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Lead removal from aqueous solution using *Ficus Hispida* leaves powder

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ABSTRACT

The potential of using activated *Ficus Hispida* L. as a new biosorbent for the removal of lead from aqueous solution was investigated. The isotherms, kinetics of lead biosorption for *F. Hispida* L. were evaluated. The results indicate that equilibrium was established in about 30 min. The effect of the pH was examined in the range of 2–10. The maximum removal obtained is at pH value 6.1. The dosage and size parameters were also evaluated to get optimum biosorption of lead. The maximum biosorption capacity at 30°C is 32.42 mg/g. The effect of temperature has been carried out at 30, 35, 40, and 45°C. The data obtained from biosorption isotherms of lead at different temperatures fit to linear form of langmuir biosorption equation followed by Temkin and Freundlich equations. Biosorption kinetics data were modeled using the pseudo-first- and pseudo-second order and Elvoich equation models. The results indicate that the pseudo-second-order model best describes biosorption kinetic data. The thermodynamic parameters such as enthalpy (ΔH), free energy (ΔG), and entropy (ΔS) were calculated. They show that biosorption of lead on *F. Hispida* L. is an endothermic process more effective at high temperatures. These results show that *Ficus Hispida* L. is a good biosorbent for heavy metals from aqueous solutions and could be used as a purifier for water and wastewater.

Keywords: Biosorption; *Ficus Hispida* L; Isotherms; Kinetics; Thermodynamics

1. Introduction

The contamination of wastewater and soil with toxic heavy metal ions is a complex problem. The removal of this contamination has received much attention in recent years. From an environmental protection point of view, heavy metal ions should be removed at the source in order to avoid pollution of natural waters and subsequent metal accumulation in the food chain. Conventional methods for removal are chemical precipitation, chemical oxidation, chemical reduction, ion exchange, filtration, electrochemical treatment, and evaporation. All these procedures present significant disadvantages, such as for instance incomplete removal, high-energy requirements, and production of toxic sludge or waste products also requiring disposal. These methods are often very expensive. Alternative methods for heavy metal removal were developed in the last decade. A great effort has been contributed to develop new

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biosorbents, such as hydroxyapatite [1–6], activated carbons [7–9], biomass [10], polymers [11], silica [12], zeolites [13,14], and clays [15,16].

In this work, systematic laboratory investigations of the removal of lead from aqueous solutions using the low-cost material *F. Hispida* L. as the biosrbent by batch biosorption techniques have been reported. The main objective of this work is to study biosorption on *F. Hispida* L. in the case of lead. Environmental parameters affecting the biosorption process, such as pH, contact time, metal ion concentration, biosorbent dosage and size, were evaluated. The equilibrium biosorption data were evaluated by Langmuir, Freundlich, Temkin and Dubinin–Radushkevich biosorption isotherm models. The kinetic experimental data were correlated by pseudo-first-, pseudo-second-order kinetic models and with Elvoich model. The thermodynamic parameters, such as ΔG, ΔH, and ΔS, from the biosorption measurements in the present study are very useful in elucidating the nature of biosorption.

2. Materials and methods

2.1. Preparation of biosorbent

The *F. Hispida* leaves were collected from the surroundings of K.L University campus, Guntur, Andhra Pradesh, India. Leaves were washed with deionized water several times to remove dirt particles. Then, the dried leaves (by sunlight) were powdered using domestic grinder and the powder size of 75–212 µm, which were used as biosorbent without any pretreatment for lead biosorption, which are having carboxylic and hydroxyl groups.

2.2. Preparation of stock solution

Analytical grades of $Pb(NO_3)_2$ were purchased from Merck (India) Lt and the lead ions were prepared by dissolving its corresponding nitrate salt in deionized water. The pH of solutions was adjusted with 0.1 N HCl and NaOH, which are prepared from the analytical grades of HCl and NaOH.

2.3. Apparatus

An atomic absorption spectrophotometer (GBC Avanta Ver 1.32, Australia) was used for the determination of lead ion concentration. Adsorbate pH and biosorbent weight were measured using a Systronics pH meter and a Shimatzu electronic balance and size of the adsorbent is measured by Taylor standard screens. Temperature is maintained in an oven.

2.4. Batch biosorption experiments

Experimental lead solutions of desired concentrations were prepared from the stock solution with the appropriate dilutions, and the pH was adjusted to 6.1 with hydrochloric acid and sodium hydroxide.

The effect of agitation time with different initial concentration of lead was studied by agitating 30 mL of different concentrations of metal solution with 0.1 g of biosorbent of size 75 µm at 180 rpm for 1 h. At the end of predetermined time intervals, the sorbent was separated by centrifugation, and the lead remaining in solution was analyzed by atomic absorption spectrophotometer (GBC Avanta Ver 1.32, Australia). Similarly, for all the parameters like pH, Inicial concentration, adsorbent dosage, size, and temperature are varied, and the analysis was made for the final product. The same spectrophotometric method was used in the subsequent experiments. The amount of metal adsorbed by *F. Hispida* L. was calculated from the differences between metal quantity added to the biosorbent biomass and metal content of the supernatant using the following equation:

$$q = (C_0 - C_f)\frac{V}{M} \tag{1}$$

where q is the metal uptake (mg/g); C_0 and C_f the initial and final metal concentrations in the solution (mg/L), respectively; V is the solution volume (mL); M is the mass of biosorbent (g).

2.5. Biosorption isotherms

Biosorption isotherms describe how adsorbate interacts with the adsorbents and how the equilibrium is established between adsorbed metal ions on the adsorbent. Equilibrium isotherms are measured to determine the capacity of the biosorbent *F. Hispida* L. for lead metal ions. The most common types of models describing this type of system are the Langmuir, Freundlich, Tempkin and Dubinin–Radushkevich models.

2.6. Biosorption kinetics

The kinetics studies were carried out by conducting batch biosorption experiments with different initial lead concentrations. Samples were taken at different time periods and analyzed for their lead concentration.

2.7. Biosorption thermodynamics

The thermodynamic effect was studied by agitating 20 mg l^{-1} of lead solution with 0.1 g of biosorbent at temperature 30, 35, 40, and 45°C for a time period of 30 min.

Biosorption of lead on the walls of glass flasks and centrifuge tubes, which was found negligible, was determined by running blank experiments. Each experiment was carried out in duplicate and the average results are presented in this work.

