewaters. The biosorption method takes place in the cell wall using non-living or inactive microorganisms [14].

Various types of adsorbents have been developed to remove these metal ions. These adsorbents include curcumin formaldehyde resin [20], polyaniline Sn(IV) silicate [21], hybrid cation-exchanger ethylenediaminetetraacetic acid-zirconium iodate [22], *Pseudomonas azotoformans* [23], halophilic bacteria *Halomonas* BVR 1 in conjunction with reduced graphene oxide [24], microalgae *Parachlorella* sp. [14], *Phanerochaete chrysosporium* [25], Ti(IV) iodovanadate cation exchanger [26] strongly acidic cation-exchange resin amberlite IR-120 [27], sodium dodecyl sulfate selenite and acrylamide Zr(IV) (SDS-AZS) [28], agricultural waste [29]. Among

the biosorbents mentioned above, sewage sludge is the most attractive biosorbent as it is easily found in any region, with low production cost and does not need a pre-treatment that will burden the sorption process.

Sewage sludge is regarded as the residue produced by the wastewater treatment process, during which liquids and solids are being separated. Liquids are being discharged to an aqueous environment while solids are removed for further treatment and final disposal. The sludge of wastewater treatment plants contains variable amounts of heavy metals; however, the sorption capacity of sludge is generally much higher and thus can be considered as a cheap sorbent [30,31].

Hammaini et al. [32] studied biosorption of different metals (Cu^{2+}, Cd^{2+}, Zn^{2+}, Ni^{2+}, and Pb^{2+}) by activated sludge and it was observed that the biomass metal uptake clearly competed with protons present in aqueous solution, making pH an important variable in the process. The study of the influence of biomass concentration revealed that the number of protons released from biomass increased with biomass concentration. This would confirm the hypothesis of ion exchange between both types of ions and Barros et al. [33] evaluated the retention behavior of sanitary sewage and sand in relation to chromium and nickel ions in up-flow reactors. The authors found that the sludge presented greater assimilation of the metals studied when compared to the inert material, probably due to the presence of anionic groups, which favors adsorption and complexation processes.

The current study, therefore, aimed to mitigate contaminants of synthetic effluent containing heavy metals (lead and cadmium) by biosorption process, using sludge as biosorbent, in the up-flow anaerobic sludge blanket reactor (UASB).

2. Materials and methods

2.1. Origin of biosorbents

The sewage sludge was originating from a UASB reactor installed and operated at the Experimental Station of Biological Treatment of Sewage. The same was disposed in a rectangular box and submitted to drying at room temperature for 7 d.

2.2. Experimental system

The experimental system consisted of three reactors with continuous up-flow fixed bed and ring road section. The reactors were built with polyvinyl chloride (PVC) pipes with an internal diameter of 0.1 m and mean height of 0.50 m (Fig. 1), the average volume of the reactor was 3.5 L. The experimental system was installed on a wooden support, which included a base for attachment of the reactors, another wooden stand was installed at 2.0 m above ground level, for fixing the containers containing the synthetic effluent, which that was fed to the reactors.

Each reactor was loaded with an average mass of 400.0 ± 0.01 g of the biosorbent sewage sludge. The system consisted of three conditioned reactors. The first reactor (R1) was fed only with distilled water to be used as a blank. The second reactor was fed with a synthetic effluent prepared from distilled water and the metal cadmium with a
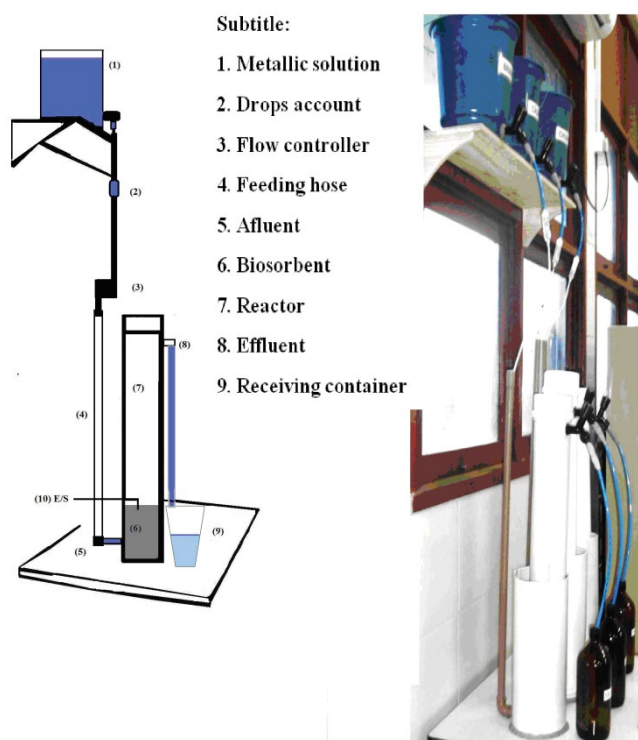
Fig. 1. Schematic representation of the biosorption reactor.