3. Results and discussion

3.1. The effect of contact time

The data obtained from the biosorption of lead ions on the *F. Hispida* L. showed that a contact time of 30 min was sufficient to achieve equilibrium and the biosorption did not change significantly with further increase in contact time. Therefore, the % biosorption and unadsorbed lead concentrations at the end of 30 min are given as the equilibrium values (q_e, mg/g; C_{eq}, mg/L), respectively (Fig. 1). They are considered as respectively for 20, 40, 60, 80, and 100 ppm solutions, which gave the response as from 20 to 100 ppm the % biosorption decreases gradually from 87.38 to 72.57 respectively.

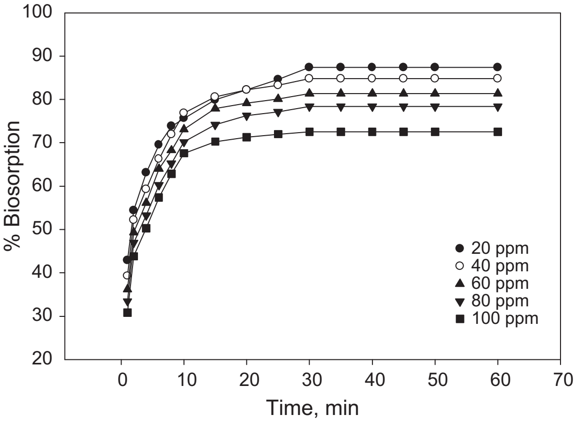

Fig. 1. Effect of contact time on biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

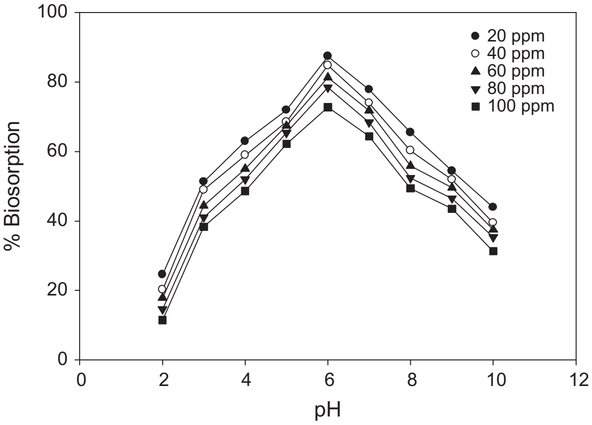

Fig. 2. Effect of pH on biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

3.2. Effect of pH

It is well known that the pH of the medium affects the solubility of metal ions and the concentration of the counter ions on the functional groups of the biomass cell walls, so pH is an important parameter on biosorption of metal ions from aqueous solutions [17–21].

F. Hispida L. has a high content of ionizable groups (carboxyl groups from mannuronic and guluronic acids) on the cell wall polysaccharides, which makes it, very liable to the influence of the pH. As shown in Fig. 2, the % biosorption of lead increased with the increase in pH from 2.0 to 6.2 for 20 ppm from 24.58 to 87.38 and decreased from 6.1 to 10 as from 87.38 to 43.94, respectively. Similarly, for all other concentrated solutions, similar trend was observed. Similar results were also reported in the literature for different biomass systems [22–24]. At pH values lower than 2.0, lead removal was inhibited, possibly as a result of the competition between hydrogen and lead ions on the sorption sites, with an apparent preponderance of hydrogen ions, which restricts the approach of metal cat ions as in consequence of the repulsive force. As the pH increased, the ligands such as carboxylate groups in *F. Hispida* L. would be exposed, increasing the negative charge density on the biomass surface, increasing the attraction of metallic ions with positive charge and allowing the biosorption onto the cell surface.

In this study, these lead cat ions at around 6.1 would be expected to interact more strongly with the negatively charged binding sites in the biosorbent. As a result, the optimum pH for lead biosorption was found as 6.1 and the other biosorption experiments were performed at this pH value.

3.3. Effect of metal ion concentration

Figs. 3 and 4 show the effect of metal ion concentration on the biosorption of lead by *F. Hispida* L. The data show that the metal uptake increases from 5.24

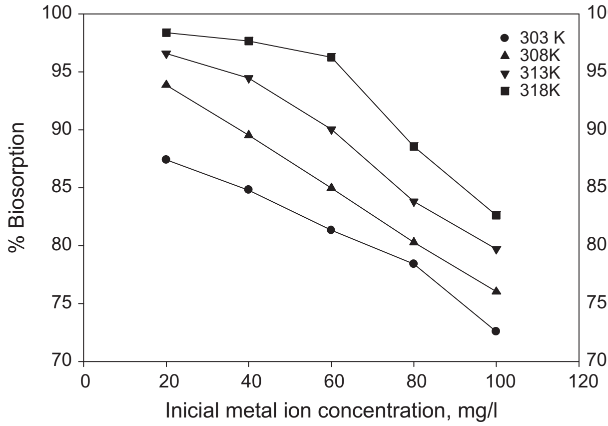

Fig. 3. Effect of metal concentration on the biosorption of lead by *Ficus Hispida* L. at different temperatures and 0.1 g/30 mL of biosorbent concentration.

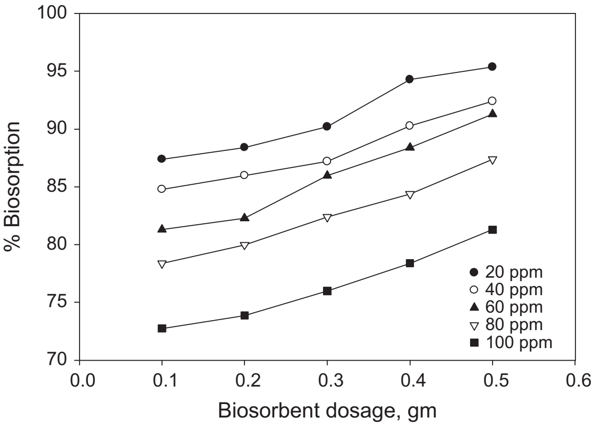

Fig. 5. Effect of *Ficus Hispida* L. biosorbent dosage on biosorption of lead for various concentrations of metal concentration.