concentration of 40 mg M^{x+} L^{-1} of ion Cd^{2+} and the third reactor (R3) was fed with synthetic effluent prepared from distilled water and lead metal with a concentration of 40 mg M^{x+} L^{-1} of ion Pb^{2+}.

The average daily feed rate adopted for the experimental system was 500 mL d^{-1}, which was controlled by a hospital medical device. The total volume of 30 L was supplied to each reactor during the operation period. The operational parameters of up-flow biosorption reactors (RBioFA) are shown in Table 1.

2.3. Analytical procedures

For characterization of biosorbent, the pH measurements were performed, which was determined with pH-meter of MS Tecnopon special equipment, Brazilian Company, located in the state of São Paulo, Model MPA-21, in aqueous suspension following the method proposed by Tan [34].

Measurements of moisture content, total solids, and their fractions, obtained before and after the sorption process of metals, were determined by the methodology recommended by American Public Health Association (APHA) [35] and the leaching test used was as described by ABNT NBR 10.005: 2004 [36].

For the affluent and effluent of the biosorption reactor electrical conductivity was determined by a conductivity meter, MS Tecnopon Special Equipments, model mCA 150, following the recommendations by APHA [35]. The total alkalinity was determined according to APHA [35]. The volatile fatty acids were determined according to the recommendations proposed by DiLallo and Albertson [37]. The sample was titrated, under slow stirring, with sodium

Table 1
Operating parameters of RBioFA

Operating parameters of biosorption reactors	
Reactor height (m)	0.5
Internal diameter (m)	0.1
Average volume (L)	3.5
Feeding form	Continuous
Sludge mass (g)	400
Average flow (mL d^{-1})	500

hydroxide from pH 4.0 to 7.0. The metal concentrations in the samples of the affluent, effluent, and the substrate of the reactors were obtained by atomic absorption spectrometry in an atomic absorption spectrophotometer Shimadzu Model AA – 6800, manufacturer SHIMADZU DO BRASIL.

The X-ray fluorescence analysis was performed with a Shimadzu EDX-720 model, in the characterization laboratory of the Academic Unit of Materials Engineering, Federal University of Campina. The analysis was conducted aiming to determine the inorganic constituents of biosorbent *in natura* of the reactors R1, R2, and R3. The analyzed samples were sieved to 100 mesh with mesh opening 150 μm. The biosorption capacity of biosorbent constant (q) of metallic ion biosorbed by g (mg) (dry mass) of the biomass and the removal efficiency (E), were calculated using the Eqs. (1) and (2), respectively:

$$q = \left(\frac{C_i - C_f}{m}\right) \times V \qquad (1)$$

$$E = \left(\frac{C_i - C_f}{C_i}\right) \times 100\% \qquad (2)$$

where C_i is the initial concentration of the metallic ion (mg L^{-1}); C_f is the final concentration of the metallic ion (mg L^{-1}); m is the mass of the biosolvent in the reaction mixture (g); V is the volume of the reaction mixture (L).

2.4. Statistical analysis

Regression analysis was used in this study, which is a statistical technique to model and investigates the relationship between two or more variables. A regression model containing one or more of a regressor is called a simple linear regression model and multiple, respectively [38]. The verification of the proposed model of simple linear regression was done following the recommendation of Montgomery and Runger [38]. The Software Minitab 15.0 [39] was used.