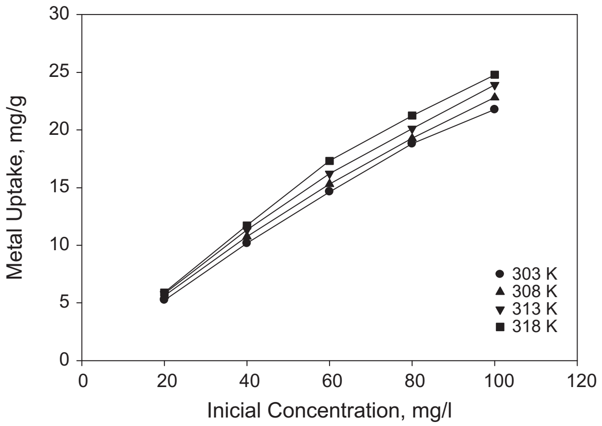

Fig. 4. Effect of metal concentration on the uptake of lead by *Ficus Hispida* L. at different temperatures and 0.1 g/30 mL of biosorbent concentration.

to 21.77 mgg^{-1} and the percentage biosorption of lead decreases from 87.38 to 72.37% with increase in metal ion concentration from 20 to 100 ppm, respectively. This increase is as a result of increase in the driving force, that is, concentration gradient. Though an increase in metal uptake was observed, the decrease in percentage biosorption may be attributed to lack of sufficient surface area to accommodate much more metal available in the solution. The percentage biosorption at higher concentration levels shows a decreasing trend, whereas the equilibrium uptake of lead displays an opposite trend. At lower concentrations, all lead ions present in solution could interact with the binding sites and thus the percentage biosorption was higher than those at higher lead ion concentrations. At higher concentrations, lower biosorption yield is due to the saturation of biosorption sites. As a result, the purification yield can be increased by diluting the wastewaters containing high metal ion concentrations.

3.4. Effect of biosorbent dosage

Fig. 5 shows the effect of biosorbent concentration on the % removed at equilibrium conditions. It was observed that the amount of lead adsorbed varied with varying biosorbent concentration. The amount of lead adsorbed increases from 87.38 to 97.34% with an increase in biosorbent concentration from 0.1 to 0.5 g. at initial concentration of 20 mg/L. Similar trends were observed for other concentrated solutions. The increase in the biosorption of the amount of solute is obvious due to increasing biomass surface area. Similar trend was also observed for lead removal using Neem leaves as biosorbent [25].

3.5. Effect of biosorbent size

The effect of different biosorbent particle sizes on percentage removal of lead is investigated and showed in Fig. 6. It reveals that the biosorption of lead on *F. Hispida* L. decrease from 87.38 to 72.39% with the increased particle size from 75 to 212 μm at an initial concentration of 20 mg/L. Similar trends were observed for all other concentrations. The smallest size obtained was 75 μm due to the limitation of available grinder configuration. It is well known that decreasing the average particle size of the biosorbent increases the surface area, which in turn increases the biosorption capacity.

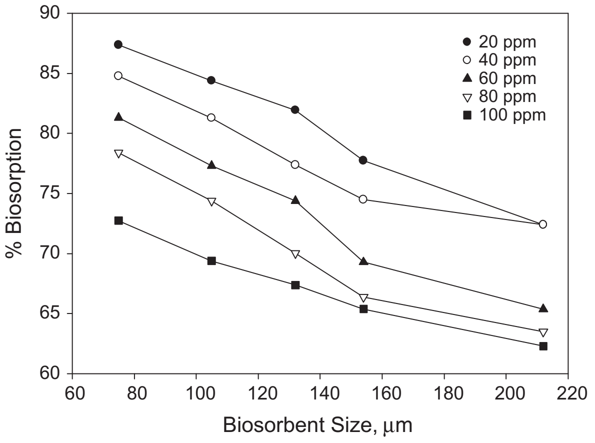

Fig. 6. Effect of *Ficus Hispida* L. particle size on biosorption of lead for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

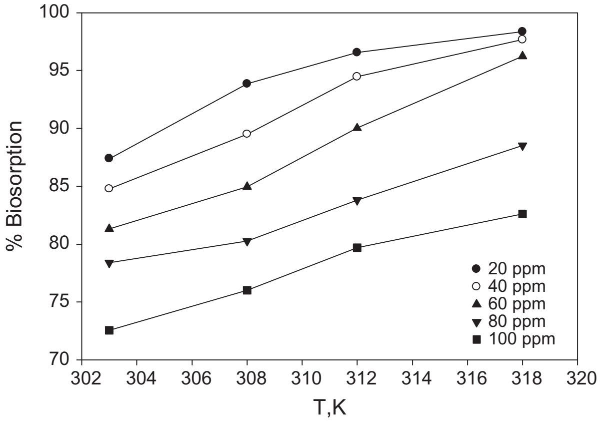

Fig. 7. Effect of temperature on biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

3.6. Effect of temperature

The effect of temperature on percentage biosorption of various concentrations for lead shows that as temperature increases from 303 to 318 K the percentage biosorption also increases from 87.38 to 97.35% for 20 ppm solution; similar trends were shown for all other solutions (Fig. 7).

3.7. Biosorption isotherms

3.7.1. Langmuir model

The Langmuir [26] sorption model was chosen for the estimation of maximum lead sorption by the biosorbent. The Langmuir isotherm can be expressed as

$$q = \frac{Q_{\max} K_a C_{eq}}{1 + K_a C_{eq}} \tag{2}$$

where $Q_{\max}$ indicates the monolayer biosorption capacity of biosorbent (mg/g) and the Langmuir constant K_a (L/mg) is related to the energy of biosorption. For fitting the experimental data, the Langmuir model was linearized as

$$\frac{C_{eq}}{q} = \frac{C_{eq}}{Q_{\max}} + \frac{1}{K_a Q_{\max}} \tag{3}$$

The linear plot of specific sorption (C_e/q_e) against the equilibrium concentration (C_e) shows that the biosorption obeys the Langmuir model with the experimental data for the sorption of lead ion onto *F. Hispida* L. at various temperatures as shown in Fig. 8. Values of the Langmuir constants, the saturated monolayer sorption capacity, $Q_{\max}$, and the sorption equilibrium constant, K_a, are presented in Table 1 for the sorption of lead ion onto *F. Hispida* L. at 303, 308, 313, and 318 K. The values of the coefficient of determinations, r^2, obtained from Langmuir model at 303 K indicates that there is strong positive evidence that the sorption of lead ions onto *F. Hispida* L. follows the Langmuir isotherm. The maximum metal uptake $Q_{\max}$ was calculated as 22.39 mg/g and it gradually increases as the temperature increases.