3. Results and discussion

3.1. Characterization of the biosorbent

The sludge classification data related to the leaching test, carried out from a specific sample are presented in Table 2. The metals, their quantified values in mg L^{-1} and mg kg^{-1}, as

Table 2
The metal content of leachate extracts of the biosorbent *in natura* and MPL

Variables	Value (mg L^{-1})	Value (mg kg^{-1})	Limits (MPL)
Nickel	<0.10	<2.0	1.0 mg L^{-1} [39]
Chromium	<0.10	<2.0	5.0 mg L^{-1} [40]
Lead	<0.10	<2.0	1.0 mg L^{-1} [40]
Copper	<0.10	<2.0	0.5 mg L^{-1} [39]
Manganese	1.09	21.8	1.0 mg L^{-1} [39]
Zinc	2.82	56,4	1.0 mg L^{-1} [39]
Cadmium	<0.05	<1.0	0.5 mg L^{-1} [40]
Aluminum	0.84	16.8	3.0 mg L^{-1} [39]

well as the maximum permitted limit (MPL) for each metal are included in the table.

The analysis of the biosorbent indicated low concentrations of the metals compared to the limits fixed by NT – 202. R.10 – criteria and standards for release of wastewater [40] and ABNT NBR 10004 (2004) [41]. Based on Table 2, the metals that were above the maximum permissible limit were zinc and manganese. The ions of manganese and zinc ions could be available to compete with the Cd(II) and Pb(II) ions for the adsorption sites and thus reduce the adsorption of these heavy metals. This did not happen, as we will see later since the removal reached values above 90%. The concentration of nickel, chromium, lead, copper, and cadmium had values below the minimum detectable by the device, thus it was observed that the sludge is suitable for use in the biosorption process, since it had no significant concentration of the metals used in this work, that is, all the metal that is detected at in the biosorbent the end of the reactor's monitoring will be the source metal of the that was adsorbed.

The pH, total organic carbon, solids, and their fractions of the biosorbent *in natura* (before the biosorption process) and of the biosorbents of the reactors R1, R2, and R3 after the biosorption process are shown in Table 3.

The pH of the fresh biosorbent used in the biosorption process was 6.3 there is no need for a chemical pretreatment of the sludge since the pH of the sludge at 6.3 will not be sufficient to change the pH of the solution to the point of interfering in the removal of the metal ions. The characterization showed that fresh biosorbent has 43.13% total solids,

53.08% organic matter, and 46.92% inorganic matter which does not volatilize at 550°C temperature. Allowing the presence of anionic sites of organic origin, which facilitate the retention of metals in the biosorbent.

3.2. pH variation over the reactor monitoring time

The behavior of the pH of the effluent of the reactors R1, R2, and R3 as a function of operating time is demonstrated in Fig. 2. The effect of solution pH is one of the most important factors in the adsorption process as it can influence the species of metal ions and the surface charge of the adsorbent [42]. Up to a specific alkaline pH range, the metal ions could exist as cationic hydroxides M(OH)$^{+}$ and this fosters electrostatic interaction with the negatively charged adsorbent surface. However, above 8.5 species such as M(OH)$_{3}^{-}$ and M(OH)$_{2}$ would be dominant and precipitate out as hydroxides thereby reducing the adsorption capacity [24].

In the publication of Hawari and Mulligan [43] pH 4 to 5.5 indicated no significant effects and, for values below this, the absorption capacity was reduced. Luo et al. [44] analyzed that the biosorption rate of Zn^{2+}, Cu^{2+}, and Cd^{2+} is higher when the pH value varies between 4–10. Cadmium removal occurred in the pH range from 6.5 to 7.5 during reactor operating time. At lower pH values, removal of Cd^{2+} is inhibited or may be impaired by competition between the H^{+} and Cd^{2+} icons at the sorption sites. With the increase in pH, the competing effect of H^{+} ions decreased and the positively charged Cd^{2+} hooked up at the free binding sites [42] and with the exception of molybdenum, selenium, and arsenic, the mobility of trace elements is reduced with increasing pH due to precipitation of insoluble forms such as hydroxides, carbonates and organic complexes [45].

There was a slight increase in pH during the first 40 d of operation of the three reactors. According to Huang et al. [46], this increase in pH occurs due to the formation of anionic ligands on the substrate surface used in the biosorption process, favoring protonation.

The analysis of variance (ANOVA) performed in Minitab 15.0, concerning the effluent pH of the reactors R2 and R3, is shown in Tables 4 and 5. The objective was to determine if there was a linear relationship between time and pH at the level of 5% significance.

The ANOVA presented a value of p for R2 equal to 0.912 and 0.945 for R3, both greater than the significance level adopted (0.05). There was no pH adjustment during biosorption in the reactors. It is seen in Fig. 2 that over the

Table 3
pH value, solids and their fractions of the biosorbent *in natura* and of the biosorbents of reactors R1, R2 and R3

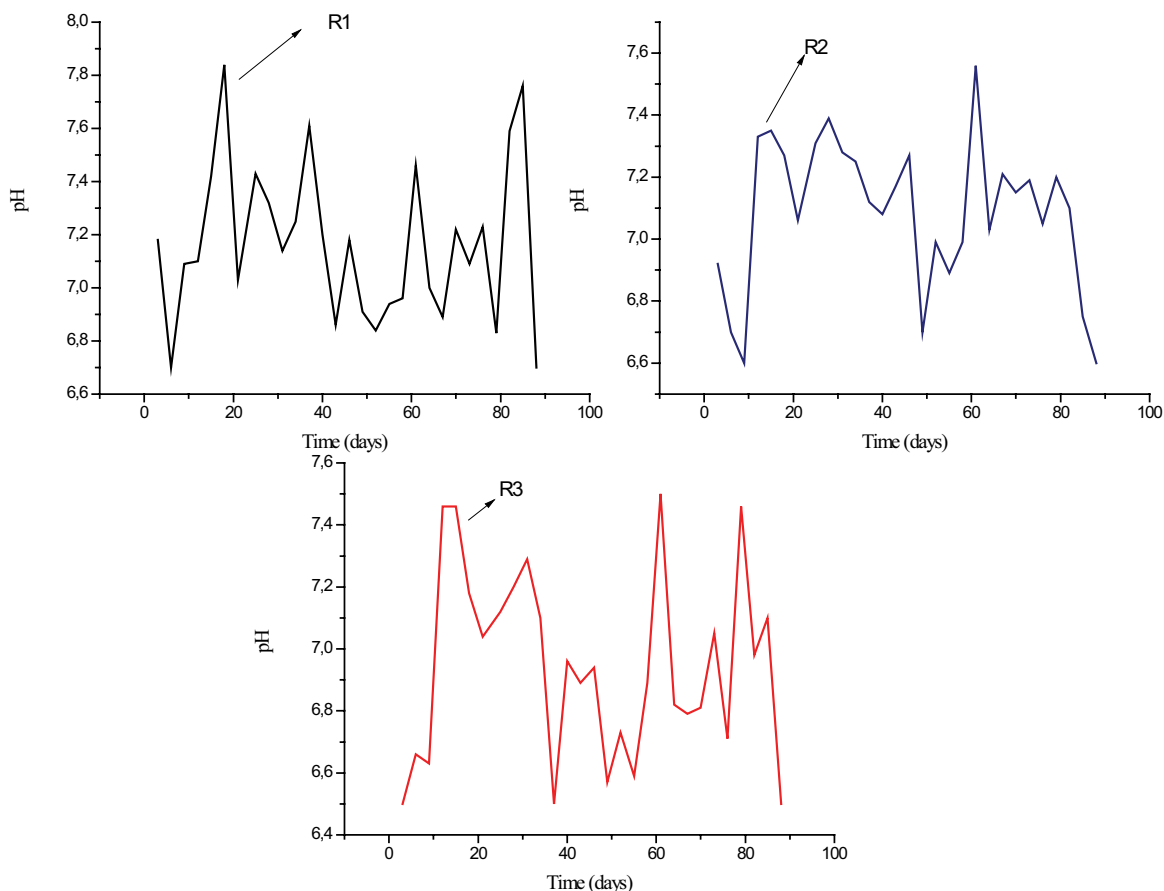| Parameter	Biosorbent *in natura*	Biosorbent R1	Biosorbent R2	Biosorbent R3
pH	6.30	6.42	6.74	6.80
Total solids (%)	43.13	74.33	72.84	90.11
Total fixed solids (%)^{a}	46.92	46.51	47.25	47.03
Total volatile solids (%)^{a}	53.08	53.49	52.75	52.97
Total organic carbon (%)	29.49	29.71	29.30	29.43

^{a}Value for the content of total solids

Fig. 2. pH behavior of effluent of R1, R2, and R3 rectors.