3.7.2. Freundlich model

The Freundlich biosorption isotherm represents the relationship between the amount of metal adsorbed per unit mass of the biosorbent *qe* and the concentration of the metal in solution at equilibrium.

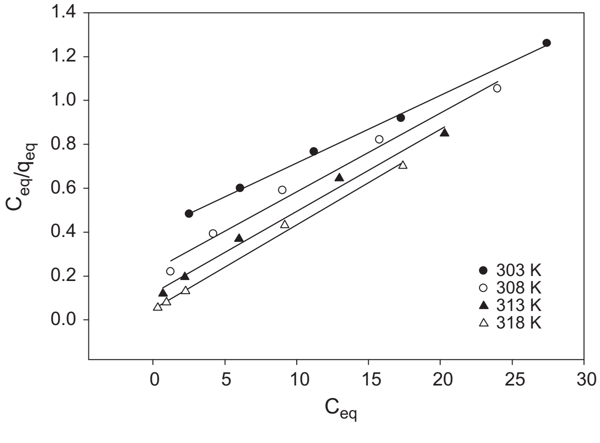

Fig. 8. Langmuir biosorption isotherm for lead at different concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

Table 1
The values of parameters and correlation coefficients for each isothermal model for lead biosorption with *Ficus Hispida* L.

Temperature (K)	Langmuir			Freundlich		
	q_m (mg/g)	b (L/mg)	R^2	n	K_f (mg/g)	R^2
303	32.42876	0.075802	0.99811167	1.648421	3.199083	0.9834755
308	27.85423	0.159672	0.98538945	2.122211	5.266604	0.9966207
313	26.70635	0.312446	0.98958623	2.460511	7.360441	0.9789568
318	26.03157	0.788274	0.99603118	2.966492	10.52115	0.9078883

	Tempkin			Dubinin–Radushkevich			
	b	A_T (L/g)	R^2	K (mol^2/kJ^2)	Q_D (mg/g)	R^2	E (kJ/mol)
303	355.83	0.76611	0.9912997	0.004460346	17.62503	0.87902	10.5877
308	447.47	1.86092	0.9799217	0.004612672	17.44425	0.82997	10.4114
313	500.01	4.11718	0.9926005	0.002041345	18.62303	0.86769	15.6504
318	575.63	13.2492	0.9807496	0.003225427	20.56831	0.93109	12.4506

The Freundlich biosorption isotherm [27] is

$$Q_e = K_F C^{1/n} \tag{4}$$

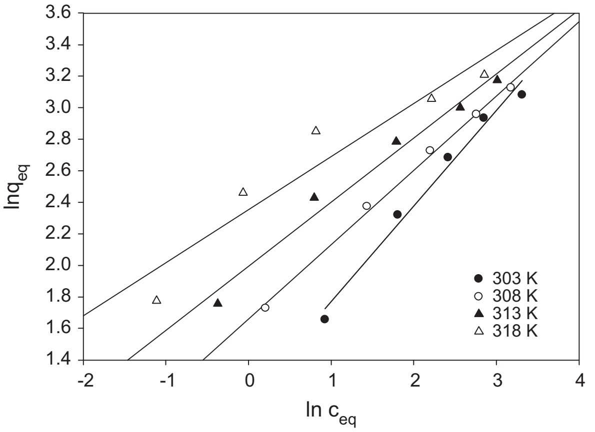

Fig. 9. Freundlich biosorption isotherm for lead at different concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

The equation can be linearized by taking logarithms to find the parameters K_F and n:

$$\log q_e = \log K_F + (1/n)\log C_e \tag{5}$$

The logarithmic plot of the Freundlich expression (Eq. (5)) for the amount of Lead adsorbed per unit mass of the biosorbent (q_e) and the concentration of Lead at equilibrium (C_e) is shown in Fig. 9. Examination of the data shows that the Freundlich isotherm provides a good description of the data over the concentration range (20–100 mg l^{-1}). The values of K_F and n were calculated from the slope and intercept of the plot (Table 2). shows the Freundlich constant and linear correlation coefficient.

3.7.3. Temkin model

Heat of biosorption and the adsorbate–adsorbate interaction on biosorption isotherms were studied by Tempkin and Pyzhev [28], who suggested that because of these interactions the energy of biosorption of all the molecules decreases linearly with coverage.

Table 2
Kinetic constants for lead onto *Ficus Hispida* L.

Inicial concentration (mg/l)	Pseudo-first-order			Pseudo-second-order			
	q_e (mg/g)	K_1	R_1^2	q_e (mg/g)	K_2	R_2^2	h (mg/g min)
20	2.306994	0.106931	0.97629	5.417459	0.115761	0.99969	3.397459
40	5.110164	0.141618	0.98248	10.50083	0.065675	0.99975	7.241827
60	7.8344	0.150641	0.98464	15.12404	0.044632	0.99972	10.2089
80	10.52293	0.149101	0.99075	19.48303	0.0323	0.99968	12.26082
100	12.44818	0.178136	0.9861	22.44954	0.032958	0.99967	16.61007

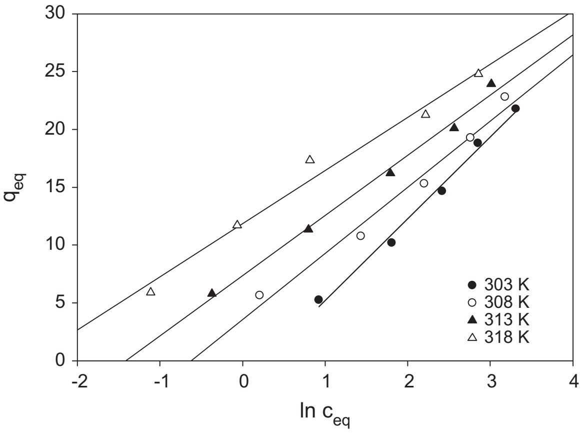

Fig. 10. Temkin biosorption isotherm for lead at different concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

The Tempkin isotherm has been used in the form

$$q_e = RT/z(\ln AC_e) \tag{6}$$

and linearized as

$$q_e = B\ln A + B\ln C_e \tag{7}$$

where $B = RT/z$. The biosorption data can be analyzed according to Eq. (7) (Fig. 10) and the constants z and A are calculated is shown in Table 2.