Table 4
Analysis of variance (ANOVA) for pH – R2

Source	Degree of freedom	Square sum (SS)	Mean-square (MS)	*p*-value
Regression	1	0.00067	0.00067	0.912
Residue	26	1.40740	0.05413	
Total	27	1.40807		
$R^2 = 0.0\%$		$R^2_{max} = 0.0\%$		

Table 5
Analysis of variance (ANOVA) for pH – R3

Source	Degree of freedom	Square sum (SS)	Mean-square (MS)	*p*-value
Regression	1	0.00045	0.00045	0.945
Residue	26	2.44336	0.09398	
Total	27	2.44381		
$R^2 = 0.0\%$		$R^2_{max} = 0.0\%$		

functioning period, there was a small increase and no significant decrease in pH in some periods. In this sense, the statistics prove this behavior and it can be stated with 95% confidence that the time factor influenced the pH neither in R2 nor in R3. This indicates that during the operating time of the reactors the pH does not change much to the point of affecting the removal of the metal.

The metal concentration in the affluent and effluent of R2 and R3 reactors in the function of the operation time is shown in Figs. 3 and 4, and the removal efficiency of Cd^{2+} and Pb^{2+}
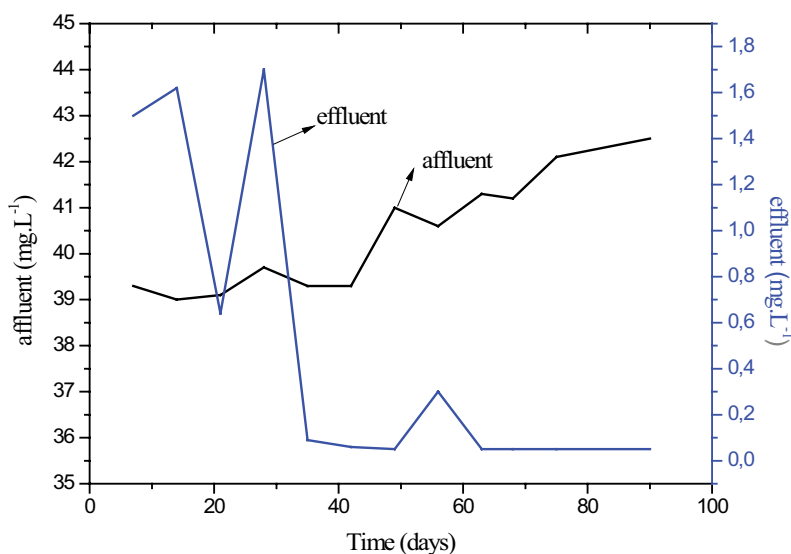
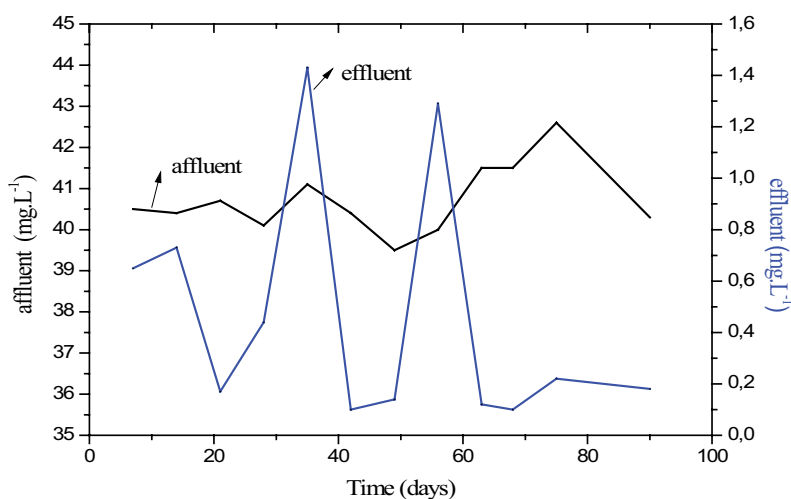Fig. 3. Metal concentration in affluent and effluent of R2 reactor.

Fig. 4. Metal concentration in the affluent and effluent of the R3 reactor.

ions by the biosorbent in the function of operation time of the reactors are presented in Fig. 5.