3.7.4. Dubinin–Radushkevich model

The Dubinin–Radushkevich (D–R) Isotherm model considers that biosorbent size is comparable with the micropore size and the biosorption equilibrium relation for a given adsorbate–biosorbent combination can be expressed independently of temperature by using the biosorption potential (ε), Eq. (8).

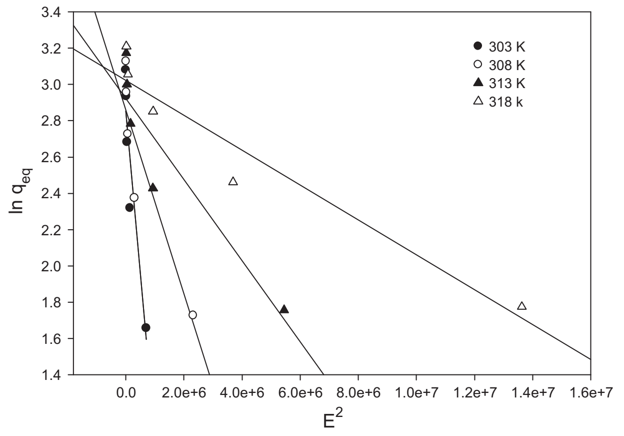

Fig. 11. Dubinin–Radushkevich biosorption isotherm for lead at different concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

$$\varepsilon = RT\ln(1 + 1/C_e) \tag{8}$$

The D–R isotherm assumes a Gaussian type distribution for the characteristic curve and the model can be described by Eq. (9).

$$\ln q_e = \ln q_s - B\varepsilon^2 \tag{9}$$

where q_s is the D–R constant (mol g^{-1}) and B gives the mean sorption free energy E (kJ mol^{-1}) per molecule of sorbate at the moment of its transfer to the solid surface from the bulk solution and can be computed using equation (Fig. 11) Eq. (10):

$$E = 1/(2B)^{1/2} \tag{10}$$

Values of q_s and B can be determined through linearization of the D–R Isotherm. Plotting ln q_e vs ε^2, using Eq. (9), results in a straight line of slope B and the intercept ln q_s [29].

From Tables 1 and 2 and it is, it is found that the biosorption of lead on the *F. Hispida* L. was correlated well with the Langmuir equation, Tempkin and Freundlich as compared to Dubinin–Radushkevich equation under the concentration range studied.

4. Kinetics of biosorption

The prediction of biosorption rate gives important information for designing batch biosorption systems. Information on the kinetics of solute uptake is required for selecting optimum operating conditions for full-scale batch process. Fig. 12 shows the plot between amount adsorbed, q_e (mg/g) vs time, t (min) for an initial concentration of 20 mg/L. The biosorption rate within the first 10 min was observed to be very high and there after the reaction proceeds at a slower rate till equilibrium, and finally, a steady state was obtained after equilibrium. The saturation time was found to be 20 min based on the initial metal concentration. The kinetics of the biosorption data was analyzed using two kinetic models, pseudo-first- and pseudo-second-order kinetic model. These models correlate solute uptake, which are important in predicting the reactor volume. These models are explained as follows:

4.1. The pseudo-first-order equation

The pseudo-first-order equation of Lagergren and Kungliga [30] is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \tag{11}$$

where q_e and q_t are the sorption capacities at equilibrium and at time t, respectively (mg/g) and k_1 is the rate constant of pseudo first-order sorption (min^{-1}). After integration and applying boundary conditions, $q_t = 0$ to $q_t = q_t$ at $t = 0$ to $t = t$; the integrated form of Eq. (11) becomes:

$$\log(q_e - q_t) = \log(q_e) - \frac{k_1}{2.303}\, t \tag{12}$$

The pseudo-first-order rate constant k_1 can be obtained from the slope of plot between log $(q_e - q_t)$ vs time, t (Fig. 12). The calculated k_1 values and their corresponding linear regression correlation coefficient values are shown in Table 3. The linear regression correlation coefficient value R_1^2 found 0.9819, which shows that this model cannot be applied to predict the biosorption kinetic model.

4.2. The pseudo-second-order equation

If the rate of sorption is a second-order mechanism, the pseudo-second-order chemisorption kinetic rate equation is expressed as [31]:

$$\frac{dq_t}{dt} = k(q_e - q_t)^2 \tag{13}$$

where q_e and q_t are the sorption capacity at equilibrium and at time t, respectively (mg/g) and k is the rate constant of pseudo-second-order sorption (g/(mg min)). For the boundary conditions $q_t = 0$ to $q_t = q_t$ at $t = 0$ to $t = t$, the integrated form of Eq. (13) becomes:

$$\frac{t}{q_t} = \frac{1}{kq_e^2} + \frac{1}{q_e}\, t \tag{14}$$

where t is the contact time (min), q_e (mg/g) and q_t (mg/g) are the amount of the solute adsorbed at equilibrium and at any time, t. Eq. (14) does not have the problem of assigning as effective q_e. If pseudo-second-order kinetics is applicable, the plot of t/q_t against t of Eq. (14) should give a linear relationship, from which q_e and k can be determined from the slope and intercept of the plot (Fig. 13) and there is no need to know any parameter beforehand.

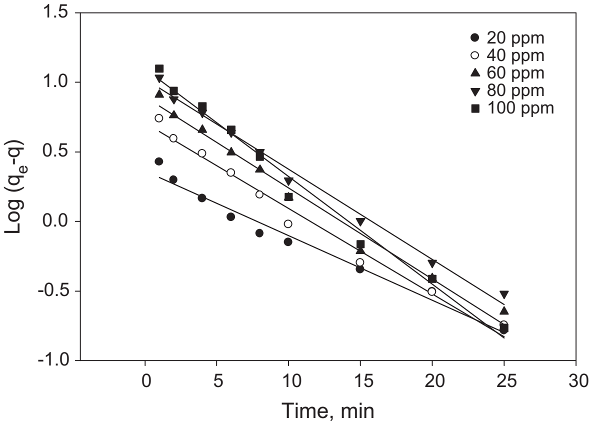

Fig. 12. Pseudo-first-order biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

4.3. Elvoich model

The simple Elovich model may be expressed in the form [32]:

$$q_t = \alpha + \beta \ln t \tag{15}$$

A plot of q_t vs ln t should give a linear relationship (Fig. 14) for the applicability of the simple Elovich kinetic.