The average concentration in the affluent of the R2 reactor was 40.37 mg L^{-1}. The effluent concentrations ranged from 0.05 to 1.70 mg L^{-1} having an average of 0.51 mg L^{-1}, there is an average removal of approximately 39.9 mg L^{-1} Cd^{+2}, which corresponds to a removal of approximately 98.7% of cadmium metal. Luo et al. [44] removal rates achieved for Cd^{+2} of 90%, which is lower than the removal observed in this study. The concentration affluent in the present study was kept at a constant and low value (40.37 mg L^{-1}), avoiding the saturation of the adsorption sites, which could occur in higher doses of Cd^{2+} metal ions, causing a reduction removal of the metal. Fact observed by Yu et al. [45] where the effect of Cd^{2+} metal ion concentration on the adsorption of Cd^{2+} by curcumin formaldehyde resin showed that the percentage removal of Cd^{2+} metal ion was decreased from 94.5% to 74.3% as the concentration of Cd^{2+} metal ion increased from 100 to 500 mg L^{-1}. Luo et al. [44] found that the percentage removal of Pb(II) was decreased from 90% to 57.5% when the concentration of Pb(II) was increased from 10 to 60 mg L^{-1}.

R3 reactor had an average concentration in the influent 40.72 and 0.46 mg L^{-1} for the effluent, representing an average reduction of 40.26 mg Pb^{2+} L^{-1}. Since less Cd^{2+} metal ions were added to the R2 reactor than Pb^{2+} metal to R3 that shows a higher lead metal removal efficiency, because even being added a higher concentration of the metal lead, it removed the same amount as cadmium. The average removal rate for Pb^{2+} was 98.9% at pH around 7.0 [24] also observed the most efficient removal order was Pb^{+2} > Cd^{+2} > Zn^{+2}. This selectivity can be attributed to the decreasing order of their ionic rays [24,47] studied lead metal biosorption process by anaerobic sludge, where he obtained a removal efficiency of 99% at pH 5.0. This removal result is similar to that obtained in the present study. However, Barros et al. [48], state that biosorption is a phenomenon that occurs due
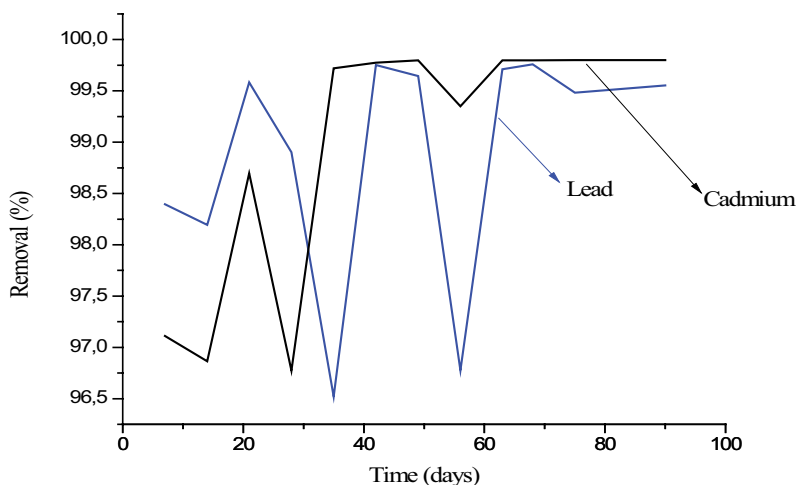
Fig. 5. The removal efficiency of Cd(II) and Pb(II) metals.

to an increase in negative charge of biosorbent surface, provided by the mechanism of its protonation and ultimately resulting in the removal of metal ions in solution.

The output of Minitab 15.0 for ANOVA on the metal concentration in the R2 reactor effluent at a 5% significance level is presented in Table 6.

The verification of the proposed model of simple linear regression was made according to the recommendation of [38], through the statistical test of hypotheses in relation to the model parameters nullity hypothesis (H0): β1 = 0 and the alternative hypothesis (Ha): β1 ≠ 0. With a probability of α = 0.05, these hypotheses were observed regarding the significance of the regression, where the null hypothesis (H0: β1 = 0) is equivalent to conclude that there is no linear relationship between x (time) and Y (response). While the alternative hypothesis (H1: β1 ≠ 0) is equivalent to claiming that there is a linear relationship between x (time) and Y (response), that is, the expected value of Y is affected by the values of x. Thus, the linear relationship between the random variable (y – dependent variable) and the non-random variable (x – independent variable) is described by the equation that we will see below.

ANOVA showed a *p*-value of 0.004 less than the significance level (0.05). It can be said, then, with 95% confidence that the time factor influenced the reduction of metal concentration in the reactor effluent; in this sense, the model adopted is shown in Eq. (3).

$$\text{Total cadmium} = 1.44 - 0{,}0202 \text{ time} \qquad (3)$$

The statistics confirm the behavior observed in Fig. 3, where there is a reduction in the concentration of Cd^{2+} in the effluent from the reactor over time.

Through the coefficient of determination (R^2) one can affirm that 58.12% of the data are explained by the model and the maximum percentage explainable (R^2_{max}) is 58.13%.

The output of Minitab 15.0 for ANOVA concerning the concentration of lead in the effluent from reactor R3 is presented in Table 7.

Table 6
Analysis of variance (ANOVA) for total cadmium

Source	Degree of freedom	Square sum (SS)	Mean-square (MS)	*p*-value
Regression	1	2.9795	2.9795	0.004
Residue	10	2.1465	0.2147	
Total	11	5.1261		
R^2 = 58.12%		R^2_{max} = 58.13%		

Table 7
Analysis of variance (ANOVA) for lead – R3

Source	Degree of freedom	Square sum (SS)	Mean square (MS)	*p*-value
Regression	1	0.2572	0.2572	0.303
Residue	10	2.1791	0.2179	
Total	11	2.4363		
R^2 = 10.6%		R^2_{max} = 1.6%		

The ANOVA showed a *p*-value of 0.303 greater than the significance level (0.05). It can be said, then, with 95% confidence that the time factor did not influence the reduction of the concentration of heavy metal lead.

3.3. Biosorption capacity of biosorbent for the cations

The variations of the biosorption capacity of the ions Cd^{2+} and Pb^{2+} by biosorbent as a function of reactor operating time are presented in Fig. 6. These concentrations of both metals were determined by atomic absorption spectroscopy.

The biosorption capacity of the biosorbent for cadmium ranged from 0.33 to 0.37 mg Cd^{2+} g^{-1} and lead(II) from 0.34 to 0.37 mg Pb^{2+} g^{-1} in biosorbent. After 90 d of reactor operation, a cadmium removal was still occurring, which may indicate that there was still a large availability of active adsorption sites. This is also an indication that the reactor had the capacity to operate for more than 90 d and still continue to remove heavy metal ions.

In the first days of monitoring the reactor, metal was detected in the effluent. This behavior followed during the system's operating time with a small increase over time, that is, a balanced balance was reached in the first 10 d of operation. This indicates that the biosorption process of Pb(II) and Cd(II) ions were rapid may be due to binding with superficial functional groups of the biosorbent [lata] biosorption capacity was no significant difference beyond the equilibrium time [49].

Each reactor was loaded with an average mass of 400.0 g of the biosorbent and fed with synthetic effluent with a concentration of 40 mg M^{x+} L^{-1} of ion metal. Liu et al. [50] performed cadmium biosorption tests in anaerobic granular sludge varying the concentration of the sludge between 50–200 mg of dry sludge L^{-1} and obtained cadmium metal biosorption capacity in the range of 43–566 mg Cd^{2+} L^{-1} sludge and noted that the biosorption process for anaerobic granular sludge depends both on the initial concentration of Cd^{2+} and on the sludge concentration. The author asserts that it is reasonable to assume that the number of binding sites

for Cd^{2+} into granular sludge is proportional to the amount of sludge added to the test, that is, a high concentration of sludge can result in a lower concentration of Cd^{2+} per mass of granular sludge. Hamdy [51] also observed this phenomenon in biosorption of heavy metals by marine algae. It is observed that the biosorption capacity of biosorbent in this study was next to than that of the above-mentioned authors, demonstrating the relationship between the biosorption and the sludge concentration since the sludge concentration used in this study was relatively higher than that used by Liu et al. [50]. The results presented by the two authors indicate that in the present study a smaller mass of biosorbent could have been used.

3.4. Energy-dispersive X-ray fluorescence

The data on the elemental composition of the inorganic fraction of biosorbent *in natura* and of R1, R2 and R3, obtained by energy-dispersive X-ray fluorescence analysis (EDX) are presented in Table 8.