During the present study, the three different kinetic models were applied and the estimated model and the related statistic parameters are reported in Tables 3 and 4. Based on linear regression ($R^2 > 0.99$) values, the kinetics of lead biosorbent can be described well by pseudo-second-order equation.

A comparison of the maximum capacity $Q_{\max}$ of *F. Hispida* L. with those of some other biosorbents reported in the literature is given in Table 5. Differences of metal uptake are due to the properties of each biosorbent such as structure, functional groups and surface area.

5. Thermodynamic parameters

In environmental engineering practice, both energy and entropy factors must be considered in order to determine what processes will occur spontaneously. Gibb's free energy change, ΔG°, is the fundamental cri-

Table 3
Elvoich constants for lead onto *Ficus Hispida* L.

Inicial concentration (mg/l)	Elvoich model		
	α	B	R_3^2
20	2.86929	0.65538	0.96002
40	5.4421	1.33281	0.9308
60	7.64525	1.97504	0.92737
80	9.512	2.62106	0.93138
100	11.3874	2.96989	0.89947

terion of spontaneity. Reactions occur spontaneously at a given temperature if ΔG° is a negative value. The thermodynamic parameters of ΔG°, enthalpy change, ΔH°, and entropy change, ΔS°, for the biosorption processes are calculated using the following equations [33]:

$$\Delta G^\circ = -RT \ln K_a \tag{16}$$

and

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \tag{17}$$

where R is universal gas constant (8.314 J/mol K) and T is the absolute temperature in K.

A plot of ΔG° obtained using Ka of Langmuir vs temperature, T, was found to be linear (Fig. 15). The values of ΔH° and ΔS° were, respectively, determined from the slope and intercept of the plots. ΔH° and ΔS° for the sorption process were calculated to be 113.09 kJ/mol and 0.37 kJ/mol, respectively. The negative value of ΔG° confirms the feasibility of the

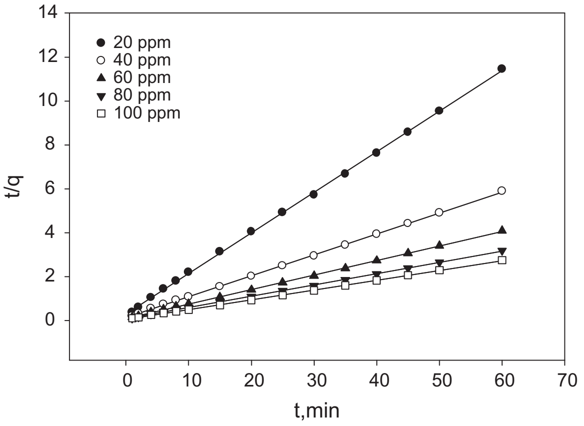

Fig. 13. Pseudo-second-order biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

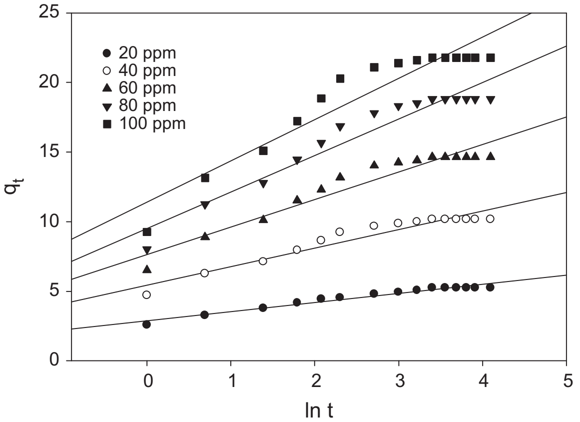

Fig. 14. Elvoich model for biosorption of lead by *Ficus Hispida* L. for various concentrations of metal and 0.1 g/30 mL of biosorbent concentration.

Table 4
Thermodynamic parameters for lead onto *Ficus Hispida* L.

Temperature (K)	Thermodynamic parameters (kJ/mol)		
	ΔG°	ΔH°	ΔS°
303	−1.84266	113.09	0.37
308	−3.89551		
313	−5.54082		
318	−7.63245		

Table 5
Maximum biosorption capacities for zinc biosorption to different biosorbents

Biosorbent material	Biosorption capacity (mg/g)	pH	Reference
Na-Mont morillonite	3.61	5	[34]
Crushed concrete fines	33	5.5	[35]
Coir	8.6	5.5	[36]
Barley straw	5.3	5.5	[37]
Peat	11.71	5.5	[38]
Coniferous bark	7.4	5.5	[39]
Sil/PE1/GA$_{0.5}$	32.79	5–6	[40]
Fontinalis antipyretica	14.7	5.0	[41]
Activated carbon	31.11	4.5	[42]
Streptoverticillium cinnamoneum	21.3	5.5	[43]
Aspergillus niger 405	4.70	5.0	[39]
Penicillium digitatum	9.7	5.5	[40]
Streptomyces noursei	1.6	5.8	[41]
Mucor rouxii (live)	4.89	5.0	[44]
Mucor rouxii (NaOH pretreated)	5.63	5.0	[45]
Mucor rouxii (Na_2CO_3 pretreated)	3.26	5.0	[46]
Mucor rouxii ($NaHCO_3$ pretreated)	6.28	5.0	[47]
Pseudomonas syringae	8.0	n.a	[48]
Rhizopus arrhizus	13.5	6–7	[49]
Citrobacter strain MCMB-181	23.62	6.5	[50]
Ficus Hispida	32.42	6.1	Present study

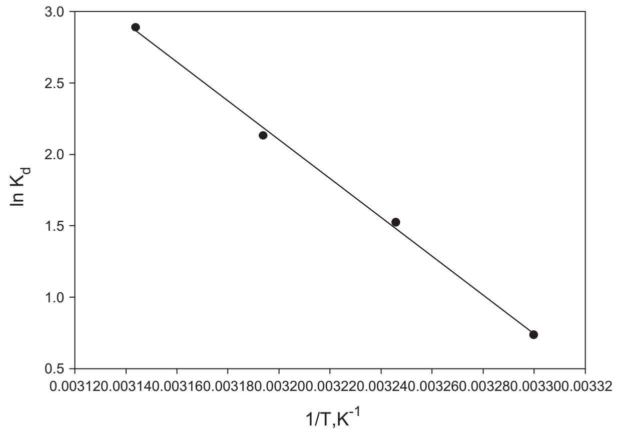

Fig. 15. Plot of Ln K_d vs temperature $1/T$ (K^{-1}).

process and the spontaneous nature of sorption with a high preference for lead (II) to sorb onto *F. Hispida* L. The value of ΔH° and ΔS° were positive, indicating that the sorption reaction is endothermic and spontaneous at high temperatures.

6. Conclusion

From the foregoing experiment, we have concluded that *F. Hispida* L. is an efficient biosorbent for removing lead from aqueous solution. In batch mode studies, the biosorption was dependent on solution pH, initial Lead concentration, and biosorbent dose and size. Biosorption of lead onto *F. Hispida* L. followed Langmuir, temkin and Freundlich isotherm models. The kinetics of biosorption of Lead on *F. Hispida* L. follows pseudo second-order kinetics. Kinetic data would be useful for the fabrication and designing of wastewater treatment plants. The results obtained with *F. Hispida* L. may be tested using metal-industry wastewater containing Pb, since *F. Hispida* L. is an inexpensive source and therefore may have the advantage of economic viability.

References

[1] Q.Y. Ma, S.J. Traina, T.J. Logan, J.A. Ryan, In situ lead immobilization by apatite, Environ. Sci. Technol. 27 (1993) 1803–1810.

[2] S.K. Lower, P.A. Maurice, S.J. Traina, E.H. Carlson, Aqueous Pb sorption by hydroxyapatite: Applications of atomic force microscopy to dissolution, nucleation, and growth studies, Am. Miner. 83 (1998) 147–158.

[3] S. Sugiyama, N. Fukuda, H. Matsumoto, H. Hayashi, N. Shigemoto, Y. Hiraga, J.B. Moffat, Interdependence of anion and cation exchanges in calcium hydroxyapatite: Pb^{2+} and Cl^-, J. Colloids Interf. Sci. 220 (1999) 324–328.

[4] S. Sugiyama, I. Takuya, H. Hayashi, T. Tomida, Lead immobilization by non-apatite-type calcium phosphates in aqueous solutions, Inorg. Chem. Commun. 5 (2002) 156–158.

[5] D.C.K. Ko, J.F. Porter, G. McKay, Optimised correlations for the fixed-bed adsorption of metal ions on bone char, Chem. Eng. Sci. 55 (2000) 5819–5829.

[6] C.W. Cheung, J.F. Porter, G. McKay, Removal of Cu(II) and Zn(II) ions by sorption onto bone char using batch agitation, Langmuir 18 (2002) 650–656.

[7] D. Mohan, K.P. Singh, Single-and multi-component adsorption of cadmium and zinc using activated carbon derivated from bagasse: An agricultural waste, Water Res. 36 (2002) 2304–2318.

[8] G. Park, J.K. Lee, S.K. Ryu, J.H. Kim, Effect of two-step surface modification of activated carbon on the adsorption characteristics of metal ions in wastewater. I. Equilibrium and batch adsorptions, Carbon Sci. 3 (2002) 219–225.

[9] J.K. Lee, G. Park, S.K. Ryu, J.H. Kim, Effect of two-step surface modification of activated carbon on the adsorption characteristics of metal ions in wastewater. II. Dynamic adsorption, Carbon Sci. 4 (2003) 14–20.

[10] J.P.K. Wong, Y.S. Wong, N.F.Y. Tam, Nickel biosorption by two chlorella species, *C. Vulgaris* (a commercial species) and *C. Miniata* (a local isolate), Bioresour. Technol. 73 (2000) 133–137.

[11] C.A. Kozlowski, W. Walkowiak, Removal of chromium(VI) from aqueous solutions by polymer inclusion membranes, Water Res. 36 (2002) 4870–4876.

[12] L.B. Khalil, A.A. Attia, T. El-Nabarawy, Modified silica for the extraction of cadmium(II), copper(II) and zinc(II) ions from their aqueous solutions, Adsorpt. Sci. Technol. 19 (2001) 511–523.

[13] J. Scott, D. Guang, K. Naeramitmarnsuk, M. Thabuot, R. Amal, Zeolite synthesis from coal fly ash for the removal of lead ions from aqueous solution, J. Chem. Technol. Biotechnol. 77 (2002) 63–69.

[14] J.S. Kim, M.A. Keane, The removal of iron and cobalt from aqueous solutions by ion exchange with Na–Y zeolite: Batch, semi-batch and continuous operation, J. Chem. Technol. Biotechnol. 77 (2002) 633–640.

[15] T. Vengris, R. Binkiene, A. Sveikauskaite, Nickel, copper and zinc removal from waste water by a modified clay sorbent, Appl. Clay Sci. 18 (2001) 183–190.

[16] R.L. Goswamee, P. Sengupta, K.G. Bhattacharyya, D.K. Dutta, Adsorption of Cr(VI) in layered double hydroxides, Appl. Clay Sci. 13 (1998) 21–34.

[17] R. Gong, Y.D. Ding, H. Liu, Q. Chen, Z. Liu, Lead biosorption by intact and pretreated *spirulina maxima* biomass, Chemosphere 58 (2005) 125–130.

[18] F.A. Abu Al-Rub, M.H. El-Naas, F. Benyahia, I. Ashour, Biosorption of nickel on blank alginate beads, free and immobilized algal cells, Proc. Biochem. 39 (2004) 1767–1773.

[19] P.X. Sheng, Y.P. Ting, J.P. Chen, L. Hong, Sorption of lead, copper, cadmium, zinc, and nickel by marine algal biomass: Characterization of biosorptive capacity and investigation of mechanisms, J. Colloid Interf. Sci. 275 (2004) 131–141.

[20] G. Ozdemir, N. Ceyhan, T. Ozturk, F. Akirmak, T. Cosar, Biosorption of chromium(VI), camium(II) and copper(II) by *Pantoea* sp. TEM 18, Chem. Eng. J. 102 (2004) 249–253.