The EDX analysis of the data showed that biosorbent before the biosorption process did not present concentrations of the metals used in this work, namely cadmium and lead. After the biosorption process, the samples of R1 had the same characteristic of biosorbent *in natura*, except for lead, which has been found in R1 since this metal was not added to the reactor, this concentration may be due to the material used in the construction of the reactors, which was PVC. Cadmium did not found in R1 since the reactor
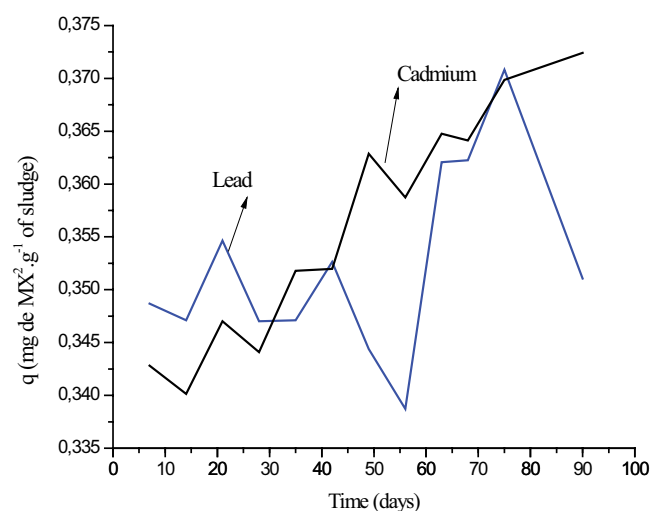
Fig. 6. Biosorption capacity of biosorbent of Cd^{2+} and Pb^{2+} ions.

Table 8
Elemental composition of the inorganic fraction of the biosorbent samples

Element	Concentration (%)			
	in natura	R1	R2	R3
Silicon	20.80	25.04	25.36	25.04
Iron	17.86	21.72	19.69	20.70
Sulphur	16.18	11.58	10.32	7.74
Aluminum	10.27	13.04	12.85	12.36
Phosphorus	4.54	4.67	4.58	4.34
Titanium	1.80	2.28	2.18	2.09
Magnesium	1.48	1.33	1.10	1.26
Zinc	0.56	0.79	0.70	0.73
Manganese	0.17	0.17	0.14	0.16
Copper	0.13	0.18	0.16	0.19
Rubidium	0.04	0.05	0.04	0.04
Molybdenium	0.03	0.04	0.03	–
Carbon	0.00	0.00	0.00	0.00
Lead	–	0.07	–	6.84
Actinium	–	0.02	–	–
Cadmium	–	–	6.53	–
Itrium	–	–	0.02	–
Francium	–	–	–	0.25
Strontium	–	–	–	0.16
Zirconium	–	–	–	0.16

was fed with only distilled water. The biosorbent in R2 presented cadmium in its composition and, similarly, R3 presented percentages of lead, confirming the retention of the metals by the biosorbent.

The concentration of lead in the biosorbent of R3 was 6.84% and 6.53% that of cadmium in R2. Barros [52] used as biosorbent sewage sludge material and obtained a 2.69% concentration of cadmium after the biosorption process. In this work, a higher concentration was found, confirming that the biosorbent has the ability to retain these metals.

4. Conclusion

In the present study, the treatment station sludge was used for the removal of heavy metals from a synthetic effluent. The biosorbent exhibited significant absorption capacity for Cd (II) and Pb (II) ions. Based on the results, one can conclude that the mean in the influent for the removal of cadmium and lead was 98.7% and 98.9%, respectively indicating a good interaction of Cd^{+2} and Pb^{+2} ions with the biosorbent. The fact that more lead ions have been added to the biosorbent and it presented almost the same as the cadmium removal is sufficient to show a higher lead removal efficiency with respect to cadmium metal. Statistical analysis of the data showed that the time factor did not influence the pH of the reactors. Removal of the metal occurred in basic pH and this did not affect the biosorption process since the results show high rates of removal of cadmium and lead.

A gradual increase in biosorption capacity of biosorbent over time was found and EDX analysis of the samples showed the presence of the metals after the process of biosorption in biosorbents in the reactors containing cadmium and lead, where the biosorbent presented cadmium and lead in its composition, confirming the retention of the metals by biosorbents. The ability of the biosorbent to treat the effluent contaminated with metals cadmium and lead is a sustainable solution to heavy metal pollution.

Symbols

q — Biosorption capacity of biosorbent, mg g^{-1}
E — Removal efficiency, %
C_i — Initial concentration of the metallic ion, mg L^{-1}
C_f — Last concentration of the metallic ion, mg L^{-1}
m — Mass of the biosorvent in the reactional, g
V — Volume of the reactional mixture, L
E — Removal efficiency, %

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