[21] A. Iyer, K. Mody, B. Jha, Accumulation of hexavalent chromium by an exopolysaccharide producing marine *Enterobacter cloaceae*, Mar. Pollut. Bull. 49 (2004) 974–977.

[22] Y. Sag, A. Kaya, T. Kutsal, The simultaneous biosorption of Cu(II) and Zn(II) on *Rhizopus arrhizus:* Application of the biosorption models, Hydrometallurgy 50(3) (1998) 297–314.

[23] J.L. Zhou, P.L. Huang, R.G. Lin, Sorption and desorption of Cu and Cd^{2+} by macroalgae and microalgae, Environ. Pollut. 101(1) (1998) 67–75.

[24] J.T. Matheickal, Q. Yu, Biosorption of lead (II) and copper(II) from aqueous solution by pre-treated biomass of Australian marine algae, Biores. Technol. 69 (1999) 223–229.

[25] K.G. Bhattacharyya, A. Sharma, Biosorption of lead from aqueous solution by *Azadirachta indica* (Neem) leaf powder, J. Hazard Mater. 113 (2004) 97–109.
[26] I. Langmuir, The biosorption gasses on plane surface of glass, mica and platinum, J. Am. Chem. Soc. 40 (1916) 1361–1368.
[27] S. Rengaraj, C.K. Joo, Y. Kim, J. Yi, Removal of lead and zinc from aqueous solution using neem leaf powder, J. Hazard Mater. B 102 (2003) 257.
[28] M.J. Tempkin, V. Pyzhev, Heavy metals removal and isotherms study, Acta Physiol. Chem. USSR 12 (1940) 271.
[29] O. Abdelwaheb, Kinetic and isotherm studies of copper(II) removal from waste water using various biosorbents, Egyptian J. Aquatic Res. 33(1) (2007) 125–143.
[30] S. Lagergren, S. Kungliga, Svenska Ventenskapsakademiens, Handlingar, Band 24(4) (1898) 1.
[31] Y.S. Ho, E. McKay, The kinetics of sorption of basic dyes from aqueous solution by *Sphagnum moss peat*, Can. J. Chem. Eng. 76 (1998) 822–827.
[32] K.P. Yadava, B.S. Tyagi, V.N. Singh, Effect of tem perature on the removal of lead (II) by biosorption on china clay and wollastonite, J. Chem. Technol. Biotechnol. 51 (1991) 47.
[33] G. Bereket, A.Z. Aroguz, M.Z. Ozel, Removal of lead, Cd(II), Cu(II), and Zn(II) from aqueous solutions by biosorption on bentonite, J. Colloid Interf. Sci. 187 (1997) 338.
[34] O. Abollino, M. Aceto, M. Malandrino, C. Sarzanini, E. Mentasti, Biosorption of heavy metals on Na-montmorillonite. Effect of pH and organic substances, Water Res. 37 (2003) 1619–1627.
[35] N.J. Coleman, W.E. Lee, I.J. Slipper, Interactions of aqueous Cu^{2+}, Zn^{2+} and Pb^{2+} ions with crushed concrete fines, J. Hazard Mater. B121 (2005) 203–213.
[36] C. Kathrine, H.C.B. Hansen, Sorption of zinc and lead on coir, Bioresour. Technol. 98 (2006) 89–97.
[37] M. Ghoul, M. Bacquet, M. Morcellet, Uptake of heavy metals from synthetic aqueous solutions using modified PEI-silica gels, Water Res. 37 (2003) 729–734.
[38] R.J.E. Martins, R. Pardo, R.A.R. Boaventura, Cadmium(II) and zinc(II) biosorption by the aquatic moss *Fontinalis antipyretica*: Effect of temperature, pH and water hardness, Water Res. 38 (2004) 693–699.
[39] Z. Filipovic-Kovacevic, L. Sipos, F. Briski, Biosorption of chromium, copper, nickel and zinc ions onto fungal pellets of *Aspergillus niger* 405 from aqueous solutions, Food Technol. 38 (2000) 211–216.
[40] M. Galun, E. Galun, B.Z. Siegel, P. Keller, H. Lehr, S.M. Siegel, Removal of metal ions from aqueous solutions by *Penicillium* biomass: Kinetic and uptake parameters, Water Air Soil Pollut. 33 (1987) 359–371.
[41] B. Mattuschka, G. Straube, Biosorption of metals by a waste biomass, J. Chem. Technol. Biotechnol. 58 (1993) 57–63.
[42] D. Mohan, K.P. Singh, Single-and multi- component biosorption of cadmium and zinc using activated carbon derived from bagasse-and agricultural waste, Water Res. 36 (2002) 2304–2318.
[43] P.R. Puranik, K.M. Paknikar, Biosorption of lead and zinc from solutions using *Streptoverticillium cinnamoneum* waste biomass, J. Biotechnol. 55 (1997) 113–124.
[44] G. Yan, T. Viraraghavan, Effect of pretreatment on the biodsorption of heavy metals on *Mucor rouxii*, Water SA 26 (2000) 119–123.
[45] J.P.S. Cabral, Selective binding of metal ions to *Pseudomonas syringae* cells, Microbios 71 (1992) 47–53.
[46] E. Fourest, J. Roux, Heavy metal biosorption by fungal mycelium byproducts: Mechanisms and influence of pH, Appl. Microbiol. Biotechnol. 37 (1992) 399–403.
[47] P.R. Puranik, K.M. Paknikar, Biosorption of lead, cadmium and zinc by citrobacter strain MCMB-181: Characterization studies, Biotechnol. Prog. 15 (1999) 228–237.
[48] A.J.P. Esteves, E. Valdman, S.G.F. Leite, Repeated removal of cadmium and zinc from an industrial effluent by waste biomass *Sargassum* sp, Biotechnol. Lett. 22 (2000) 499–502.
[49] F. Banat, S. Al-Asheh, F. Mohai, Batch zinc removal from aqueous solution using dried animal bones, Sep. Purif. Technol. 21 (2000) 155–164.
[50] S. Tunali, A. Tamer, Zn(II) biosorption properties of *Botrytis cinerea* biomass, J. Hazard Mater. 12 (2005) 132–136.